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Occupational Exposure to Inhalable Wood Dust in the Member States of the European Union

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The aim of this study was to estimate occupational exposure to inhalable wood dust by country, industry, the level of exposure and type of wood dust in 25 member states of the European Union (EU-25) for the purposes of hazard control, exposure surveillance and assessment of health risks. National labour force statistics, a country questionnaire (in 15 member states, EU-15), a company survey (in Finland, France, Germany and Spain), exposure measurements (from Denmark, Finland, France, Germany, The Netherlands and the United Kingdom) and expert judgements were used to generate preliminary estimates of exposure to different types of wood dust. The estimates were generated according to industrial class (six wood industries, four other sectors) and level of exposure (five classes). These estimates were reviewed and finalized by national experts from 15 member states. Crude estimates were generated also for 10 new member states (EU-10). The basic data and final estimates were included in the WOODEX database. In 2000–2003, about 3.6 million workers (2.0% of the employed EU-25 population) were occupationally exposed to inhalable wood dust. Of those, construction employed 1.2 million exposed workers (33%), mostly construction carpenters. The numbers of exposed workers were 700 000 (20%) in the furniture industry, 300 000 (9%) in the manufacture of builders' carpentry, 200 000 (5%) in sawmilling, 150 000 (4%) in forestry and <100 000 in other wood industries. In addition, there were 700 000 exposed workers (20%) in miscellaneous industries employing carpenters, joiners and other woodworkers. The numbers of exposed workers varied by country ranging from <3000 in Luxembourg and Malta to 700 000 in Germany. The highest exposure levels were estimated to occur in the construction sector

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and furniture industry. Due to limited exposure data there was considerable uncertainty in the estimates concerning construction woodworkers. About 560 000 workers (16% of the exposed) may be exposed to a level exceeding 5 mg m^{-3}. Mixed exposure to more than one species of wood and dust from wooden boards was very common, but reliable data on exposure to different species of wood could not be retrieved. This kind of assessment procedure integrating measurement data, company data, country-specific data and expert judgement could also serve as one model for the assessment of other occupational exposures.

Keywords: European Union; occupational exposure; wood dust

INTRODUCTION

Exposure to wood dust may cause respiratory and dermal symptoms and diseases. The most serious health effect is the risk of nasal and sinonasal cancers, which have been observed predominantly among workers exposed to hardwood dusts such as those from oak and beech. The International Agency for Research on Cancer (IARC) has classified wood dust as carcinogenic to humans based on epidemiological evidence (IARC, 1995). The European Union (EU) Directive (1999/38) has also classified hardwood dusts as carcinogenic, and has set the occupational exposure limit (OEL) for hardwood dust to 5 mg of inhalable dust in cubic metre of workroom air (mg m^{-3}). The Scientific Committee for Occupational Exposure Limits (SCOEL) of the EU has stated that exposure to wood dust above 0.5 mg m^{-3} induces pulmonary effects and should be avoided (SCOEL, 2002). In 2003, SCOEL proposed a factor for conversion of total dust into inhalable dust (2–3) that results in a proposal of an OEL of 1–1.5 mg m^{-3} (inhalable fraction) (SCOEL, 2003).

Based on possible cancer risk and other health concerns a research project called 'Risk assessment of wood dust: Assessment of exposure, health effects and biological mechanisms' (acronym: WOODRISK) was launched in 2001 with the support from the programme Quality of Life and Management of Living Resources (Key Action 4, Environment and Health) of the European Union. The general objective of the project was to provide up-to-date data on occupational exposure to wood dusts in Europe, to assess associations between exposure and molecular alterations of sinonasal cancers and to study biological mechanisms of pulmonary inflammation related to exposure to wood dusts. Occupational exposure to wood dust was assessed in a separate subproject (acronym: WOODEX from 'wood' and 'exposure') with the help from national experts from 15 old member states of the EU (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden and the United Kingdom, referred to as EU-15).

Previously, estimates on occupational exposure to carcinogens including wood dust in the EU in the 1990s (CAREX project) have been published (Kauppinen *et al.*, 2000, 2001). However, the CAREX estimates concerned only numbers of exposed workers by country and industry, and they did not provide any information on the type of wood dust, or on the levels of exposure, which could be compared with OELs. The CAREX data on wood dust may also be considered rather crude, because wood dust was only one out of 85 carcinogens assessed in CAREX, and the method used was less detailed and data-based than the present procedure.

To provide improved and updated exposure estimates, the aim of the present study was set to estimate occupational exposure to wood dust in the member states of the EU for the purposes of hazard control, exposure surveillance and assessment of health risks. The assessment procedure was designed to provide the numbers of exposed workers by country, industry, the level of exposure and major species of wood.

METHODS

Overview of the exposure assessment method

The assessment procedure included several phases which are described in more detail in the following sections. First, the types of wood dust to be assessed were defined and the concept of occupational exposure and relevant industrial classes were agreed upon. Labour force data were requested from EUROSTAT. The basic principles and procedures of exposure assessment were discussed and the first version of the WOODEX database was constructed and tested. Country and company questionnaire forms were drafted and piloted in France and Finland. Company surveys were carried out in four countries (Finland, France, Germany and Spain). National experts in EU-15 countries were identified by the Finnish-French assessment team. Many of them were experienced industrial hygienists, safety engineers and other scientists who had participated in previous exposure assessment projects (e.g. CAREX project). Some of the experts were identified also by contacting labour safety authorities and organizations representing wood industries. The experts were asked to fill out a country questionnaire on the use of different species of wood and some other issues

needed in exposure assessment. Detailed exposure data were collected from industrial hygiene measurement databases and from some large studies in six countries (Denmark, Finland, France, Germany, the United Kingdom and The Netherlands). Aggregated exposure data were also obtained from the literature. Preliminary exposure estimates were determined from national labour force statistics, country questionnaires, company surveys, exposure measurements, expert judgements and the systematic calculation methods of the WOODEX database. Levels of exposure were estimated for different industry groups. These preliminary estimates and draft reports were sent to national experts to be reviewed and modified. The estimates and reports were finalized after a review meeting. Crude estimates on exposure in 10 new member states of the EU (the Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia, referred to as EU-10) were generated by the Finnish-French assessment team, and all data and documentation were entered in WOODEX database.

Definitions of wood dust and occupational exposure

'Wood dust' in this project refers to the inhalable fraction of dust originating from solid wood including bark. Both freshly cut and dried wood dusts are included, but pulp (cellulose) and paper dusts are not considered to be wood dusts. Dusts from wooden boards and chemically treated wood are included in this definition, although these dusts may contain also other chemicals, such as glues or wood preservatives.

This study also aimed to assess exposure to different species of wood dust. Wood dust was therefore divided into four mutually exclusive subcategories as follows: softwood dust, hardwood dust, wooden board dust and unspecified wood dust. 'Softwood dust' was considered to be dust from coniferous species of wood, and 'hardwood dust' that from deciduous species of wood. 'Wooden board dust' refers to dust from plywood, particleboard, fibreboard and other wooden boards, which also contain glues and other chemicals. 'Unspecified wood dust' indicates that the species composition of the wood dust is unknown, or that data on composition are lacking. Softwood and hardwood dusts were further divided into subcategories based on the extent of use and toxicological importance. After discussions in the research team of the whole WOOD-RISK project, it was decided to assess exposure to 'pine dust', 'spruce dust', 'other softwood dusts', 'oak dust', 'beech dust', 'birch dust' and 'other hardwood dusts' separately whenever possible.

In this project the concept of 'occupational exposure' was restricted to exposure by inhalation. Dermal contact with wood or wood dust was thereby excluded from the assessment. Inhalatory exposure was quantified by daily mean (8-h time-weighted average) concentration of inhalable wood dust among exposed workers during a random workday. No lower limit of exposure was set, so workers whose exposure level may be very low were counted as exposed to wood dust. The concentration of inhalable dust was measured and estimated in a standard unit, milligrams of wood dust in a cubic metre of workroom air (mg m^{-3}). The EU has set an exposure limit for inhalable hardwood dust (5 mg m^{-3} as an 8-h time-weighted average). In many countries this same exposure limit is applied to all types of wood dust. The calculation algorithms of WOODEX distributed workers' daily exposures into quantitative classes based on an assumed log-normal distribution of exposure, as specified by geometric mean (GM) and geometric standard deviation (GSD) of the concentration. The exposure level classes were <0.5 mg m^{-3}, 0.5–1 mg m^{-3}, 1–2 mg m^{-3}, 2–5 mg m^{-3} and >5 mg m^{-3}.

The exposure entity selected for this study was inhalable dust which covers particles deposited both in the nasal airways and lower respiratory tract. Another reason for selecting inhalable dust was that in the EU the OEL and its measurement method have been set to inhalable dust. The size distribution of wood dust particles in the workroom air is likely to vary, e.g. by the distance from the emission source, processing method and wood material processed. The particle size distribution of wood dust has been reviewed and discussed in the literature (e.g. IARC, 1995). The inhalable dust fraction has been defined by the BS EN 481 (1993) and ISO 7708 (1995) standards. The performance of instruments for measurement of airborne particle concentrations has been standardized in BS EN 13205 (2002).

Industries and labour force

All industries in the European classification of economic activities (NACE revision 1) were covered. Industries which predominantly carry out mechanized processing of wood were identified and referred to as 'wood industries'. They were sawmilling and planing of wood, impregnation of wood (NACE class 201); manufacture of veneer sheets, plywood, laminboard, particleboard, fibreboard and other panels and boards (202); manufacture of builders' carpentry and joinery (203); manufacture of wooden containers (204); manufacture of other products of wood, cork, straw and plaiting materials (205); and manufacture of furniture (361).

Because exposure to wood dust also occurs outside the actual wood industries (i.e. in 'non-wood industries'), exposure measurement data and data on workers holding typical woodworking occupations

(construction carpenter, woodworking machine operator, sawyer, cabinet maker, joiner, bench carpenter, etc.) were inspected. It turned out that within the EU a substantial number of woodworkers were employed in construction (NACE class 45), forestry (02) and building and repairing of ships and boats (351). These industries were therefore assessed separately. All other industries were combined (under 'all other employment'), and the occurrence of exposure to wood dust was assessed also for this aggregate to cover the whole employed population.

Labour force data were requested from EUROSTAT, which provided the preliminary figures. They were partially incomplete and from different years (1999–2001). These labour force figures were checked by national experts who completed, modified and updated figures from national sources.

Company survey

Company surveys were carried out mainly because there were only sparse data available on the use of different species of wood by industrial class at the national level. For example, the numbers of workers handling only one type of wood versus several species of wood were unknown. The distribution of workers by the duration of exposure (continuous versus occasional) and the vicinity of emission sources (close to versus far away from woodworking machines) was largely unknown. These are factors, which companies can assess, and they were also key factors in the exposure assessment of this project.

There were not sufficient resources to carry out the company survey in all EU countries. The company survey was therefore restricted to four selected countries: Finland (representing Northern Europe), Germany and France (representing Central Europe), and Spain (representing Southern Europe). These four countries employ about 50% of all woodworkers in the EU (EU-15).

Based on the numbers of exposure measurements on wood dust in the French COLCHIC database (Vincent and Jeandel, 2001) and the numbers of exposed workers in the CAREX database, the company survey was directed to 12 industrial sectors (by NACE revision 1 code) as follows: sawmilling and planing of wood, impregnation of wood (201); manufacture of veneer sheets, manufacture of plywood, laminboard, particleboard, fibreboard and other panels and boards (202); manufacture of builders' carpentry and joinery (203); manufacture of wooden containers (204); manufacture of other wood products, manufacture of articles of cork, straw and plaiting materials (205); manufacture of chairs and seats (3611); manufacture of other office and shop furniture (3612); manufacture of kitchen furniture (3613); manufacture of other furniture (3614); erection of roof coverings and frames (4522); joinery installation (4542); and building and repairing of pleasure and sporting boats (3512).

A random sample of factories (n = 9386) in the target population was investigated by a postal survey. The target population was stratified by industrial sector and the number of workers in the workplace (size of workplace). This stratification enabled the calculation of representative national estimates of exposure. The questionnaires were translated into national languages and filled out by safety inspectors in Germany and by company representatives in the other countries. Statistical analyses were carried out by SAS software.

Country survey

Because the company survey could not be carried out in 11 of the 15 old EU countries, a country questionnaire was drafted and piloted to collect available information on the use of different species of wood by industries in these countries. The country questionnaire was less detailed than the company questionnaire. For example, there were no questions on mixed exposure or distribution of workers by type of work (continuous/intermittent or near/far-field), because these questions turned out to be too difficult to reply to in the pilot of the questionnaire. Because reliable figures on labour force by industry were essential for the adopted estimation procedure, national experts were asked to verify, modify, complete and update the preliminary figures obtained from EUROSTAT. They were also encouraged to contact relevant industrial associations and other appropriate bodies to fill out the questionnaire. It was indicated that expert judgements were acceptable, if exact data were not available. In Finland, France, Germany and Spain a short version of the country questionnaire, excluding data collected in the company survey, was used.

Exposure measurements

Data on exposure measurements of wood dust were collected from France (INRS, the COLCHIC database), Denmark (National Institute of Occupational Health, Copenhagen, and a research project), Germany (Holz-Berufsgenossenschaft, Munich), the UK (Health and Safety Executive, Bootle, national exposure database NEDB and a measurement survey), The Netherlands (Utrecht University) and Finland (FIOH, the register of industrial hygiene measurements and some research projects). There were 2704 measurement results from Denmark, 1230 from Finland, 7881 from France, 20 872 from Germany, 389 from The Netherlands and 2665 from the UK, totalling 35 760.

Each measurement result was characterized by the following variables: country, year of measurement, industry (detailed code of NACE revision 1), type of work task (sawing, planing, etc.), type of wood dust (pine, spruce, etc.), sampling method (IOM sampler, GSP sampler, open face 37 mm cassette, etc.), duration of sampling (in minutes), type of sample (personal, area in near-field, area in far-field), concentration measured (mg m^{-3}), conversion factor (if conversion to inhalable dust was required), concentration of inhalable dust (mg m^{-3}, directly measured or converted) and remarks (representativeness, etc.). Because dust sampling methods do not always provide comparable results, all measured concentrations were converted to concentrations of inhalable dust, if necessary, by using conversion factors. However, these factors are uncertain because they vary depending on the particle size distribution of dust. SCOEL considered the conversion factor for 'total dust' to 'inhalable dust' to be often 2–3 (SCOEL, 2003). In this study, the following conversion factors were used. Danish 'organic dust' results were multiplied first by 1.18 (Vinzents and Laursen, 1993) for the conversion to 'total dust', and then the 'total dust' results were multiplied by 1.59 to convert them to inhalable dust (Schlünssen *et al*., 2001). The French measurement method is comparable to the Danish 'total dust' method, and the results were converted by multiplying by 1.59. The results of Finnish 'total dust' breathing zone samples were multiplied by 2 (Kallas *et al*., 1997; Rosenberg *et al*., 1999; Liukkonen, 2001). The German and British measurements were done by sampling methods which directly measured the concentration of inhalable dust (Dilworth, 2000; Black, 2004). Also the Dutch measurement method was approximately comparable with methods measuring inhalable dust (Scheeper *et al*., 1995; Spee *et al*., 2004).

Based on trend analyses, which showed decreasing exposure over the years in most datasets, it was decided to restrict further analysis to data from 1993–2002, except in Finland and Denmark where data from 1990–2000 and 1987–1998 were used, respectively. Also measurements with unknown industry code and short-term (<2 h) samples were excluded. After these exclusions, data were analysed by country, industry and type of sample. Range, arithmetic mean (AM), GM and GSD were calculated for the concentration of inhalable wood dust, assuming that the concentration was log-normally distributed. Summary data were entered in the WOODEX database and used in estimating the exposure levels of exposed workers.

Exposure assessment in the wood industries

The exposure assessment procedure integrated labour force data, company survey data, country questionnaire data and exposure measurement data in a systematic way. It took into account the species of wood and multiple (mixed) exposures to different species of wood to the extent that the available data allowed. The assessment in the wood industries (NACE 201–205, 361) was based on the exclusion of unexposed worker groups (Fig. 1).

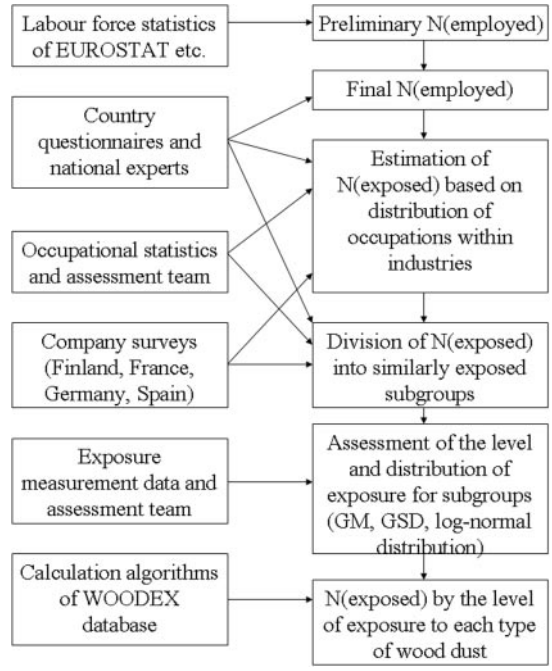

Fig. 1. Exposure assessment in the wood industries (NACE revision 1 codes 201–205 and 361).

The estimation procedure started from the industry-specific number of employed. The unexposed 'white-collar' (administrative and office workers) and unexposed 'blue-collar' workers were excluded based on the company surveys carried out in the country, or in the proxy country selected by the national expert. The remaining workers were considered to be exposed and were distributed into similarly exposed subgroups.

Similarly exposed groups (here called 'exposure groups') were defined on the basis of country, industry, similarity of wood dust and similarity of their spatio-temporal exposure pattern. Wood dust was considered to be similar if its species composition was the same. For example, pure oak dust (100%), dust from wooden boards (100%) or mixed wood dust containing pine and spruce (on average 60% pine, 40% spruce). The proportions of workers exposed only to pure specific wood dusts (100%) were asked for in the company surveys. The remainder of the exposed workers was assumed to have been exposed to a mixture species that were reported by the survey in that industry. However, exclusions had to be made, because it was not considered likely that all workers

with mixed exposure were exposed to minor species of wood. The limit of excluding minor species was set to 1% of the use. In countries, where the company survey was not made, all exposed workers were assigned as being exposed to mixed wood dust having the same composition as the total use of wood species (excluding use <1%). If no data on the use of specific species were available, workers were assigned as being exposed to 'unspecified wood dust'.

The spatio-temporal 'exposure patterns' were used to distinguish between exposure groups having different mean levels of exposure. Each woodworking task (sanding, sawing, assembly, etc.) has a different exposure pattern, but because it was not possible to collect data on the occurrence and distribution of tasks in the companies, a simplified procedure was adopted. Two basic factors were considered in the determination of exposure patterns: the continuity of exposure (continuous versus occasional) and the vicinity of emission source (close versus far). The concepts 'near-field' and 'far-field' have been used previously in the exposure assessment of epidemiological studies (Cherrie, 1999). The following exposure patterns were used in WOODEX: continuous exposure in the near-field (close to woodworking machines or other emission sources of wood dust), continuous exposure in the far-field (far from the emission sources), occasional exposure during maintenance or other short-term task, and occasional exposure of control room workers. Separate exposure patterns were used also for carpenters, installers of joinery and floor layers, but these were rare patterns in the wood industry. The distribution of workers by these exposure patterns was asked for in the company surveys. In countries where the company survey was not done, a suitable proxy country was selected by the national expert from among those countries where a survey was carried out. The exposure pattern in the industry was assumed to be the same as in the proxy country.

The exposure groups were identified by the industry, exposure pattern and composition of wood dust. For example: 'Danish builders' carpentry and joinery plant workers continuously exposed to mixed wood dust close to woodworking machines/ type of wood dust: unspecified softwood dust 90%, unspecified hardwood dust 5% and wooden board dust 5%. This procedure resulted in a large number of exposure groups whose exposure level was assessed based on exposure measurement data.

Exposure measurement data were classified by country, industry and exposure pattern. For each of the datasets, GM concentration of inhalable dust and its GSD were calculated. Daily exposures were assumed to be log-normally distributed between the workers of an exposure group. GM and GSD define completely the log-normal distribution, and they enable therefore the calculation of the numbers of workers exposed to different levels of exposure in each exposure group. This calculation routine was included in the WOODEX database, which also estimated the concentrations of specific wood dusts based on the assumed composition of the wood dust.

When setting the values of GM and GSD for exposure groups, the preference was given to national exposure data. Own data were therefore used for Denmark, Finland, France, Germany, the UK and The Netherlands, whenever the data were assessed to be valid and sufficient to represent the exposure group. For other countries a suitable proxy country was selected by the assessment team with the help of the national expert. Direct national data covering all exposure groups were not available for any country. The assessment team estimated the missing values based on their own experience in the wood industry workplaces. This influenced mainly far-field and occasional exposures, because the near-field exposure data were abundant. The coding of near/far-field was not always possible. As a result, definite background measurements were excluded, and the rest of the data were regarded to represent near-field exposure. The GMs of far-field workers were estimated by multiplying the respective GM of measurements among near-field workers by 0.5. Similarly, the multiplier for the occasional exposure of maintenance and related workers was 0.5, and that of occasionally exposed control room workers 0.3. The multipliers were based on such exposure measurement dataset, where the results of near-field and far-field measurements could be compared. The value of GSD was assumed to be the same as in the corresponding near-field exposure. Most of the GSDs used were in the range of 2–4, which is in accordance with the results of a comprehensive analysis of industrial hygiene datasets (Kromhout *et al*., 1993). When the exposure groups and their exposure levels (GMs and GSDs) were set and entered in the WOODEX database, the internal calculation routines gave preliminary numbers of exposed workers by country, industry, type of wood dust and classified level of exposure. These preliminary figures were provided for the national experts to be modified if needed. The figures were finalized by the assessment team in collaboration with national experts.

Exposure assessment in the non-wood industries

A slightly different assessment procedure was adopted because the proportion of workers exposed to wood dust in the non-wood industries (forestry, construction, building and repairing of ships and boats, all other employment) was smaller than in the wood industries. Instead of excluding unexposed workers, the estimation was based on the inclusion of exposed groups of workers. The major difference, as

compared with the procedure for the wood industries, was that the exposure groups were defined based on occupational distribution of woodworkers by industry. Occupational and industrial distributions of the employed are often available separately, but not in a cross-tabulated form. Such a dataset was ordered from Statistics Finland based on Census data from 1995. In that dataset occupation is coded into 311 classes according to the Finnish classification of occupations (longitudinal census classification) and industry according to 3-digit NACE revision 1 code. This dataset was updated (extrapolated) to correspond to the industry-specific labour force of the year 2000. The occupational distribution within industrial classes was assumed to have remained the same in 1995–2000. This allowed the calculation of proportions of construction carpenters (occupation code 673), forestry workers and lumberjacks (340), and other woodworkers (i.e. sawyers 671, builders of wooden boats 674, bench carpenters 675, cabinet makers and joiners 676, woodworking machine operators 677, and other woodworking occupations 679) in any industry. A similar procedure was used for France by using statistics from the French National Institute for Statistics and Economic Studies (INSEE).

The preliminary estimates of workers possibly exposed to wood dust in the non-wood industries of other countries were calculated on the basis of Finnish proportions (prevalences). The national experts were asked to replace these figures with national data. If they considered the Finnish figures accurate enough, they were used in the estimation of exposure. It was possible to propose another proxy country to be used in the estimation, if it was suspected that wood was used significantly less or more than in Finland in the corresponding non-wood industries.

In construction (NACE 45) three exposure groups were formed as follows: construction carpenters, floor layers and all other woodworkers employed in building. Construction carpenters were all assumed to be exposed to the major species of wood (mixed exposure) used in construction plants according to the company survey. Species used in small quantities were excluded, and major species (wooden boards, pine and spruce) were adjusted to add up to 100%. Other woodworkers in construction plants were assumed to be exposed to similar wood dust as carpenters. All floor layers were assumed to be employed by the construction sector, and they were assigned to the mixed exposure group exposed to species used in parquets, including softwood in the base section of parquet. The major types of parquet were asked for in the country questionnaire. If data were not provided, workers were assigned as being exposed to 'unspecified wood dust'. The proportions of woodworkers among all construction workers varied by country, ranging from 6% in Greece and Sweden to almost 20% in Denmark. Six of the 15 EU countries did not provide an own estimate of construction woodworkers. For them we used the value 9.4% calculated as the weighted average from countries providing own national data.

The exposure levels of the construction woodworkers were derived from sparse measurement data. Comprehensive measurement surveys were not available for construction workers' exposure to wood dust. The available data came from France (COLCHIC database, unpublished results), The Netherlands (Spee *et al*., 2004) and Finland (Liukkonen *et al*., 2004). All these datasets suggest relatively high exposure levels. After discussing the issue, the assessment team decided to set the GM of the construction woodworkers to 2.2 mg m^{-3} (GSD 2.8) in most countries based on French data, which were by far the most comprehensive (n = 372 samples). For the Nordic countries a GM of 1.5 mg m^{-3} (GSD 3.1) was used for construction woodworkers based on Finnish measurements on carpenters. For The Netherlands a GM of 3.3 mg m^{-3} (GSD 2.1) was used, based on Dutch measurements. When data allowed distinction between installers and other construction woodworkers, the French values of installers were used. When parquet floor layers could be separated from the group, the French values (GM 6.6 mg m^{-3}, GSD 2.6) were applied. The group of specialized parquet layers was small, and in many countries parquet laying was included in the tasks of carpenters or other construction woodworkers.

In forestry (NACE 02) only forest workers and lumberjacks (occupation code 340) who used chainsaws were considered to be exposed. The use of chainsaws has decreased in the past few decades. For example, in Finland only 5% of wood was being cut by chainsaws in 2000 according to Metsäteho (referred to in Helsingin Sanomat 2 November 2002), while the share was over 90% in the 1970s. Based on this fact, only 10% of forest workers and lumberjacks were considered as being exposed to the major species of wood harvested in Finland. The proportion of forest workers and lumberjacks using chainsaws was asked for in the country questionnaire, and it ranged from 10% in Finland and Sweden to 80% in Greece. If no data were available, 35% of forestry workers were assumed to be exposed, based on French data. The level of exposure in forestry may be considered low (outdoor work, intermittent exposure and low inhalability of saw dust). The exposure assessment team set the GM to 0.1 mg m^{-3} and the GSD to 3 based on a small number of German measurements from chainsawing (provided by Holz-Berufsgenossenschaft, Munich).

Building and repair of ships and boats (NACE 351) offers work to installers of joinery, builders of wooden boats and other woodworkers. For example,

5% of Finnish workers in this sector were estimated to have a typical woodworking occupation in 2000. The company surveys also included this industry, revealing the numbers of workers exposed to only one species of wood or several species of wood. The estimates were obtained by dividing the exposed workers into those exposed to one species and those with mixed exposure. In countries where no data were available on exposure in this industry, 5% of the workers were assigned as being exposed to 'unspecified wood dust'. Because measurements of wood dust in this industry were scarce, GM and GSD were set based on the most comprehensive dataset (French COLCHIC data). The same values (GM = 2.9 mg m^{-3}, GSD = 2.8) were applied in every country, except in the UK, where these values were modified to correspond to the general exposure level in woodworking (slightly higher than in France).

All other non-wood industries employ a substantial number of carpenters (0.33% of all other workers in non-wood industries in Finland) and other woodworkers (0.20% of all other workers in non-wood industries in Finland). The national experts were asked to replace precalculated figures (based on Finnish prevalences) by national data, but very few modifications were made due to the lack of national data on this issue. Carpenters were assumed to have similar exposure levels to construction carpenters in the same country, and other woodworkers similar levels to the other woodworkers in the French furniture industry (GM = 0.7 mg m^{-3}, GSD = 3.3). If the ratio between carpenters and other woodworkers was unknown, the levels of carpenters were applied, again with the exception of the UK.

Proxy countries and proxy data used

Because not all the information necessary for this assessment procedure was available at the national level, a proxy country approach was adopted. If reliable data were missing, data from a country having reliable data, and judged to resemble the country with missing data were used as proxy (surrogate) data. National experts gave their opinion about the best proxy country in respect of the distribution of exposure patterns (continuous exposure in the near-field, etc.) and the level of exposure (i.e. GM and GSD). The species of wood were estimated only on the basis of national data, because even neighbouring countries may have significantly different use patterns for wood. Whenever national data were not available, the exposing agent was considered to be 'unspecified wood dust'.

RESULTS

In 2000–2003, about 3.6 million workers (2.0% of the employed population) were occupationally exposed to inhalable wood dust in 25 member states of the EU. The numbers of exposed workers varied by country ranging from <3000 in Luxembourg and Malta to 700 000 in Germany (Table 1).

Construction employed 1.2 million exposed workers, most of which were construction carpenters. The numbers of exposed workers were 700 000 in the furniture industry, 300 000 in the builders' carpentry industry, 200 000 in sawmilling, 150 000 in forestry and <100 000 in other wood industries. In addition, there were 700 000 exposed workers in miscellaneous industries employing carpenters, joiners and other woodworkers. The highest exposure levels were estimated to occur in the construction sector and furniture mills. About 560 000 workers (16% of the exposed) may be exposed to a level exceeding 5 mg m^{-3}. The concentration of 2 mg m^{-3} may be exceeded by 1.5 million workers (41%) and 1 mg m^{-3} by 2.2 million workers (62%). About 750 000 workers (21%) were exposed to levels below 0.5 mg m^{-3} of inhalable wood dust (Table 2).

Substantial part of workers exposed to high concentrations (>5 mg m^{-3}) were construction woodworkers (parquet layers, installers and carpenters), many of whom are using woodworking machines indoors without local exhaust or general ventilation. The OEL was often exceeded also among woodworking machine operators in furniture industry and various other industries who were continuously working (e.g. sanding and cutting of wooden boards) close to the woodworking machines.

Mixed exposure to more than one species of wood was very common, which complicated the exposure assessment of individual species. Reliable data on exposure to certain species of wood (e.g. oak and beech) were not available or estimable at the national level in most of EU countries. The percentage of companies using certain species of wood could be estimated from the company surveys for Finland, France, Germany and Spain (Table 3). Some data on the use of different species of wood were provided also by national experts from Austria, Belgium, Denmark, Greece, Italy and Luxembourg (data not shown).

The reliability of the WOODEX estimates was tested also by sensitivity analysis (Monte Carlo simulation, 5000 trials, Crystal Ball® software, version 4.2 Pro) conducted for three exposure scenarios in France, Germany and Finland. The results of the analysis indicated that the variance of the estimated number of workers exposed to low levels of wood dust is highly influenced by the total number of exposed workers reflecting the structure of national labour force. The variance of the number of workers exposed to high levels was more dependent on GM and GSD emphasizing the reliability of exposure data, and the selection of the proxy country when national data were missing. The detailed results of the sensitivity analyses have been reported to EU, and

Table 1. Numbers of workers exposed to inhalable wood dust, and distribution of exposed workers (%) by country and level of exposure in 25 member states of the European Union (EU-25) in 2000–2003

Country	Employed (thousand)	Exposed (thousand)	Exposed (% of employed)	<0.5 mg m^{-3}	0.5–1 mg m^{-3}	1–2 mg m^{-3}	2–5 mg m^{-3}	>5 mg m^{-3}
Austria	3008	84	2.8	19	15	18	20	12
Belgium	4197	51	1.2	7	8	12	14	9
Cyprus[a]	315	8.0	2.5	1.6	1.4	1.8	2	1.2
The Czech Republic[a]	4751	148	3.1	40	25	30	33	20
Denmark	2170	72	3.3	20	16	16	14	7
Estonia[a]	586	27	4.6	8	5	5	5	3
Finland	2372	65	2.7	24	12	12	11	6
France	22 855	308	1.3	68	52	65	75	47
Germany	36 536	704	1.9	143	119	153	178	110
Greece	4092	70	1.7	13	10	15	19	13
Hungary[a]	3847	62	1.6	15	10	13	15	9
Ireland	1836	44	2.4	5	7	10	13	9
Italy	18 785	351	1.9	72	62	77	87	53
Latvia[a]	990	45	4.5	15	8	8	9	5
Lithuania[a]	1403	41	2.9	12	7	8	9	5
Luxembourg	186	2.7	1.5	0.6	0.4	0.6	0.7	0.4
Malta[a]	148	2.9	2.0	0.7	0.5	0.6	0.7	0.4
The Netherlands	7510	116	1.5	9	12	25	44	26
Poland[a]	13 709	310	2.3	79	52	63	72	44
Portugal	4013	110	2.7	24	20	24	26	16
Slovakia[a]	2129	42	2.0	14	6	8	9	5
Slovenia[a]	925	29	3.1	7	5	6	7	4
Spain	16 258	433	2.7	79	73	97	114	70
Sweden	3975	58	1.5	17	11	12	12	6
The United Kingdom	22 843	384	1.7	53	58	84	108	81
EU-25	179 400	3600	2.0	747	597	763	897	563

[a]One of 10 new member states (EU-10) which joined the European Union (EU-15) in May 2005.

the national exposure data will be reported in another article.

DISCUSSION

Occupational exposure to wood dust

Occupational exposure to wood dust is widespread in the 25 member states of the EU (2.0% of the employed population exposed). The proportion of the exposed population ranged from 1.2% in Belgium to 4.5-4.6% in Estonia and Latvia. Altogether 3.6 million workers were exposed in 2000–2003. About 2.9 million of them (1.9% of the employed) were employed in the old member states (EU-15) and 0.7 million (2.5% of the employed) in the new member states (EU-10) in 2000–2003. The higher fraction of the exposed in EU-10 is explained by the higher share of the wood industries in these countries as compared to EU-15.

The CAREX project estimated occupational exposure to wood dust in the EU-15 countries in 1990–1993, and found that about 2.6 million workers were exposed (Kauppinen *et al*., 2000). The present estimate for 2000–2003 is slightly higher (2.9 million) than the previous estimate, suggesting that exposure to wood dust increased during the 1990s in EU-15. From the early 1990s to the early 2000s the employment has increased in the wood product industry (from 760 000 to 810 000), in the furniture industry (from 790 000 to 950 000) and construction (from 11.0 to 11.7 million), but has decreased in forestry (from 410 000 to 266 000). The WOODEX estimates of exposed workers are higher than the CAREX estimates in the wood product industry (+240 000), the furniture industry (+80 000) and other miscellaneous non-wood industries (+220 000), but lower in construction (−100 000) and especially in forestry (−200 000). There has been a major change in the forest technology which explains partly the difference in the estimates regarding forestry. Chainsawing has been in many countries partially replaced by forest harvesters and other equipment not entailing exposure to wood dust. Also the number

Table 2. Numbers of workers exposed to inhalable wood dust, and distribution of exposed workers (%) by industry and level of exposure in 25 member states of EU (EU-25) in 2000–2003

Industry (NACE revision 1 code)	Employed (thousand)	Exposed thousand)	Exposed (% of employed)	<0.5 mg m^{-3}	0.5–1 mg m^{-3}	1–2 mg m^{-3}	2–5 mg m^{-3}	>5 mg m^{-3}
Sawmilling (201)	259	196	76	63	40	38	35	20
%				32	20	19	18	10
Manufacture of wooden boards (202)	124	92	74	32	19	18	15	8
%				35	21	20	16	9
Manufacture of builders' carpentry (203)	472	333	71	70	66	77	78	42
%				21	20	23	23	13
Manufacture of wooden containers (204)	80	57	71	12	11	13	13	9
%				21	19	23	23	16
Manufacture of other wood products (205)	147	97	66	21	17	20	22	15
%				22	18	21	23	15
Manufacture of furniture (361)	1210	713	59	201	140	145	141	87
%				28	20	20	20	12
Building of ships and boats (351)	294	31	11	1	3	6	11	10
%				4	11	21	34	30
Forestry (02)	445	148	33	137	8	2	<0.5	<0.1
%				93	5	1	0	0
Construction (45)	13 000	1190	9	92	173	285	388	254
%				6	15	24	33	21
All other employment	163 400	709	0.4	118	119	160	193	118
%				17	17	23	27	17
All industries	179 400	3600	2.0	747	597	763	897	563
%				21	17	21	25	16

of lumberjacks and other forest workers has decreased. Some of the differences in estimates are likely to be caused by methodological factors. WOODEX assigns exposure more comprehensively to those workers in the wood industries whose exposure is only occasional and thereby relatively low. The numbers of these workers could be assessed from the company surveys, which were used in WOODEX but not in CAREX. Another methodological difference was that the CAREX approach neglected a part of exposures in the miscellaneous non-wood industries. Instead, the WOODEX methodology estimated them more thoroughly based on the distribution of typical woodworking occupations in the 'other' non-wood industries. The exposures of these 'scattered' woodworkers added up to about 570 000, while CAREX identified only about 350 000 workers exposed to wood dust in this heterogenous sector.

With the considerable number of exposed workers, the present results suggest that the exposure of construction woodworkers warrants more attention and further study. Carpenters are probably the largest group of workers with substantial exposure to wood dust and little is known about their level and duration of exposure. Construction woodworkers often work in rather confined spaces (garment rooms, kitchens and saunas) where dust control is difficult to arrange.

Mixed exposure to several species of wood dust was very common throughout the EU. For example, in France >75% of exposed workers were exposed to mixtures of dusts from different species, usually to a combination of softwood, hardwood and wooden board dusts. Mixed exposure complicated the exposure assessment of different species of wood, because no data on typical exposure patterns were available and it turned out to be difficult to obtain this kind of information even at the company level. In many countries no data or estimates on exposure to different species of wood could be provided. Therefore, the numbers of workers exposed to certain species of wood (e.g. oak and beech) are very incomplete at the European level in WOODEX. Two-thirds of all workers exposed to wood dust in WOODEX are reported as exposed to 'unspecified wood dust'.

Table 3. Percentages (%) of companies using different types of wood by country and industry (NACE revision 1) in 2001

Type of wood and country	Sawmilling (201)	Manufacture of wooden boards (202)	Manufacture of builders' carpentry (203)	Manufacture of wooden containers (204)	Manufacture of other wood products (205)	Manufacture of furniture (361)
Pine						
Finland	66	40	87	61	57	39
France	29	24	38	34	23	18
Germany	45	17	68	39	30	36
Spain	82	55	79	89	66	55
Spruce						
Finland	52	60	52	69	7	13
France	37	62	70	35	17	18
Germany	82	32	62	86	36	46
Spain	31	21	31	19	17	12
Other softwoods						
Finland	–	–	8	–	4	1
France	11	1	10	3	9	5
Germany	42	1	26	17	12	11
Spain	11	22	19	6	15	9
Oak						
Finland	–	20	24	–	44	32
France	34	24	58	27	30	45
Germany	36	22	42	10	33	42
Spain	35	36	44	14	27	29
Beech						
Finland	–	20	22	–	44	43
France	16	23	38	20	11	29
Germany	38	37	48	25	52	64
Spain	27	40	36	13	35	40
Birch						
Finland	3	51	45	7	52	54
France	2	7	–	–	3	2
Germany	5	11	4	8	12	7
Spain	13	20	1	13	2	8
Other hardwoods						
Finland	–	14	11	8	47	15
France	28	88	63	15	29	43
Germany	23	35	56	22	63	45
Spain	42	53	51	27	44	32
Wooden boards						
Finland	1	12	57	29	50	64
France	–	17	72	15	29	43
Germany	12	61	74	57	61	86
Spain	20	48	77	50	63	74

At least 37% of the daily exposures of workers were to inhalable dust levels below 1–1.5 mg m^{-3}, which according to the expert group of EU (SCOEL) are unlikely to cause significant symptoms among the exposed workers. According to this assessment procedure about 16% of the workers were exposed to high levels (>5 mg m^{-3}) exceeding the OEL of EU for hardwood dust. Many of these workers are exposed only to dusts from softwood or wooden boards, and exposure to high levels of hardwood dust is rarer. However, in many countries the OEL of any kind of inhalable wood dust is 5 mg m^{-3} or even lower.

Assessment methods

The assessment method used may be considered to have a number of strengths, such as systematic

approach, wide coverage of industries and countries, use of company data, use of national experts, species of wood and level of exposure assessed, comprehensive documentation and generality of the estimation process.

The same assessment method was applied to each country, which improves comparability of the estimates across countries. Wood dusts, industries and occupational exposure were accurately defined. All economic sectors were covered, including miscellaneous non-wood industries. All 15 old and 10 new EU countries were covered. The present estimates are the first ones for many of these countries, and more specific than any previous estimates. We expect that the reliability of the estimates was also improved when data from company surveys in four countries were incorporated. These data could partially be used also as proxy (surrogate) data for other countries when national data were missing. Data obtained from national experts in 15 EU countries was likely to improve labour force data in particular, and to some extent data on the species of wood used. Major species of wood were addressed, possibly for the first time. The toxicological characteristics of wood dust depend to some extent on the species. However, in this respect the assessment was not completely satisfactory because of the scarcity of species-specific data in several countries. Several measurement databases and published exposure data were reviewed and used in the systematic assessment of the exposure levels. The exposed worker groups were also specified, enabling the identification of groups whose exposure possibly exceeds the national or EU exposure limit. Preventive measures, such as dust control, can be directed more effectively based on quantitative exposure data. The estimates and their grounds are documented in the WOODEX database. The estimation process is transparent, enabling the estimates to be improved, if more accurate data becomes available. This procedure integrates the use of measurement data, company data, country data and expert judgements. It can serve as one model in the assessment of other occupational exposures in the EU and elsewhere.

The procedure was developed on the basis of experiences in previous EU projects, particularly in the CAREX project (Kauppinen *et al.*, 2000). In spite of several means to improve the validity of the estimates (see Methods) and in spite of comprehensive data collection, the adopted procedure includes uncertainty and the results should be interpreted with caution. The sources of possible inaccuracy include several factors, such as missing national data, mixed exposures, use of proxy data, application problems of measurement results and the subjective nature of expert judgements.

Limited data on the species of wood used in different industries were available from most countries other than those where the company survey was carried out. The implication of this is that whenever specific data are missing, workers are assigned as being exposed to 'unspecified wood dust', and the extent of exposure to specific species of wood may therefore be an underestimate.

In most industries a substantial part of the workers were exposed to several species of wood. Workers with mixed exposure were assumed to be exposed to dust mixture containing different species of wood in the same proportions as used in that industry (excluding small amounts). However, the actual use patterns of wood are mostly mill-specific, and the adopted procedure may therefore over- or underestimate exposure to certain species of wood. This possible bias affects both the numbers of workers and the levels of exposure to different species of wood, but not estimates on wood dust itself.

When national data on the distribution of exposure patterns and on the levels of exposure were lacking, the data from a suitable proxy country were used. The selection of proxy countries may nevertheless not have been fully appropriate in some cases, resulting in inaccurate estimates. For example, measures to control exposure and their effectiveness may vary between countries, rendering proxy data misleading. The measurement devices (inhalable dust samplers) vary considerably between countries. Correction factors might not have been accurate.

It was also difficult to evaluate the representativeness of the measurement data as to exposure groups. Some datasets could be associated with continuous near-field exposure and other exposure patterns, but for some national datasets this was impossible. In such cases the applicability of the exposure data (the applied values of GM and GSD) was decided by the assessment team in collaboration with the national expert. The exposure assessment team based its judgements on reliable data as far as possible, but subjective decisions based on professional experience were sometimes unavoidable. An example is the decision to use French measurement data in most countries for construction woodworkers, which is a large group with sparse exposure data.

In summary, in countries where a company survey was carried out, the reliability of the estimates of the numbers of exposed workers may be considered high for wood dust and moderate for specific types of wood and for levels of exposure. In other countries the reliability of the estimates depends on the availability of national data. The numbers of workers exposed to wood dust are probably fairly reliable, and the levels of exposure to wood dust moderately so. Data on specific species of wood in these countries are often missing or may be underestimated.

CONCLUSIONS

Exposure to dust from softwood, hardwood and wooden boards is common among European workers, but the exposure levels to hardwood dust are usually below 5 mg m^{-3}, the OEL of the EU. However, over 0.5 million workers may be exposed to a dust level (any type of wood dust) exceeding 5 mg m^{-3}. High exposures occur particularly in the construction sector and furniture industry. Mixed exposure to more than one species of wood is very common, which complicates the exposure assessment of different species of wood. Due to limited exposure data there is considerable uncertainty in the estimates concerning construction woodworkers. Due to the fact that construction woodworkers often work in poorly ventilated spaces, the situation warrants more attention and further study. The assessment procedure used in the present project that integrates measurement data, company data, country-specific data and expert judgement could serve as one model also in the assessment of other occupational exposures in the EU and elsewhere.

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