

# Workplace risk factors for cancer in the German rubber industry: part 1. Mortality from respiratory cancers

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## Abstract

**Objectives**—To determine the cancer specific mortality by work area among active and retired male workers in the German rubber industry.

**Methods**—A cohort of 11 663 male German workers was followed up for mortality from 1 January 1981 to 31 December 1991. Cohort members were classified as active (n=7536) or retired (n=4127) as of 1 January 1981 and had been employed for at least one year in one of five study plants producing tyres or technical rubber goods. Work histories were reconstructed with routinely documented "cost centre codes" which were classified into six categories: I preparation of materials; II production of technical rubber goods; III production of tyres; IV storage and dispatch; V maintenance; and VI others. Standardised mortality ratios (SMRs) adjusted for age and calendar year and 95% confidence intervals (95% CIs), stratified by work area (employment in respective work area for at least one year) and time related variables (year of hire, lagged years of employment in work area), were calculated from national reference rates.

**Results**—SMRs for laryngeal cancer were highest in work area I (SMR 253; 95% CI 93 to 551) and were significant among workers who were employed for >10 years in this work area (SMR 330; 95% CI 107 to 779). Increased mortality rates from lung cancer were identified in work areas I (SMR 162; 95% CI 129 to 202), II (SMR 134; 95% CI 109 to 163), and V (SMR 131; 95% CI 102 to 167). Mortality from pleural cancer was increased in all six work areas, and significant excesses were found in work areas I (SMR 448; 95% CI 122 to 1146), II (SMR 505; 95% CI 202 to 1040), and V (SMR 554; 95% CI 179 to 1290).

**Conclusion**—A causal relation between the excess of pleural cancer and exposure to asbestos among rubber workers is plausible and likely. In this study, the pattern of excess of lung cancer parallels the excess deaths from lung cancer among rubber workers. The study provides further evidence for an increased mortality from laryngeal cancer among workers in the rubber industry, particularly in work area I.

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Keywords: respiratory cancer; mortality; rubber industry; workplace risk factors

Excess cancer risks in the rubber industry were first noted in a report of the British Registrar General in 1924,<sup>1</sup> but systematic epidemiological investigations were not started before the second half of this century. In 1982, and updated in 1987, an International Agency for Research on Cancer (IARC) working group reviewed the evidence for cancer risks in the rubber industry and concluded that there was sufficient evidence for excess occurrence of cancer of the bladder, lung, stomach and leukaemia and limited evidence for excess occurrence of lymphoma as well as cancer of the skin, colon, and prostate.<sup>2,3</sup>

Many agents occurring in the work environment in the rubber industry have been shown to be mutagens and carcinogens. However, it has generally not been possible to identify specific carcinogens which are responsible for the observed excess occurrences of malignant neoplasms among workers in the rubber manufacturing industry. Two exceptions are bladder cancer, which has been associated with exposure to aromatic amines (especially  $\beta$ -naphthylamine and perhaps benzidine), and leukaemia, which has been associated with exposure to solvents (especially benzene). However, the postulated exclusive link of bladder cancer to exposure to  $\beta$ -naphthylamine may be questioned by recent results that indicate an excess of deaths from bladder cancer among workers who were not exposed to  $\beta$ -naphthylamine or workers who

Table 1 Classification of work areas by stage and type of the production process

Description of the work area	Work area
Preparation of materials:	I
Raw material handling, weighing	
Mixing	
Milling, extruding and calendering	
Tyre recycling	
Production of technical rubber goods:	II
Production of tyres:	III
Component assembly	
Curing, vulcanisation, inspection, and finishing	
Inner tubes	
Various	
Storage and dispatch:	IV
Storage: tyres	
Storage: technical rubber goods	
Dispatch	
Maintenance and general service:	V
Maintenance	
General service (transport etc)	
Others (power plant etc):	VI

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Table 2 Distribution of person-years by age at risk and work areas (I–VI)

	Preparation of materials (I)	Technical rubber goods (II)	Tyres (III)	Storage dispatch (IV)	Maintenance (V)	Others (VI)
Age at risk:						
≤39	1944	4520	1701	545	3703	761
40–49	3519	8519	5664	1031	6327	1756
50–59	7834	14696	10797	2617	8768	4116
60–69	7062	10877	7611	2330	7043	4309
≥70	5047	6589	4659	1683	4883	3780
Total	25406	45201	30432	8206	30724	14722

were first hired in the 1960s and not substantially exposed to  $\beta$ -naphthylamine. Studies published since 1982 also could not provide further evidence of causal associations between other cancer sites and specific workplace characteristics in the rubber industry.

Recently, we reported the excess mortality from cancer of several sites among a historical cohort of men employed in the German rubber industry.<sup>4</sup> The objectives of the present study are to examine the relation between mortality from specific cancers and characteristics of the work environment, taking several time related factors—such as year of hire and years of employment in specific work areas—into account. The results for respiratory cancers are reported in the first part of this report, and our findings on non-respiratory cancers which had previously been associated with the rubber industry are presented in part II.

## Methods

### COHORT DEFINITION AND FOLLOW UP

The cohort definition and follow up, including the assessment of vital status and cause of death, have previously been described in detail<sup>4</sup> and are only briefly summarised here. The cohort included all male German blue collar workers at five study plants who were alive and actively employed or retired on 1 January 1981. Follow up of individual cohort members started on 1 January 1981 but not before completion of one year of employment, and ended at the age of 85 years, at death, date of loss to follow up, or the end of the follow up period, 31 December 1991.

Health insurance data and personnel files of the participating plants as well as German population registries were used to determine the vital status at the end of the observation

period. For all cohort members reported to have died, death certificates were requested from the respective community health departments. To assure comparability of coded underlying causes of death with the reference population, death certificates were coded by four professional nosologists from the State Institute of Statistics of North-Rhine/Westphalia according to the ninth revision of the International Classification of Diseases, Injuries, and Deaths (ICD-9).<sup>5</sup>

### EXPOSURE CLASSIFICATION

Complete individual work histories within the rubber companies were reconstructed with routinely documented and archived cost centre codes (Kostenstellen). The schemes of cost centre codes are company specific and have changed over time; thus a complete reconstruction of all cost centre codes for each of the five study plants was required for the whole period covered by the collective work experience of the cohort members. Originally, these codes were generated for accounting purposes, but they allow assignment of employment periods to specific work areas. They do, however, provide no information about specific jobs or tasks within work areas.

For active employees information on cost centre codes was obtained from employer personnel files. For retirees and employees with missing information in these electronic files, individual work histories were abstracted from paper records. For a small proportion of people with missing information on the exact time of change between work areas, the midpoint between start of work in the first and end of work in the second work area was used.

All cost centre codes were classified into six work areas (table 1). There were several reasons for this categorisation. Firstly, a categorisation according to type and stage of the manufacturing process allowed for analyses of the entire cohort across the five study plants. Secondly, this classification dates back to early epidemiological studies of cancer risks in the rubber industry, which presented analyses stratified by department<sup>1</sup> or depicted graphically the number of cases of bladder cancer by department.<sup>6</sup> This classification scheme was largely adopted by subsequent epidemiological

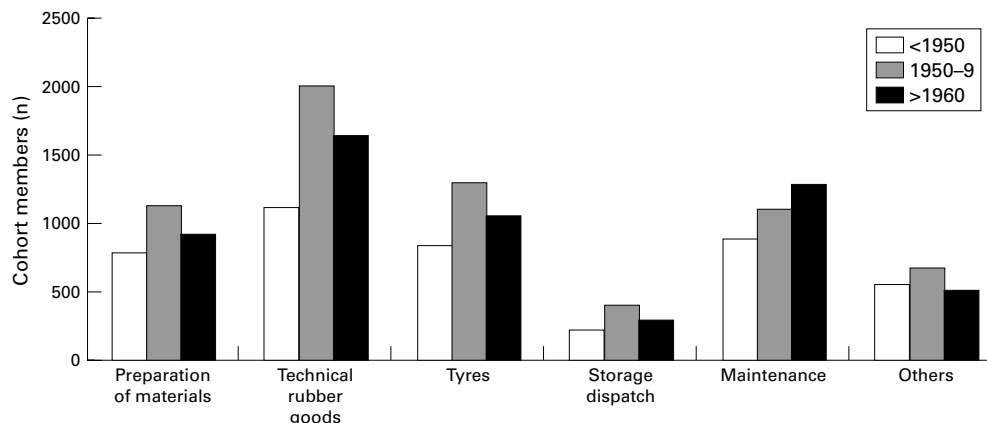


Figure 1 Distribution of cohort members (n=11633) by work area and year of hire.

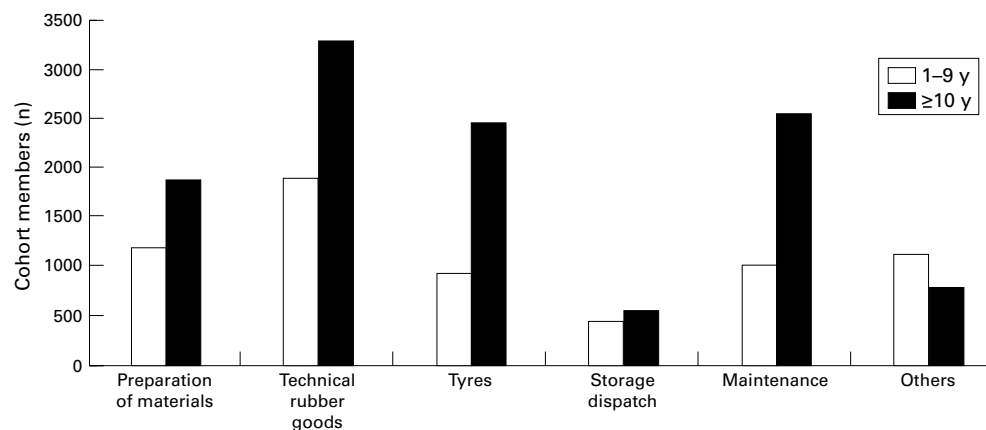


Figure 2 Distribution of cohort members ( $n=11633$ ) by years of employment in work area.

studies of rubber workers. In our analysis we grouped the work areas to be compatible with exposure categories used in the IARC evaluation<sup>3</sup> and epidemiological studies published since 1982. Some of the nine categories which were used in the IARC evaluation were grouped together to allow consistent presentation of all outcomes of interest, while achieving sufficient statistical power for rare cancers. Therefore our categorisation of work areas is comparable with previously published studies, including those that were restricted to either the tyre or the technical rubber goods sector. Finally, results of industrial hygiene surveys within the rubber industry are often reported by these categories of work areas.<sup>7-10</sup> Our study results may therefore be related to exposure measurements specific to discrete work areas.

#### DATA ANALYSIS

The mortality experience of the cohort was compared with the mortality of the general population with analyses of standardised mortality ratios (SMRs). The population of former West Germany was used as the reference, because the participating plants were in three different states of former West Germany. The National Institute of Statistics provided data on the number of residents by calendar year, five year age group, nationality (German *v* non-German) and sex, as well as the number of respective deaths by ICD-9 categories. All SMRs were standardised for calendar year and five year age group. Person-years at risk were calculated for each cohort member and summed across all people in each stratum of interest (calendar year, age group, work area, year of hire). The respective stratum specific rates from the reference population of men with German nationality were multiplied by these person-year weights to obtain the expected number of deaths with the statistical software programme SAS 6.11. The SMRs were calculated by dividing the observed number of deaths from specific causes by the expected number.

For causes with at least five expected deaths, approximate 95% confidence intervals (95% CIs) were constructed.<sup>11</sup> For causes for which less than five deaths were expected and for which the observed number of deaths was at

least two, 95% CIs were constructed with an exact method<sup>11</sup>; 95% CIs were not reported for causes with one or no observed death. Mortality from respiratory cancers was analysed separately for laryngeal cancer (ICD-9 161), lung cancer (ICD-9 162), and pleural cancer (ICD-9 163). The SMRs were stratified by year of hire and duration of employment in specific work areas. Workers were stratified into categories of cumulative duration of employment in respective work areas, implying that workers may appear in more than one work area. Years of employment in work areas were lagged based on empirical knowledge of minimal latency periods—10 years for laryngeal and lung cancer and 20 years for pleural mesothelioma.<sup>12 13</sup>

## Results

### COHORT CHARACTERISTICS

Vital status at the end of follow up was known for 99.7% of the 11 663 cohort members, and causes of death were determined for 96.8% of the 2719 already dead. Table 2 shows the distribution of person-years by age at risk and work area. Work histories within the companies were obtained for 99.7% of the cohort members. Across all work areas about 40%–50% of the person-years were among age groups  $\geq 60$  years. With the exception of work areas IV and VI, the results are based on about 25 000–45 000 person-years (table 2).

All cohort members were hired between 1911 and 1981 and more than 75% of all cohort members were hired after 1950. Within all work areas the cohort members are similarly distributed across the three categories of year of hire (fig 1). The distribution of cohort members by years of employment indicates that in work areas I to V the number of workers in the high exposure category (employed  $\geq 10$  years in the respective work area) exceeds the number of workers who were employed between one and 10 years in the respective work areas (fig 2). In the total cohort the all cause mortality (SMR 108; 95% CI 104 to 112) and the all cancer mortality (SMR 111; 95% CI 103 to 119) were slightly increased.

Table 3 Cancer of the larynx (ICD-161): number of observed deaths, and SMRs (95% CIs) among male German rubber workers (n=11663) between 1981 and 1991 by work area (I-VI), year of hire, and years of employment in work area (lagged 10 y)

	Preparation of materials (I)			Technical rubber goods (II)			Tyres (III)		
	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)
Year of hire:									
≥1960	3	534	(110 to 1558)	1	112	—	0	0	—
1950-1959	2	186	(23 to 673)	2	110	(13 to 398)	1	84	—
<1950	1	111	—	2	155	(19 to 559)	3	294	(61 to 859)
Years of employment in work area:									
1-9	1	116	—	3	228	(47 to 666)	3	424	(87 to 1238)
≥10	5	330	(107 to 769)	1	41	—	1	49	—
Total (≥1 y)	6	253	(93 to 551)	4	106	(29 to 271)	4	146	(40 to 373)

Table 4 Cancer of the lung (ICD-162): number of observed deaths, and SMRs (95% CIs) among male German rubber workers (n=11663) between 1981 and 1991 by work area (I-VI), year of hire, and years of employment in work area (lagged 10 y)

	Preparation of materials (I)			Technical rubber goods (II)			Tyres (III)		
	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)
Year of hire:									
≥1960	15	153	(86 to 253)	26	179	(117 to 262)	13	135	(72 to 231)
1950-1959	35	165	(115 to 229)	42	125	(90 to 169)	25	115	(74 to 169)
<1950	32	155	(106 to 218)	37	128	(90 to 176)	31	133	(90 to 188)
Years of employment in work area:									
1-9	30	171	(115 to 244)	39	151	(107 to 206)	18	134	(80 to 212)
≥10	50	158	(117 to 208)	60	124	(95 to 160)	50	125	(92 to 164)
Total (≥1 y)	80	162	(129 to 202)	99	134	(109 to 163)	68	127	(99 to 161)

Table 5 Cancer of the pleura (ICD-163): number of observed deaths, and SMRs (95% CIs) among male German rubber workers (n=11663) between 1981 and 1991 by work area (I-VI), year of hire, and years of employment in work area (lagged 20 y)

	Preparation of materials (I)			Technical rubber goods (II)			Tyres (III)		
	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)
Year of hire:									
≥1960	0	0	—	1	291	—	0	0	—
1950-1959	3	659	(136 to 1925)	3	405	(83 to 1181)	2	415	(50 to 1498)
<1950	1	240	—	5	855	(277 to 1991)	1	213	—
Years of employment in work area:									
1-9	1	204	—	4	549	(149 to 1406)	2	419	(51 to 1512)
≥10	3	742	(153 to 2167)	3	455	(94 to 1328)	1	176	—
Total (≥1 y)	4	448	(112 to 1146)	7	505	(202 to 1040)	3	287	(59 to 837)

#### MORTALITY FROM LARYNGEAL CANCER

A small and statistically non-significant increase in mortality from laryngeal cancer (13 deaths, SMR 129; 95% CI 69 to 221) was observed among the entire cohort.<sup>4</sup> The highest point estimate for the SMR was seen among workers in work area I (SMR 253; 95% CI 93 to 551, table 3). Further stratification by years of employment and year of hire showed a significant excess risk in employees who had worked ≥10 years in work area I, and among those hired after 1960. Non-significant increased risks were also seen in work area III (year of hire before 1950, and one to nine years of employment) and in work area V (≥10 years of employment, year of hire before 1950). No deaths from laryngeal cancer were recorded among workers who had worked more than one year in work area IV. However, only 0.7 deaths were expected among the workers employed in this work area.

#### MORTALITY FROM LUNG CANCER

Mortality from lung cancer was increased among the entire cohort (257 deaths, SMR 130; 95% CI 115 to 147). After stratification by work area we found significantly increased risks in work areas I, II, and V, and an increase of borderline significance in work area III

(SMR 127; 95% CI 99 to 161). The highest point estimate occurred in work area I. Further stratifications by year of hire or by years of employment in this work area show significantly increased occurrence of lung cancer among workers employed before 1960 and increased risks in both strata of duration of employment. In work areas II and V significantly increased risks were found among workers hired after 1960 and among those with an employment duration of one to nine years (table 4).

#### MORTALITY FROM PLEURAL CANCER

The highest relative risk for any cause of death among our cohort was found for mortality from pleural cancer (17 deaths, SMR 401; 95% CI 234 to 642). Analyses by work area show that mortality was increased in all six work areas; a significant increase was found in work areas I, II, and V. The highest point estimates were found among workers with ≥10 years of employment in work areas I or V. Most of the excess deaths occurred among workers hired before 1960 (table 5).

#### Discussion

The cohort was restricted to workers who were alive and active or retired on 1 January 1981.

Table 3 continued

Storage, dispatch (IV)			Maintenance (V)			Others (VI)		
Obs	SMR	(95% CI)	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)
0	0	—	1	149	—	0	0	—
0	0	—	1	99	—	1	162	—
0	0	—	2	195	(24 to 703)	2	303	(37 to 1093)
0	0	—	0	0	—	1	137	—
0	0	—	4	214	(58 to 548)	0	0	—
0	0	—	4	154	(42 to 394)	1	73	—

Table 4 continued

Storage, dispatch (IV)			Maintenance (V)			Others (VI)		
Obs	SMR	(95% CI)	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)
5	152	(49 to 355)	20	188	(115 to 290)	5	70	(23 to 163)
8	101	(43 to 199)	15	77	(43 to 128)	11	90	(45 to 161)
3	51	(10 to 148)	35	154	(107 to 214)	19	126	(76 to 197)
3	45	(9 to 130)	28	197	(131 to 284)	18	116	(69 to 183)
12	131	(67 to 228)	39	106	(76 to 145)	16	112	(64 to 182)
15	94	(53 to 155)	67	131	(102 to 167)	34	114	(79 to 159)

Table 5 continued

Storage, dispatch (IV)			Maintenance (V)			Others (VI)		
Obs	SMR	(95% CI)	Obs	SMR	(95% CI)	Obs	SMR	(95% CI)
0	0	—	1	392	—	0	0	—
1	588	—	0	0	—	1	387	—
0	0	—	4	880	(240 to 2254)	1	329	—
1	619	—	1	233	—	2	753	(91 to 2717)
0	0	—	4	843	(229 to 2157)	0	0	—
1	382	—	5	554	(179 to 1290)	2	460	(56 to 1660)

This may lead to a cohort of survivors and thus result in underestimation of the true risk associated with exposure. In contrast, if more heavily exposed workers or those ill with cancer stay on and less exposed or mostly the fit move on, this cohort definition may result in overestimation of the true risk. However, the slightly increased all cause mortality (SMR 108; 95% CI 104 to 112) and all cancer mortality (SMR 111; 95% CI 103 to 119) among the total cohort may be explained by excess mortality from diseases previously associated with the rubber industry. This argues against a strong healthy worker survivor effect<sup>4</sup> as well as against a substantial overestimation of risks. Furthermore, the comparison of SMRs between different exposure categories within our study cohort and with other studies has to be interpreted with caution, because the calculation of SMRs depends on the age distribution of the exposed population as the standard. Comparing more than two groups, this procedure may result in invalid comparisons, if the age distributions of the compared subcohorts differ markedly.

With the exception of lung cancer, other respiratory cancers among workers in the rubber industry have not yet been evaluated by IARC.<sup>3</sup> This study reports the highest number of pleu-

ral cancers found in a cohort of rubber workers. All 17 deaths occurred more than 20 years after hire. Pleural mesothelioma was recorded on the death certificates in 16 of the 17 cases of pleural cancer. Necropsy reports were available for three cases and all three confirmed the diagnosis of pleural mesothelioma. Only one other study so far reported an excess occurrence of pleural cancer: Nine cases in an Italian rubber tyre factory resulted in a significantly increased risk (SMR 1098)<sup>14</sup>; among workers hired after 1940 the SMR was lower, but was still significantly increased (SMR 490). The Italian study found significantly increased mortality among workers in extruding and calendering (SMR 1538), maintenance (SMR 2353), and "various services" (SMR 1666). Our results by work area are consistent with the results of the Italian study, but numbers are small. In our cohort only two deaths were recorded among workers hired after 1960. Among these workers the maximum latency period is only 32 years, and it may be too early to conclude that the risk has stopped.

In numerous epidemiological studies exposure to asbestos has been established as a causal factor for pleural mesothelioma; no other occupational or lifestyle risk factors, such as smoking, have been determined.<sup>15</sup> Within our cohort, exposure to asbestos was probably highest in work area I, where asbestos and asbestos contaminated talc were used as filler materials. Exposure to asbestos also occurred in work area II in the production lines of heat resistant technical rubber goods and among maintenance workers. Furthermore, talc has been widely used in the German rubber industry as antitacking material. Depending on the source, talc may be highly contaminated with asbestos fibres. It has been suggested that the occurrence of non-malignant diseases related to exposure to asbestos in the rubber industry could have been due to talc contaminated with asbestos.<sup>3 16 17</sup> One reason that the striking excess of pleural cancer among rubber workers had not been reported by most previous studies may be because of the combined analyses of all respiratory cancers,<sup>18-21</sup> the combined analyses of lung and pleural cancer,<sup>22-24</sup> or the focus on lung cancer.<sup>18 25-29</sup>

In 1982 the IARC working group concluded that there was sufficient evidence for increased occurrence of lung cancer in the rubber industry, but the evidence for a causal association was limited.<sup>3</sup> In our study excess risks in work area I were significant and stratification by time related factors was consistent with a causal association with occupational risk factors. Three other studies also found relative risks (RRs) between 1.43 and 3.3 in the mixing and weighing department.<sup>18 26 30</sup> In a Swedish cohort,<sup>26</sup> risks of lung cancer with long latency were highest in a subgroup of weighers and mixers, with long employment in this work area, and early date of hire. In the cohort of the British Rubber Manufacturers Association (BRMA) the exposure to dust, which was similarly defined as work area I in our study, was analysed. There was no positive trend with duration of exposure to dust.<sup>24</sup> In a study from Poland an increased risk

of 1.9 was found in a category combining mixing, milling, and curing.<sup>28</sup>

Excess deaths from lung cancer in the general rubber goods production and the tyre sector, as observed in our work areas II and III, were also noted in more recent publications among British rubber workers.<sup>24</sup> No increased occurrence of lung cancer was found in a sub-cohort of a United States study among rubber workers manufacturing industrial products.<sup>23</sup> Relative risks between 1.5 and 2.9 in the curing department were found among United States tyre workers<sup>31</sup> and—together with the inner tubes department—in a cohort from China.<sup>29</sup>

The only other study that reported an excess of pleural cancer also described an excess of lung cancer in maintenance workers.<sup>14</sup> Interestingly, the overall pattern of excess occurrence of lung cancer in our data parallels the excess occurrence of pleural cancer in work areas I, II, and V, possibly pointing to asbestos as one common risk factor.

Altogether, our results add further evidence of an association of lung cancer risk with specific work areas in the rubber industry. There is, however, little information on specific carcinogens, which might be responsible for the excess deaths from lung cancer. Reporting the results of the British Health and Safety Executive cohort, Baxter and Werner discussed exposure to asbestos as a potential risk factor for the increased mortality from lung cancer in belting.<sup>32</sup> The increased deaths from lung cancer among workers employed in other work areas was not attributed to asbestos and no relation was found with exposure to talc in the tyre sector. Zhang *et al*, however, noted an excess of lung cancer in work areas where talc was abundantly used as an anti-tacking material.<sup>29</sup>

Our study also represents the largest cohort in which risks of lung cancer among rubber workers hired after 1960 were investigated and we have previously reported an increased risk among these workers (60 deaths, SMR 136; 95% CI 104 to 175).<sup>4</sup> After stratification by work area we found an increased occurrence of lung cancer among workers hired after 1960 in all work areas except area VI (SMRs between 135 and 188). Significant results were obtained in work areas II and V. Three other studies provide data for workers hired after 1960.<sup>18 25 33</sup> Two studies, with a combined total of 16.3 expected cases, found no increased risk, but did not present data by work areas.<sup>25 33</sup> Thus the possible mixing of high and low exposure work areas might be one reason for not finding an association. The third study presented data by work area and year of hire after 1960 and found excess deaths among weighers and mixers and other production workers (six observed, 1.1 expected).<sup>18</sup> Based on this Swedish cohort and on our results, the increased risk of lung cancer among rubber workers might be relevant to the current work force.

As a high prevalence of smoking among rubber workers had been anecdotally suggested, lung cancer risks among rubber workers might be confounded by smoking or result from a synergistic action of occupational exposures and smoking. Only two studies have presented

lung cancer data adjusted for smoking habits. Both essentially found no difference between crude and adjusted odds ratios (ORs).<sup>29 34</sup> Furthermore it is unlikely that an increased risk of more than 50% could be attributed solely to the confounding effect of smoking.<sup>35</sup>

In our cohort excess deaths from laryngeal cancer were reported for workers who were employed in work areas I, III, and V; the results were significant among employees who had worked  $\geq 10$  years in work area I. It is noteworthy that most other cohort studies published since 1982 have reported either an increased incidence<sup>26 27</sup> or an increased mortality<sup>14 24 25 28</sup> from laryngeal cancer. The increased risks ranged between 19% and 113%. Highly increased risks were also found in two record linkage studies from Scandinavian countries.<sup>36 37</sup> Analyses by either work area or exposure conditions were presented by only three studies. Excess risks were found in the weighing and mixing department (based on one incident case)<sup>26</sup> and among workers with exposure to dust, who were defined as having worked in the compounding, weighing, mixing, extruding, or calendaring department.<sup>24</sup> In that study a non-significant trend with cumulative duration of employment in these work areas was found (test statistic for trend = +1.33). One of the three studies that reported mortality from laryngeal cancer by work area found no excess risk in weighing and mixing, possibly due to the combined analysis with the vulcanising area. Instead a relatively high excess (the only significant increase (six deaths, SMR 591)) was found in lacquering and product building.<sup>28</sup>

The findings of our study suggest an association between mortality from laryngeal cancer and employment in work area I. Furthermore, the patterns of mortality from laryngeal cancer by work area in our study closely resemble those of pleural cancer and lung cancer. There is mounting evidence of an association between exposure to asbestos and laryngeal cancer<sup>38</sup>; future analyses of laryngeal cancer among rubber workers should consider asbestos and asbestos contaminated talc as potential risk factors. An association with nitrosamines, with presumably high exposures in work areas II, III and IV, has been suggested, but our data do not support this hypothesis.

No cohort or nested case-control studies in the rubber industry have so far investigated the potential confounding effect of differential smoking and alcohol habits. Only weak and indirect evidence may be drawn from the two available studies investigating the potential confounding of risks of lung cancer in the rubber industry by smoking. Both studies found no evidence for confounding.<sup>29 34</sup> Studies assessing the potential confounding effect of alcohol among rubber workers are not available. However, two hospital based case-control studies of laryngeal cancer reported an increased risk for rubber workers after adjustment for smoking and alcohol.<sup>39 40</sup>

Exposure conditions in the rubber industry are known for their complexity and variability over time and between work areas. In general,

these exposures may be broadly summarised predominantly as dust exposure in weighing and mixing; low temperature fumes (<130°C) in milling, extruding, and calendaring; high temperature fumes arising from vulcanisation (160°C–280°C) in curing and inspection<sup>10</sup>; and solvent exposures in mixing and component assembly. Most exposure surveys in the rubber industry have concentrated on airborne particulates and solvents.<sup>41–45</sup> However, for respiratory cancers, specific carcinogens such as asbestos and asbestos contaminated talc, polycyclic aromatic hydrocarbons, nitrosamines, and carbon black, used as a filler and reinforcing agent,<sup>46</sup> need to be considered. Measurements in the rubber industry are available for nitrosamines,<sup>7–9, 47</sup> and to a lesser extent for polycyclic aromatic hydrocarbons and carbon black. We shall consider such measurements when a job exposure matrix based on exposure assessments by experts for relevant respiratory carcinogens will be constructed for all cost centre codes.

### Conclusion and outlook

A causal relation between exposure to asbestos and the excess of pleural cancer among rubber workers is plausible and likely. In our study the pattern of mortality from lung cancer by work areas parallels the pattern of mortality from pleural cancer. This might point to asbestos as one risk factor for increased lung cancer mortality among some groups of rubber workers. Our study provides further evidence for an increased mortality from laryngeal cancer among workers in the rubber industry, which may also be related to asbestos. Only recently, asbestos related laryngeal cancer has been listed as a recognised occupational disease in Germany. The excess of respiratory cancers among workers hired after 1960 suggests that these risks may not only reflect problems of the distant past. The role of specific carcinogens and their relevance to respiratory cancers among workers in the rubber industry could not be considered with the currently available data, but will be the focus of future analyses specific to exposures.

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