Cancer Mortality Among European Asphalt Workers: An International Epidemiological Study. I. Results of the Analysis Based on Job Titles

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Background *Inhalation of bitumen fumes is potentially carcinogenic to humans.*
Methods *We conducted a study of 29,820 male workers exposed to bitumen in road paving, asphalt mixing and roofing, 32,245 ground and building construction workers unexposed to bitumen, and 17,757 workers not classifiable as bitumen workers, from Denmark, Finland, France, Germany, Israel, the Netherlands, Norway, and Sweden, with mortality follow-up during 1953–2000. We calculated standardized mortality ratios (SMRs) and 95% confidence intervals (CIs) based on national mortality rates. Poisson regression analyses compared mortality of bitumen workers to that of building or ground construction workers.*
Results *The overall mortality was below expectation in the total cohort (SMR 0.92, 95% CI 0.90–0.94) and in each group of workers. The SMR of lung cancer was higher among bitumen workers (1.17, 95% CI 1.04–1.30) than among workers in ground and building construction (SMR 1.01, 95% CI 0.89–1.15). In the internal comparison, the relative risk (RR) of lung cancer mortality among bitumen workers was 1.09 (95% CI 0.89–1.34). The results of cancer of the head and neck were similar to those of lung cancer, based on a smaller number of deaths. There was no suggestion of an association between employment in bitumen jobs and other cancers.*
Conclusions *European workers employed in road paving, asphalt mixing and other jobs entailing exposure to bitumen fume might have experienced a small increase in lung cancer*

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mortality risk, compared to workers in ground and building construction. However, exposure assessment was limited and confounding from exposure to carcinogens in other industries, tobacco smoking, and other lifestyle factors cannot be ruled out. Am. J. Ind. Med. 43:18–27, 2003. *© 2003 Wiley-Liss, Inc.*

KEY WORDS: asphalt; epidemiology; lung neoplasms; mortality; occupational exposures; road paving; roofing

INTRODUCTION

Bitumen is an organic binder derived from distillation of crude oil that is combined with inorganic filler such as sand and gravel to produce asphalt. Bitumen forms fumes when it is heated during application to surfaces such as roads and roofs. Asphalt workers, the asphalt industry, and regulatory agencies are concerned about the potential carcinogenicity posed by inhalation of bitumen fume. The International Agency for Research on Cancer (IARC) considered in 1985 and 1987 extracts of steam-refined and air-refined bitumens carcinogenic in experimental animals and classified them as possible human carcinogens (IARC Group 2B), while for undiluted bitumens, the evidence was limited (IARC Group 3) [International Agency for Research on Cancer, 1985, 1987]. The evaluations relied mainly on data from animal studies.

Assessment of the carcinogenicity of bitumen fume may have far-reaching industrial, economic, and public health implications. Although precise figures on the number of workers exposed to bitumen fume in Europe are not available, a conservative estimate, based on the number of asphalt plants and paving companies, is in the order of 100,000–200,000. In Finland, an estimated 0.9% of the total workforce is exposed [Kauppinen et al., 2003].

The epidemiological studies informative of cancer hazard in asphalt workers and roofers were identified and reviewed by Partanen and Boffetta [1994]. The aggregated data suggested an increased risk of cancers of the lung, stomach, and possibly non-melanoma skin cancer and leukemia in roofers.

Most of the results available for the meta-analysis were based on routine statistics and record linkage studies, and cohort studies include populations of workers such as roofers [Hammond et al., 1976; Stern et al., 2000] and mastic asphalt workers [Hansen, 1989], whose exposure circumstances experienced might not represent those typical of asphalt workers. Furthermore, the available results did not address explicitly the effects of bitumen fume. In particular, uncontrollable confounding exposures to fumes from carcinogenic coal tar-based materials precluded disentangling independent effects of bitumen fumes.

To address carcinogenicity of bitumen fume, the IARC and its collaborators assembled a retrospective cohort of workers from the asphalt industry (road paving, asphalt mixing, and roofing) in seven European countries (Denmark, Finland, France, Germany, the Netherlands, Norway, and Sweden) and Israel [Partanen et al., 1995]. The primary goal of the study was to assess whether an increased risk of lung cancer is associated with bitumen fume exposure. We report the results of cancer mortality based on an analysis of job titles. In a companion report, we report results based on assessment of exposure to bitumen fume and other agents [Boffetta et al., 2003]. Details on the study design and the results of the mortality analysis (including systematic presentation of country-specific results) have been reported [Boffetta et al., 2001].

METHODS

The study cohort included workers first employed during 1913–1999 in road paving and asphalt mixing companies in seven participating countries (Denmark, Finland, France, Germany, Israel, the Netherlands, and Norway) and in a nationwide health surveillance program in Sweden. The procedures of identification of suitable companies varied in the participating countries, as did the number and average size of the companies included in the study.

The number of companies varied from 1 in Israel to 138 in Germany. The periods of employment varied among countries: the first year was between 1910–1930 in all countries but Denmark (1953) and Germany (1965); the last year varied from 1992 in Sweden to 1999 in Germany and the Netherlands. A basic requirement was the availability of complete retrospective employee rosters during the enrollment period. In all countries except for Sweden, personal identifiers and employment histories of workers were abstracted from company records to the extent to which they were available. Once a company had been selected for the study, efforts were made to enroll all manual workers. Workers employed in jobs entailing exposure to bitumen fume, i.e., those employed in paving, roofing, water proofing, or asphalt mixing (referred to as 'bitumen workers' thereafter), formed the main group under study; other workers (building and ground construction workers, mainly involved in the construction of roads before pavement) provided a comparison group.

Enrollment of the cohort in Sweden followed a different approach. The Swedish Construction Industry's Organization for Working Environment Safety and Health

(Bygghälsan) provided nationwide out-patient medical services to construction workers during 1969–1992 [Engholm and Englund, 1995]. The organization was a joint venture between trade unions and the employers' association, consisting of stationary and mobile field units and a central unit. A major activity was preventive health examinations, offered to all employees in the construction industry through regular personal invitations (every 1–5 years, depending on exposure and time period). Beginning in 1971, data from the examinations were compiled in a computerized register. For the purpose of this study, we selected from the computerized database of construction workers all road pavers and asphalt mixers as well as a sample of other workers in the construction industry.

Full employment histories in recruited companies were coded according to an ad hoc classification of jobs which included the two main groups (bitumen workers and building and ground construction workers) as well as additional groups where we classified "other and unspecified blue collar workers" as well as "non-blue collar workers". Jobs of bitumen workers were divided into (i) road paving (further subdivided into asphalt paving, surface dressing, mastic asphalt laying, emulsion paving, recycling, and other jobs in road paving), (ii) asphalt mixing, (iii) unspecified whether road paving or asphalt mixing, (iv) water proofing and roofing, and (v) other and unspecified bitumen jobs.

We excluded women from the data analysis, since they represented a very small proportion of cohort members (N = 2,028, from four countries). We also excluded workers with less than one full season of employment in the target companies, in order to have a consistent definition of minimal duration of employment across countries (N = 42,802, 67% of whom were from Denmark). The duration of the season was company-specific. Short-term workers were also excluded since they may differ from long-term employees in their occupational and non-occupational risk factors. Additional workers were excluded because of missing data. Out of the 124,871 workers originally included in the cohort, 79,822 were retained in the analysis.

Table I shows the distribution of cohort members by country and major job group. Out of the 79,822 workers in the analysis, 29,820 were ever employed as bitumen workers, 32,245 were employed as building or ground construction workers, and 17,757 workers who could not be classified as either bitumen or building and ground construction workers. The Danish cohort contributed 32% of bitumen workers, the cohort from Norway and Sweden contributed 15–19% each, and those from Finland, France, and Germany between 8 and 11% each. Over half of all building and ground construction workers included in the cohort were from Sweden.

In order to control for the possible confounding effect of coal tar exposure, a coal tar-free sub-cohort was identified, which consisted of 17,443 bitumen workers and 30,273 building or ground construction workers employed in companies or periods in which exposure to coal tar was considered not to have occurred.

Mortality follow-up was conducted in all participating countries. The date of beginning of follow-up spanned from 1953 in Norway to 1979 in France, the end of follow-up was between 1995 and 2000. Mean duration of follow-up was 16.7 years in the whole cohort, with no difference between bitumen workers and building or ground construction workers. It varied between 11.7 years in France and Germany to 21.9 years in Norway.

A total of 1,287,209 person-years of observation were accumulated by cohort members, of which 481,089 person-years by bitumen workers and 537,281 person-years by building or ground construction workers. A total of 10,096 cohort members were reported to have died by the end of the follow-up, of whom 3,987 were bitumen workers and 3,876 were building and ground construction workers. The overall proportion of cohort members lost to follow-up was 0.7%;

TABLE I. European Asphalt Workers and Controls, Person-Years by Country and Job Title

	Bitumen worker (ever employment)		Building or ground construction worker (only employment)		Other worker		Total	
Country	N	PY	N	PY	N	PY	N	PY
Denmark	9652	158311	1129	12314	4366	74278	15147	250398
Norway	5687	110789	2467	57173	1033	25822	9187	197284
Sweden	4381	65265	16518	309730	61	1005	20960	392579
Finland	2642	44510	2652	46447	382	6958	5676	100949
Netherlands	541	9692	702	12897	2437	41563	3680	67291
Germany	3223	36433	2486	29824	2271	26978	7980	97992
France	2513	33266	5789	57494	6714	81056	15016	184319
Israel	1181	22823	502	11402	493	11179	2176	46399
Total	29820	481089	32245	537281	17757	268839	79822	1337211

N, number of workers; PY, person-years.

an additional 0.5% of cohort members emigrated during the follow-up.

Age-, calendar period- and sex-specific national mortality reference rates, derived from the mortality data bank of the World Health Organization, were used to calculate the expected numbers of deaths. Standardized mortality ratios (SMRs) were calculated as ratios of observed and expected numbers of deaths, using ad hoc SAS programs [Sas Institute, 1990]; 95% CIs were based on the Poisson distribution of observed numbers of deaths.

Heterogeneity of results among countries was evaluated using the statistic

$$Q = \Sigma^k w_i (SMR_i - SMR)^2$$

which has a χ^2 distribution with k-1 degrees of freedom ($w_i = 1/var_i$, where var_i is the variance of the SMR for country i, SMR is the overall SMR). Country-specific results are not systematically reported: they can be found in the study report [Boffetta et al., 2001] and in companion papers in this issue [Bergdahl and Järvholm, 2003; Hooiveld et al., 2003; Kauppinen et al., 2003; Randem et al., 2003; Shaham et al., 2003; Stücker et al., 2003]. However, country-specific results for lung cancer and other important causes of death among bitumen workers are discussed when there is evidence of heterogeneity.

In addition, relative risks and associated 95% CI were estimated using multivariate Poisson regression analysis [Breslow and Day, 1987]. In the regression models, we included age (10 five-year groups), calendar period ($\leq$ 1974, 1975–1979, 1980–1984, 1985–1989, 1990 and later), country and total duration of employment ($<$ 1, 1–4, 5–9, 10–14, 15–19, 20 + years) as covariates. Poisson regression analyses were carried out using the statistical package STATA [Stata Corporation, 1997].

RESULTS

Table II presents the SMRs of detailed causes of death for bitumen workers, building or ground construction, and other and unspecified workers.

Overall mortality was below expectation in all three main job categories. The pattern of mortality from all malignant neoplasms combined paralleled very closely that of all cause mortality.

The SMR for lung cancer among bitumen workers was 1.17 (95% CI 1.04–1.30), based on 330 deaths. In building and ground construction workers, the lung cancer SMR was 1.01 (95% CI 0.89–1.15). Among bitumen workers there was little evidence of heterogeneity of lung cancer SMRs among countries: the *P*-value of the test of heterogeneity was 0.4. Country-specific results are reported in Figure 1. Among building and ground construction workers, however, there was evidence of heterogeneity (*P*-value 0.01; Fig. 1).

The overall SMR for head and neck cancer among bitumen workers was 1.27 (95% CI 1.02–1.56). There were no significant SMR excesses for other malignant neoplasms. The following significant deficits were found: cancers of the colon and the brain and nervous system in bitumen workers; liver cancer in building and ground construction workers; cancers of the buccal cavity and pharynx and of the prostate in other workers. In country-specific analyses of bitumen workers, an increased SMR was found for head and neck cancer in Germany (SMR 2.69, 95% CI 1.54–4.37; 19 observed deaths), and a decreased SMR was found for pancreatic cancer in Norway (SMR 0.40, 95% CI 0.13–0.93; 5 observed deaths). Among building and ground construction workers in Sweden, there was a decrease in the SMR of liver cancer (SMR 0.45, 95% CI 0.23–0.81; 11 observed deaths) and neoplasms of connective and soft tissues (SMR 0, 95% CI 0–0.94; no observed and 3.91 expected deaths).

Table III presents the SMRs of selected neoplasms by specific jobs among bitumen workers. Road pavers experienced a statistically significant deficit in all-cause mortality (SMR 0.94, 95% CI 0.90–0.98). There was a significant excess of lung cancer in this group (SMR 1.17, 95% CI 1.01–1.35), the increase being statistically significant in the German cohort only (SMR 1.87, 95% CI 1.13–2.92; 19 observed deaths). In all job groups with exposure to bitumen, the SMR of lung cancer exceeded unity (range 1.12–1.33). Mortality from head and neck cancer was increased overall and in all job groups except asphalt mixing plant workers. The mortality pattern of hot mix (asphalt) pavers, a major constituent group of road pavers, followed closely that of road pavers (data not shown in detail).

A total of 33 deaths occurred among mastic asphalt workers, of which five were from lung cancer (2.09 expected, SMR 2.39, 95% CI 0.78–5.57). The small number of workers in this group is due to the fact that the information from company records was not specific enough to classify them in the relevant job class. It is likely that additional mastic asphalt workers were included in the broader group of road pavers.

Workers of asphalt mixing plants contributed 234 deaths. Mortality from all causes and from all cancers combined both showed a significant deficit. The SMR of lung cancer was 1.12 (95% CI 0.73–1.66); there was no evidence of an increased mortality from other neoplasms. A further 162 deaths occurred among asphalt workers unspecified as road pavers or asphalt mixers: they were mainly from Israel. Their mortality pattern paralleled that of road pavers, with a significant decrease in all-cause mortality and a non-significant increase in the SMR of lung and head and neck cancers.

Waterproofers and roofers contributed 141 deaths, mainly from Denmark and Finland. Their mortality from lung and head and neck cancers was marginally increased. In a small group of these workers from Germany, however, four deaths from lung cancer occurred, versus one expected.

TABLE II. Standardized Mortality Ratios (SMRs) of Selected Neoplasms, by Job Title

	Bitumen worker (ever employment)			Building or ground construction worker (only employment)			Other worker		
Cause of death (9th ICD revision)	Observed	SMR	95% CI	Observed	SMR	95% CI	Observed	SMR	95% CI
All causes 001–999	3987	0.96	0.93–0.99	3876	0.91	0.88–0.94	2233	0.89	0.85–0.93
All malignant neoplasms 140–208	1016	0.95	0.90–1.01	1030	0.96	0.90–1.02	690	0.95	0.88–1.02
Upper aero-digestive tract 140–150, 161	92	1.27	1.02–1.56	82	1.10	0.87–1.36	58	0.80	0.61–1.04
Oral cavity and pharynx 140–149	35	1.21	0.84–1.68	35	1.10	0.76–1.53	17	0.58	0.34–0.93
Oesophagus 150	37	1.29	0.91–1.78	37	1.23	0.87–1.70	29	1.09	0.73–1.56
Stomach 151	70	0.99	0.77–1.25	81	1.05	0.83–1.30	50	1.19	0.88–1.56
Colon 153	55	0.71	0.54–0.93	58	0.80	0.61–1.03	57	1.16	0.88–1.50
Rectum 154	43	0.89	0.64–1.20	37	0.86	0.60–1.18	29	1.05	0.70–1.50
Liver 155	17	0.73	0.43–1.17	25	0.67	0.43–0.98	16	0.84	0.48–1.37
Pancreas 157	43	0.76	0.55–1.02	67	1.03	0.80–1.31	36	1.04	0.73–1.45
Nose and nasal sinuses 160	4	0.92	0.25–2.34	4	0.79	0.22–2.02	9	1.30	0.59–2.47
Larynx 161	20	1.34	0.82–2.07	10	0.79	0.38–1.45	12	0.73	0.38–1.27
Lung 162	330	1.17	1.04–1.30	249	1.01	0.89–1.15	216	1.01	0.88–1.15
Pleura 163	5	0.72	0.23–1.68	5	0.70	0.23–1.64	7	1.30	0.52–2.67
Connective and other soft tissue 171	6	1.23	0.45–2.68	2	0.32	0.04–1.15	3	1.00	0.21–2.93
Melanoma of skin 172	15	0.74	0.41–1.21	16	0.69	0.40–1.12	7	0.70	0.28–1.44
Prostate 185	82	0.85	0.68–1.05	118	1.09	0.90–1.30	34	0.64	0.44–0.89
Testis 186	4	0.77	0.21–1.98	2	0.51	0.06–1.85	1	0.36	0.01–1.99
Bladder 188	45	1.05	0.77–1.41	24	0.73	0.47–1.09	35	1.24	0.87–1.73
Kidney 189	26	0.76	0.50–1.11	37	0.86	0.61–1.19	17	0.83	0.48–1.33
Nervous system 191–192	22	0.63	0.40–0.96	37	0.92	0.65–1.27	14	0.72	0.39–1.21
Ill-defined and unspecified sites 195, 199	52	0.95	0.71–1.24	48	1.01	0.74–1.33	29	0.72	0.48–1.03
Non-Hodgkin's lymphoma 200, 202	23	0.78	0.49–1.17	42	1.18	0.85–1.60	13	0.74	0.39–1.27
Hodgkin's disease 201	8	1.24	0.54–2.45	4	0.62	0.17–1.58	3	0.80	0.16–2.33
Multiple myeloma 203	12	0.70	0.36–1.22	24	1.20	0.77–1.78	12	1.24	0.64–2.17
Leukaemia 204–208	28	0.78	0.52–1.12	38	1.04	0.73–1.42	19	0.86	0.52–1.35
Lymphoid leukemia 204	8	0.68	0.30–1.35	13	1.16	0.62–1.99	7	0.99	0.40–2.03
Myeloid leukemia 205	13	0.70	0.37–1.20	22	1.18	0.74–1.78	10	0.93	0.45–1.71

CI, confidence interval.

A relatively large number of asphalt workers employed in jobs entailing exposure to bitumen fume (mainly from Denmark) could not be further classified as road pavers, asphalt mixers, or water proofers/roofers. They had a significantly elevated all-cause mortality. Mortality from lung and head and neck cancers in these workers was non-significantly increased over expectation.

Table IV presents the results of the Poisson regression analysis of mortality from all neoplasms, lung cancer, and head and neck cancer among bitumen workers. In all analyses, the unexposed (reference) category consisted of building and ground construction workers. The RR of lung cancer was only slightly increased among asphalt workers as a whole (RR 1.09, 95% CI 0.89–1.34), as compared to building and ground construction workers. The pattern by country showed a significantly increased RR in Denmark (RR 2.61, 95% CI 1.07–6.35), a non-significantly increased RR in the Netherlands, Germany, and Israel, and a non-significantly decreased RR in Finland, Norway, France, and Sweden (Fig. 2).

The RR of head and neck cancer was non-significantly elevated in all groups of bitumen-exposed workers, except asphalt mixing plant workers.

These analyses were repeated using only ground construction workers as unexposed (reference category). The results, not shown in detail, were remarkably similar to those reported in Table IV, which were based on a reference group composed by building and ground construction workers.

DISCUSSION

Our analysis of mortality among European asphalt workers revealed a reduced overall mortality in most

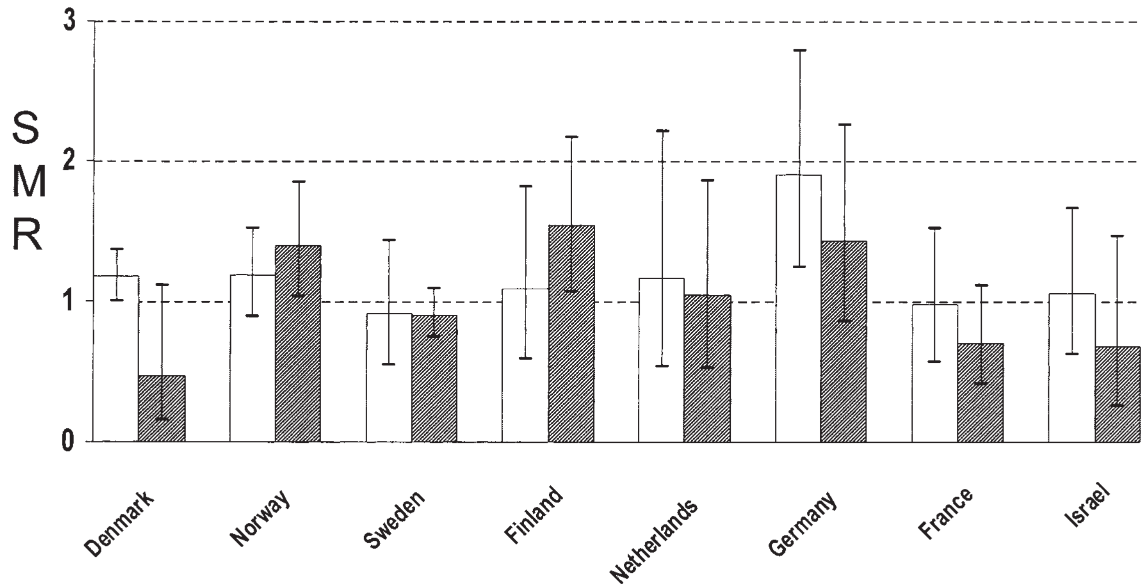

FIGURE 1. Standardized mortality ratio (SMR) of lung cancer among bitumen workers (white bars) and building and ground construction workers (striped bars), by country.

countries and job classes. The SMR of lung cancer was higher among workers employed in jobs entailing exposure to bitumen fume than among workers from building or ground construction; however, the difference in risk of lung cancer between the two groups was reduced in the internal analysis. The results of cancer of the buccal cavity and the pharynx were similar to those of lung cancer; however, they were based on a small number of deaths. There was no clear suggestion of an association between employment in jobs entailing exposure to bitumen and mortality from other neoplasms, although some excesses were apparent in country-specific analyses.

There was a reduced mortality from all causes, when cohort members were compared to national reference populations, most likely attributable to a selection of healthy workers in the asphalt industry, and to a selection of unhealthy workers out of it the so-called ''healthy worker effect'' as described by Checkoway et al. [1989]. With

TABLE III. Standardized Mortality Ratios (SMRs) by Job Title Among European Bitumen Workers

Cause of death		Bitumen worker	Road paver[a]	Asphalt paver[b]	Asphalt mixer[a]	Unspecified paver/mixer[a]	Roofer, waterproofer[a]	Unspecified bitumen worker[a]
	Person-years	481089	320060	212860	41740	15039	34519	88742
All causes	Obs	3987	2411	1368	234	162	141	1162
	SMR	0.96	0.94	0.89	0.77	0.80	0.88	1.08
	95% CI	0.93–0.99	0.90–0.98	0.85–0.94	0.67–0.87	0.68–0.93	0.74–1.04	1.02–1.15
All cancers	Obs	1016	623	362	55	33	44	292
	SMR	0.95	0.96	0.95	0.66	0.73	1.21	1.01
	95% CI	0.90–1.01	0.89–1.04	0.86–1.06	0.50–0.86	0.50–1.02	0.88–1.62	0.90–1.13
Head and neck cancer	Obs	92	59	38	4	4	4	23
	SMR	1.27	1.30	1.37	0.50	1.93	1.49	1.37
	95% CI	1.02–1.56	0.99–1.68	0.98–1.88	0.14–1.29	0.52–4.95	0.40–3.81	0.87–2.06
Lung cancer	Obs	330	189	100	25	12	14	99
	SMR	1.17	1.17	1.15	1.12	1.18	1.33	1.13
	95% CI	1.04–1.30	1.01–1.35	0.93–1.40	0.73–1.66	0.61–2.07	0.73–2.23	0.92–1.37

Obs, observed deaths; CI, confidence interval.
[a]Subgroup within bitumen workers.
[b]Subgroup within road pavers.

TABLE IV. Relative Risk (RR) of Selected Causes of Death Among European Bitumen Workers

		Bitumen worker	Road paver[a]	Asphalt paver[b]	Asphalt mixer[a]	Unspecified paver/mixer[a]	Roofer/ waterproofer[a]	Unspecified bitumen worker[a]
All causes	RR	0.98	1.01	0.97	0.87	0.86	0.93	1.23
	95% CI	0.93–1.04	0.95–1.07	0.90–1.03	0.76–1.01	0.72–1.03	0.77–1.14	1.06–1.41
All cancers	RR	0.98	1.01	0.96	0.74	0.76	1.27	1.19
	95% CI	0.88–1.09	0.90–1.13	0.84–1.09	0.55–0.99	0.51–1.12	0.87–1.84	0.89–1.60
Head and neck cancer	RR	1.24	1.24	1.34	0.44	2.08	1.23	1.29
	95% CI	0.93–1.65	0.91–1.68	0.93–1.94	0.16–1.18	0.73–5.91	0.45–3.37	0.77–2.17
Lung cancer	RR	1.09	1.08	0.99	1.18	1.07	1.34	1.53
	95% CI	0.89–1.34	0.87–1.34	0.77–1.27	0.75–1.84	0.55–2.10	0.71–2.53	0.92–2.57

Reference category: building and ground construction workers. CI, confidence interval.
[a]Subgroup within bitumen workers.
[b]Subgroup within road pavers.

respect to lung cancer, the healthy worker effect usually has a limited impact [Checkoway et al., 1989].

The assessment of mortality from lung cancer among bitumen workers was the main objective of the study. The discrepancy of results between the SMR and the Poisson regression analysis is due to confounding by country in the former, since the countries with increased lung cancer mortality in the total cohort, such as Denmark and Norway, contributed disproportionately to the group of bitumen workers. Therefore, while the SMR results are important for comparison with previous investigations and national comparisons with other groups of workers, the inference on possible cancer risk from exposure to bitumen workers should be based mainly on the results of the internal comparisons.

As in all retrospective cohort studies, our investigation might suffer from several biases. It is possible that the companies included in our study are not representative of the asphalt industry in their countries. In such case, the SMRs are not valid estimates of the corresponding SMRs of a representative sample of European asphalt workers. However, it should be noted that this problem does not apply to Sweden, where the cohort was based on a program including at least 80% of the workers in the industry.

Misclassification of exposure, which depends on the completeness and validity of job history information and job classification, is a matter of serious concern. Although through the feasibility study we aimed to select countries and companies with good information on employment history [Partanen et al., 1995], the final cohort included a

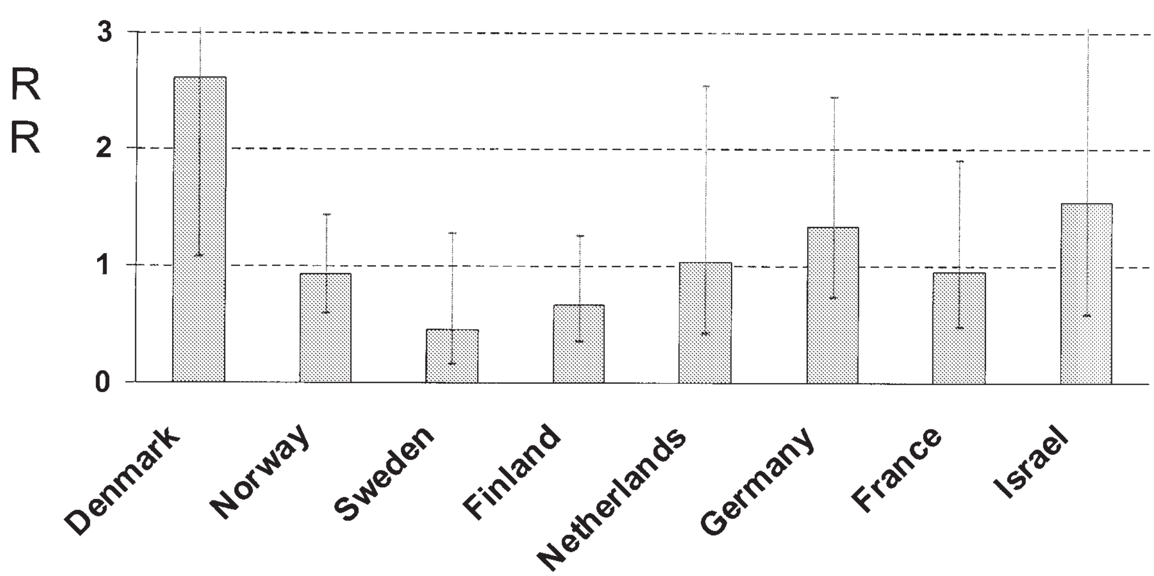

FIGURE 2. Relative risk (RR) of lung cancer among bitumen workers, by country.

large number of workers with poor employment data, who were either excluded from the analysis or classified in unspecific job groups, in which exposure misclassification is greatest.

However, it should be stressed that, given the nature of the study, the sources of information bias discussed above can only result in exposure misclassification that is non-differential with respect to outcome. This type of misclassification generates results towards the null value in the case of binary exposure variables, such as those used in this investigation. This consideration applies in particular to the assessment of exposure to chemical agents, such as bitumen fume and coal tar, since substantial misclassification might occur when using job titles or job groups to estimate exposure to specific agents. In a companion report, we describe the mortality of this cohort with respect to estimated exposure to bitumen fume, polycyclic aromatic hydrocarbons, and other agents [Boffetta et al., 2003]. It should be noted, however, that misclassification of job for a group of workers at increased risk would result in an overestimate of the risk in the job categories in which such workers were wrongly classified.

A further source of bias in this study derives from the lack of comparability of SMRs calculated for different populations, such as different countries and job groups [Miettinen, 1972]. This is due to the fact that the result of each standardization depends on the age structure of the population under study. This usually causes a bias of small magnitude, but it may have important implications in the interpretation of the results when combined with a large sample size, as in this study. This problem does not apply to the results of internally standardized analyses, such as those based on multivariate Poisson regression modeling.

The positive associations observed between mortality from lung cancer and employment in several country-specific analyses of bitumen-exposed job groups can be due to confounding factors. One group of confounders consists of occupational carcinogens to which cohort members might have been exposed in jobs held in companies other than those included in the study (both within and outside the asphalt industry). Many members of the cohort have a rather short duration of employment in the cohort (the overall average duration of employment is 6.2 years, and that in jobs entailing exposure to bitumen is 6.8 years), and it is plausible that they have been exposed to occupational carcinogens in jobs held in other industries. The lack of information on employment in other companies in the asphalt industry would bias the risk estimates in an unpredictable direction. The lack of information on other jobs is a potential source of confounding, since it is possible that workers employed within our cohort in jobs with higher levels of bitumen fume exposure might have also experienced more frequently exposure to carcinogens in other industries.

A further group of potential confounders includes non-occupational factors, chiefly tobacco smoking. We did not systematically collect information on smoking among workers included in this study; however, some national cohorts included limited data on smoking habits. Among 1138 current employees in the Dutch cohort, the prevalence of never smokers was slightly lower among workers ever employed in jobs entailing exposure to bitumen (21%) than in other workers (27%). In studies from the USA, workers in jobs comparable to those included in this cohort (roofers, heavy equipment operators, etc.) reported a higher consumption of tobacco than other workers [Brackbill et al., 1988; Stellman et al., 1988; Nelson et al., 1994]. Other possible lifestyle-related confounders include a diet poor in fruits and vegetables, exposure to environmental lung carcinogens and factors associated with low social class [Blot and Fraumeni, 1996]. Since these factors tend to be positively correlated with tobacco smoking, their effect on risk estimates for the agents under study—if any—is likely to have been similar to that of tobacco smoking. However, since the association of lung cancer risk with diet, environmental exposures, and other social class-related factors is much weaker than that with tobacco smoking, the potential confounding effect of these other factors—if present—would be of a smaller magnitude than that of smoking. The results of internal analyses, however, would only suffer from differences in tobacco smoking and other lifestyle factors between workers in different job groups within the asphalt industry. However, analyses of smoking patterns among groups of Dutch, Finnish, and Norwegian workers suggest that confounding by smoking can contribute to explain differences in lung cancer mortality between different jobs [Hooiveld et al., 2003; Kauppinen et al., 2003; Randem et al., 2003].

Heterogeneity of country-specific results on lung cancer mortality was present for building and ground construction workers: it can result from different selection factors within and outside the industry, from a different distribution of tobacco smoking and other potential confounders, or from chance. This result, however, begs for additional caution in the interpretation of the results of the internal comparison analysis in the absence of information on the possible sources of bias.

In the meta-analysis published by Partanen and Boffetta [1994], the pooled RR among road pavers and highway maintenance workers was 0.87 (95% CI 0.74–1.01), based on three cohort studies, including a study of Swedish pavers overlapping with the Swedish component of the present study [Engholm et al., 1991], and one case-control study. The pooled RR among roofers was 1.78 (95% CI 1.50–2.10). Since the meta-analysis, the proportionate mortality of members of a large US union of roofers has been reported [Stern et al., 2000]; its results on lung cancer are compatible with those of the meta-analysis. Included in the meta-analysis was also a cohort study of Danish mastic asphalt workers [Hansen, 1989, 1991], in which the standardized incidence ratio of lung cancer was 3.44. In none of the previous studies there was an assessment of individual exposure to bitumen fume or other occupational agents.

Arguments similar to those applied to lung cancer can be used to discuss the increased risk of head and neck cancer among bitumen workers. Excesses of these cancers are not consistently reported in occupational settings in which elevated polycyclic aromatic hydrocarbon exposure occurs and lung cancer risk is increased [Boffetta et al., 1997], and the fact that our results are largely dependent on the contribution of the German component detracts from a causal interpretation. Results on head and neck cancer are not systematically reported in previous studies of asphalt workers, raising the possibility of publication bias. The incidence of cancers of the mouth and pharynx was increased in the study of Danish mastic asphalt workers [Hansen, 1989], mortality from laryngeal cancer was increased in two studies of roofers from the USA [Milham, 1983; Stern et al., 2000]. Alcohol drinking and use of smokeless tobacco products, in addition to tobacco smoking, are important causes of this group of neoplasms and should be considered as potential confounders.

In conclusion, European asphalt workers employed in jobs entailing exposure to bitumen fume appear to have experienced a small increase in lung cancer mortality. The reasons behind the excess are unclear. A more complete understanding of the lung cancer pattern in this cohort is gained from analyses based on indicators of exposure to bitumen fume and other agents [Boffetta et al., 2003] and, ultimately, from a nested case-control study of lung cancer, with individual data on exposures and confounders.

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