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by Bugge MD, Kjuus H, Martinsen JI, Kjærheim K

**Affiliation:** National Institute of Occupational Health, N–0033 Oslo, Norway. mdb@stami.no

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# Cancer incidence among short- and long-term workers in the Norwegian silicon carbide industry

by Merete Drevvatne Bugge, Cand Med,[1] Helge Kjuus, MD,[1] Jan Ivar Martinsen,[2] Kristina Kjærheim, MD[2]

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**Objectives** A previous study among workers in the Norwegian silicon carbide industry, followed until 1996, revealed an excess incidence of lung and total cancer. The present study adds nine years of follow-up and focuses on cancer risk among short- and long-term workers, based on the assumption that these two groups have different exposure and lifestyle characteristics.

**Methods** The total cohort for this study comprised 2612 men employed for >6 months between 1913–2003. The follow-up period for cancer was 1953–2005. Short-term workers were defined as having <3 years of total employment in the industry. We estimated standardized incidence ratios (SIR) using national rates as the expected values.

**Results** Among the short-term workers, we observed an overall excess incidence of cancer [SIR 1.4, 95% confidence interval (95% CI) 1.2–1.6], with an excess of lung cancer (SIR 2.6, 95% CI 1.9–3.5) as the most important contributing factor. The long-term workers also had an excess incidence of total cancer (SIR 1.2, 95% CI 1.1–1.3) and lung cancer (SIR 1.7, 95% CI 1.3–2.2). We observed an increased risk of cancers at other sites, specifically among short-term workers.

**Conclusions** We observed an increased risk of cancer (especially in the lung but also at other sites) among both short- and long-term workers. Dust exposure in the silicon carbide industry may have contributed to the increased risk among long-term workers, whereas the increased risk among short-term workers may be due to a combination of occupational and lifestyle factors.

**Key terms** dust exposure; epidemiology; lung neoplasm; lung; neoplasm; smoking.

Crystalline silica (quartz and cristobalite) and silicon carbide (SiC) particles and fibers are the main constituents of the dust found in the SiC industry's working atmosphere (1, 2). In vitro and animal studies have shown SiC fibers to be highly toxic and comparable to crocidolite asbestos with regard to carcinogenic potential (3–7). The SiC industry's working environment may also be polluted by carbon monoxide, sulphur dioxide, and small amounts of volatile polycyclic aromatic hydrocarbons (PAH) (8, 9).

Since around the 1920s, possible health risks related to the production of SiC have been discussed. In 1919, Winslow et al (10) reported an increased risk of tuberculosis among SiC workers and commented: "We have every reason to expect … that dusts of this nature should be exceedingly deleterious to health." The first published study on cancer risk among SiC workers (11) showed an increased mortality from cancer of the lung [standardized mortality ratio (SMR) 1.69, 95% confidence intervals (95% CI) 1.09–2.52] and stomach cancer (SMR 2.18, 95% CI 0.88–4.51). More recently, the Norwegian Cancer Registry performed a cancer incidence study among 2620 SiC workers in three Norwegian plants (12). The study reported an overall increased cancer risk [standardized incidence ratio (SIR) 1.2, 95% CI 1.1–1.3], mainly due to increased risk of lung cancer (SIR 1.9, 95% CI 1.5–2.3). In addition, the study found an increased risk of cancer of the stomach (SIR 1.5, 95% CI 1.1–2.0) and the upper respiratory tract (SIR 1.7, 95% CI 1.0–2.7), together with a borderline increased risk of lip cancer (SIR 2.0, 95% CI

1 National Institute of Occupational Health, Oslo, Norway.
2 Cancer Registry of Norway, Oslo, Norway.

Correspondence to: Merete Drevvatne Bugge, National Institute of Occupational Health, Postbox 8149 Dep, N–0033 Oslo, Norway. [E-mail: mdb@stami.no]

0.9–3.9) and non-melanoma skin cancer (SIR 1.5, 95% CI 0.9–2.5).

These are the only two published epidemiologic studies of cancer risk among workers in the SiC industry. Both addressed lung cancer in relation to cumulative exposure to total dust and indicated an exposure–response relationship between lung cancer incidence and cumulative dust exposure. However, the Canadian study (11) was very small (N=585), and – even if the SMR of lung cancer showed increasing risk estimates with increasing exposure – the power of the study was too weak to give statistically significant results (11). In the Norwegian study (12), the non-exposed group had a risk of 0.6 of the expected number, whereas the SIR increased to 1.9 in the group at the lowest level of exposure, flattened out, and showed only a limited increase with increasing exposure levels. The authors suggested that the approximate nature of the exposure estimates and chance may have led to errors that easily could have biased the shape of the exposure–response relation.

Previous studies in different industries have found divergent cancer risk patterns between short- and long-term workers with the former having the highest risk (eg, of lung cancer) (13, 14). It has been suggested that this may be due to, on the one hand, exposure characteristics (eg, short-term workers have a tendency to get jobs with the heaviest dust exposure) and, on the other hand, lifestyle factors (eg, short-term workers are heavier smokers than long-term workers) (15–17).

The previous Norwegian Cancer Registry study comprised 74 lung cancer cases. In the present study, nine more years of observation have been conducted (1997–2005). Our aim was to examine cancer incidence, especially that of lung cancer, in relation to (i) duration of employment, (ii) period of first employment, and (iii) time since first employment. We specifically addressed cancer incidence among short- and long-term workers, respectively.

## Methods

### Study population

The study population is based on the earlier SiC cohort (12). The cohort was established on the basis of personnel registers at three Norwegian plants, comprising altogether 2720 men. With the omission of 40 workers, who died before 1953, and 60 unidentifiable individuals, the previous follow-up included 2620 men with a working history of >6 months in the SiC industry (12).

In our study, the cohort (see table 1) was extended with employment histories and new employees from the period 1997–2003 (N=130 men). One double registration in the old cohort was removed, and three formerly unidentifiable persons omitted from the old cohort were identified and added to the present cohort.

Following a request from the Norwegian Data Inspectorate, we sent an information letter to all registrants still living, giving them the opportunity to refuse participation in the follow-up study. Altogether, 121 persons refused participation, which left us with a study cohort of 2631 men employed in the SiC industry for a total of ≥6 months, and first employed at one of the three plants between 1913 and 2003. The regional Ethics Committee endorsed the study.

Employment records were the main source of individual information on employment. We recorded the employee's name, date of birth, and/or the unique 11-digit identification number (established in 1964, and given to all Norwegians alive in 1960 or born later) and, where available, up to 11 employment periods with location of work and work tasks. When available, we obtained the individual's smoking history from the occupational health services at the plants. Through linkage via the 11-digit ID number, cancer diagnoses and dates of death and emigration were obtained from the Cancer Registry of Norway. For employees deceased before

**Table 1.** Some characteristics of the cohort of 2612 workers in the Norwegian silicon carbide industry.

| | Total cohort (N=2612) | | | | Short-term workers (N=925) | | | | Long-term workers (N=1687) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | Median | $5^{th}$–$95^{th}$ percentile | N | % | Median | $5^{th}$–$95^{th}$ percentile | N | % | Median | $5^{th}$–$95^{th}$ percentile |
| Year at start of first employment | – | · | 1968 | 1932–1996 | – | · | 1966 | 1936–2001 | – | · | 1969 | 1928–1995 |
| Age at start of first employment | – | · | 27.9 | 17.1–54.9 | – | · | 26.5 | 16.5–53.7 | – | · | 28.8 | 17.7–55.3 |
| Duration of total employment (years) | – | · | 6.1 | 0.7–35.3 | – | · | 1.25 | 0.6–2.7 | – | · | 14.8 | 3.4–37.5 |
| Year at death | – | · | 1988 | 1962–2004 | – | · | 1986 | 1961–2004 | – | · | 1989 | 1962–2004 |
| Duration of follow-up (years) | – | · | 24.1 | 3.7–45.5 | – | · | 25.5 | 2.0–47.2 | – | · | 23.6 | 5.0–44.7 |
| Person-years of observation 1953–2005 | 63 407 | 100 | · | · | 22 998 | 36 | · | · | 40 409 | 64 | · | · |

1960, Cancer Registry data were obtained through linkage with the individual's name and date of birth. After linkage, we made the database anonymous. The variables for further analyses were: (i) year and month of birth, (ii) up to four cancer diagnoses with year and month of diagnosis, (iii) diagnostic code, (iv) histology or morphology code, (v) year and month of death or emigration, (vi) and employment information. For 2067 persons (78.6%), we also had information on whether they had ever been smokers.

### Follow-up and analysis of cancer incidence

We defined long-term employees as workers with >3 years of total employment in the SiC industry. The follow-up of cancer incidence among long-term workers started after 3 years duration of employment or from 1 January 1953 (when the Cancer Registry was established), if the 3 years duration of employment was reached earlier.

The follow-up of short-term workers started one year after the end of last employment in the SiC industry or from 1 January 1953 in order to exclude short-term workers quitting because of disease or death. Before the start of follow-up, 19 short-term workers died or emigrated, reducing the cohort to 2612 workers. For analyses of lung cancer incidence, the end of follow-up was the date of lung cancer diagnosis, date of death or emigration, or the end date of study (ie, 31 December 2005). For the study of total cancer, the end of follow-up was the date of death or emigration or the end date of study. Table 1 shows the distribution of person-years for the follow-up of total cancer. For the follow-up of lung cancer, a total of 63 197 person-years was accumulated (data not shown). Among the lung cancer cases, one subject had two primary diagnoses of lung cancer.

Through the Cancer Registry of Norway, we had access to cancer diagnoses in the population for all sites and types of cancer except basal cell carcinoma, which is not included in the present study. Pathology laboratories and clinical departments compulsory reporting of cancer ensures a complete register (18). During the entire follow-up period, cancer diagnoses classified according to a modified version of the World Health Organization's International Classification of Diseases (ICD-7) were available. We calculated the expected numbers of cancer cases in the cohort on the basis of national incidence rates for 5-year calendar periods and age groups. We used the national incidence rates of all cancers, except basal cell carcinoma, for the analyses of total cancer. For the analyses of lung cancer, the national incidence rates of lung cancer were used. We computed the SIR as the ratio between the observed and expected number. Assuming a Poisson distribution of the observed numbers, we calculated 95% CI using Stata software (StataCorp LP, College Station, TX, USA). We analyzed the possible effects of (i) duration of employment, (ii) period of first employment, and (iii) time since first employment; the analyses were performed separately for the two sub-cohorts of short- and long-term workers. To investigate the effect of smoking on lung cancer, we performed incidence analyses stratified by never-/ever-smokers.

## Results

Altogether, we observed 531 cancer cases among the 2612 workers in the total cohort, compared to the expected number of 424.9, which gives a SIR of 1.3 (95% CI 1.1–1.4). The most important single cancer site contributing to the observed excess was an increased lung cancer incidence with 103 cases versus the 51.7 expected (SIR 2.0, 95% CI 1.6–2.4).

Table 2 shows the SIR of all cancers for short- and long-term workers, respectively. In both groups, the SIR of total cancer were increased. Short-term employees had a SIR of 1.4 (95% CI 1.2–1.6), and long-term employees had a SIR of 1.2 (95% CI 1.1–1.3). Elevations were also seen for lung cancer and cancers of the oral cavity and pharynx (OCP). For lung cancer, we observed SIR of 2.6 and 1.7 among the short- and long-term workers, respectively.

The short-term workers also had increased incidence of non-melanoma skin cancer, thyroid cancer, Hodgkin's lymphoma, and cancer at unspecified sites. Elevated SIR levels, although non-significant, were seen for several others cancers sites, such as lip, esophagus, stomach, liver, pleura, and bladder. In the long-term worker group, there was an increased incidence of lip cancer and leukemia, in addition to a borderline increased incidence of prostate cancer. We also observed non-significant excesses of cancers of the stomach, nose, and skin.

By separating lung cancers into subgroups by histological type, we found that the group "other and unspecified lung cancer" contained the major part of the lung cancer cases and was significantly increased among both short- (24 cases, SIR 4.4, 95% CI 3.0–6.6) and long-term workers (28 cases, SIR 2.4, 95% CI 1.7–3.5). There was a significant increase of small-cell cancer among the short-term workers and squamous-cell cancer among long-term workers. Adenocarcinoma was non-significantly increased in both groups (data not shown).

Table 3 shows the SIR for lung cancer related to the duration of employment. These were significantly elevated for those with ≤5 years of employment. For longer employment durations, risk estimates were somewhat lower but still above unity.

Among short-term workers, the risk estimates for the group "cancer, all sites except lung" were higher for those first employed in the more recent time periods (table 4), whereas the long-term workers had fairly stable, slightly elevated SIR irrespective of the period of first employment. In both sub-cohorts, lung cancer risk was significantly elevated in all periods of first employment except for workers employed after 1980, where only one lung cancer case was observed. The SIR for lung cancer was highest among those employed in the earlier periods, in particular among the short-term workers.

The analyses stratified by time since first employment (table 5) showed an increased lung cancer incidence ≥20 years after first employment, among both short- and long-term workers. Among the latter, the SIR were the same regardless as to whether workers had been employed less or more than 10 years.

We also performed analyses of lung cancer stratified by smoking status (table 6). No lung cancer cases occurred among never-smoking, short-term workers, and there was only one case among never-smoking, long-term workers.

**Table 2.** Observed (Obs) number of cases and standardized incidence ratio (SIR) of cancer, all sites, with 95% confidence interval (95% CI), 1953–2005, among 2612 male Norwegian silicon carbide short- and long-term workers employed >6 months 1913–2003. [ICD-7= International Classification of Diseases, 7th revision].

| Site (ICD-7 code) | Short-term workers (N=925) | | | Long-term workers (N=1687) | | |
|---|---|---|---|---|---|---|
| | Obs | SIR | 95%CI | Obs | SIR | 95%CI |
| Lip (140) | 3 | 2.1 | 0.7–6.7 | 7 | 2.4 | 1.2–5.1 |
| Oral cavity, pharynx (141, 143–148) | 6 | 2.5 | 1.1–5.6 | 10 | 2.1 | 1.1–3.9 |
| Digestive organs (150–159) | 37 | 1.0 | 0.8–1.4 | 82 | 1.1 | 0.9–1.3 |
| Esophagus (150) | 3 | 1.9 | 0.6–5.8 | 3 | 0.9 | 0.3–2.7 |
| Stomach (151) | 13 | 1.4 | 0.8–2.4 | 25 | 1.3 | 0.9–1.9 |
| Small intestine (152) | 0 | 0.0 | 0.0–8.0 | 2 | 2.1 | 0.5–8.3 |
| Colon (153) | 11 | 1.0 | 0.5–1.8 | 26 | 1.0 | 0.7–1.5 |
| Rectum (154) | 3 | 0.4 | 0.1–1.3 | 15 | 1.0 | 0.6–1.7 |
| Liver (155) | 2 | 2.3 | 0.6–9.1 | 2 | 1.1 | 0.3–4.2 |
| Pancreas (157) | 5 | 1.2 | 0.5–2.8 | 9 | 1.0 | 0.5–1.9 |
| Nose, sinuses, etc (160) | 0 | 0.0 | 0.0–9.7 | 2 | 2.6 | 0.6–10.4 |
| Larynx (161) | 2 | 1.3 | 0.3–5.1 | 3 | 0.9 | 0.3–2.8 |
| Trachea, bronchus, and lung (162) | 43 | 2.6 | 1.9–3.5 | 60 | 1.7 | 1.3–2.2 |
| Pleura (163) | 2 | 3.7 | 0.9–14.7 | 1 | 0.8 | 0.1–6.0 |
| Prostate (177) | 26 | 0.9 | 0.6–1.3 | 77 | 1.2 | 1.0–1.5 |
| Testis (178) | 1 | 0.5 | 0.1–3.9 | 2 | 0.6 | 0.2–2.4 |
| Kidney, ureter (180) | 4 | 0.8 | 0.3–2.2 | 10 | 1.0 | 0.5–1.9 |
| Bladder and other urinary organs (181) | 13 | 1.4 | 0.8–2.4 | 19 | 0.9 | 0.6–1.5 |
| Melanoma of skin (190) | 6 | 1.2 | 0.5–2.7 | 15 | 1.5 | 0.9–2.5 |
| Other skin (non-melanoma) [a] (191) | 11 | 2.1 | 1.1–3.7 | 18 | 1.5 | 0.9–2.3 |
| Brain, nervous system (193) | 3 | 0.8 | 0.3–2.5 | 5 | 0.7 | 0.3–1.7 |
| Thyroid gland (194) | 4 | 5.8 | 2.2–15.4 | 1 | 0.7 | 0.1–5.2 |
| Hodgkin lymphoma (201) | 4 | 5.2 | 2.0–13.9 | 1 | 0.7 | 0.1–5.1 |
| Non-Hodgkin lymphoma (200 + 202) | 1 | 0.3 | 0.0–2.3 | 8 | 1.2 | 0.6–2.4 |
| Multiple myeloma (203) | 4 | 1.8 | 0.7–4.7 | 3 | 0.6 | 0.2–1.9 |
| Leukemia (204) | 2 | 1.8 | 0.5–7.4 | 6 | 2.8 | 1.2–6.1 |
| Unspecified sites (199) | 10 | 2.1 | 1.2–4.0 | 11 | 1.1 | 0.6–2.0 |
| Other specified sites | 2 | 0.8 | 0.2–3.4 | 6 | 1.3 | 0.6–2.8 |
| All sites (140–204) | 184 | 1.4 | 1.2–1.6 | 347 | 1.2 | 1.1–1.3 |

[a] Except basal cell carcinoma.

## Discussion

In the present study, we observed an increased risk of lung cancer among workers in the Norwegian SiC industry, among both short- and long-term workers. Lung cancer risk was specifically elevated among workers with <5 or >20 years of employment and those with first employment in earlier periods. In addition to lung cancer, we observed an increased risk of other types of cancer among both short- and long-term workers.

### The cohort

In this study, we had access to a large cohort of more than 2600 workers, with the first employments dating back almost 100 years and a follow-up time of >50 years. The Cancer Registry of Norway claims a high level of completeness of cancer diagnoses, and the Norwegian unique 11-digit identification number ensures correct linkage between databases.

Workers in the cohort were employed at two smelters located in the southern region of Norway and one in the mid-region of the country. Since the incidence of lung cancer varies in the different regions of Norway,

**Table 3.** Observed number of cases (Obs), and standardized incidence ratio (SIR) of lung cancer, with 95% confidence interval (95% CI), 1953–2005, among 2612 male Norwegian silicon carbide workers employed >6 months 1913–2003, by duration of employment.

| Duration of employment | Person-years | Obs | SIR | 95% CI |
|---|---|---|---|---|
| Short-term workers | | | | |
| 0.5–0.9 years | 8406 | 12 | 2.0 | 1.1–3.5 |
| 1–1.9 years | 9886 | 21 | 3.0 | 1.9–4.5 |
| 2–2.9 years | 4656 | 10 | 3.1 | 1.7–5.8 |
| Long-term workers | | | | |
| 3–4.9 years | 7958 | 12 | 2.2 | 1.3–3.9 |
| 5–9.9 years | 10 438 | 10 | 1.5 | 0.8–2.8 |
| 10–19.9 years | 11 890 | 13 | 1.4 | 0.8–2.4 |
| ≥20 years | 9963 | 24 | 1.8 | 1.2–2.7 |

use of regional rates might give somewhat different results. When substituting the national rates for lung cancer with the rates for the region that contributed the largest number of cases, we found that the SIR of lung cancer was reduced from 2.0 (95% CI 1.6–2.4) to 1.7 (95% CI 1.4–2.0), which was still a significant increase. The SIR levels were still significantly increased when dividing the cohort into short- and long-term workers, using these regional rates. We chose to use the national incidence rates for the calculation of expected values due to their robustness.

In the present study, cohort members still living were given the opportunity to refuse participation, and 121 of 1477 individuals did so. If refusal is outcome dependent, a possible bias is introduced. We have no information as to the reasons for non-participation. Comparing the non-participants with the participating, living members of the cohort, we found that the non-participants were older, had their first employments in earlier time periods, and had a shorter duration of employment. We have no reason to believe that workers who already had been diagnosed with cancer, systematically declined

**Table 4.** Observed (Obs) number of cases, and standardized incidence ratio (SIR) of cancer, with 95% confidence interval (95% CI), 1953–2005, among 2612 male Norwegian silicon carbide short- and long-term workers employed >6 months 1913–2003, by period of first employment.

| Period of first employment | Short-term workers | | | | Long-term workers | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Obs | SIR | 95% CI | N | Obs | SIR | 95% CI |
| Cancer, all sites except lung | | | | | | | | |
| 1913–1939 | 69 | 10 | 0.7 | 0.4–1.2 | 184 | 54 | 1.2 | 0.9–1.6 |
| 1940–1959 | 280 | 73 | 1.3 | 1.0–1.6 | 294 | 76 | 1.0 | 0.8–1.2 |
| 1960–1979 | 389 | 51 | 1.4 | 1.0–1.8 | 772 | 143 | 1.4 | 1.2–1.6 |
| 1980–2003 | 187 | 7 | 3.5 | 1.7–7.4 | 437 | 14 | 1.8 | 1.0–3.0 |
| Lung cancer | | | | | | | | |
| 1913–1939 | 69 | 6 | 3.7 | 1.6–8.2 | 184 | 10 | 2.1 | 1.1–3.9 |
| 1940–1959 | 280 | 23 | 2.7 | 1.8–4.1 | 294 | 24 | 2.1 | 1.4–3.2 |
| 1960–1979 | 389 | 14 | 2.6 | 1.5–4.3 | 772 | 25 | 1.7 | 1.1–2.5 |
| 1980–2003 | 187 | 0 | 0.0 | 0.00–16.8 | 437 | 1 | 1.0 | 0.1–6.8 |

**Table 5.** Observed (Obs) number of cases, and standardized incidence ratio (SIR) of lung cancer, with 95% confidence interval (95% CI), 1953–2005, among 2612 male Norwegian silicon carbide short- and long-term workers employed >6 months 1913–2003, by time since first employment and employment duration.

| Employment duration | Time since first employment | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | <20 years | | | | ≥20 years | | | |
| | Person-years | Obs | SIR | 95% CI | Person-years | Obs | SIR | 95% CI |
| Short-term workers | 11 296 | 2 | 0.70 | 0.2–2.8 | 11 652 | 41 | 3.04 | 2.2–4.1 |
| 3–9.9 years | 12 890 | 8 | 1.78 | 0.9–3.6 | 5 511 | 14 | 1.87 | 1.1–3.2 |
| ≥10 years | 8 094 | 2 | 0.53 | 0.1–2.1 | 13 760 | 35 | 1.86 | 1.3–2.6 |

**Table 6.** Observed (Obs) number of cases, and standardized incidence ratio (SIR) of lung cancer, with 95% confidence interval (95% CI), 1953–2005, among 2631 male Norwegian silicon carbide short- and long-term workers employed >6 months 1913–2003, by smoking status.

| Smoking status | Short-term workers | | | | | Long-term workers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | % | Obs | SIR | 95% CI | N | % | Obs | SIR | 95% CI |
| Ever-smokers | 362 | 39.1 | 22 | 3.3 | 2.2–5.0 | 1165 | 69.1 | 55 | 2.3 | 1.7–3.0 |
| Never-smokers | 166 | 17.9 | 0 | 0 | 0.0–2.3 | 359 | 21.3 | 1 | 0.1 | 0.0–0.9 |
| Unknown smoking status | 397 | 42.9 | 21 | 2.6 | 1.7–4.0 | 163 | 9.7 | 3 | 1.1 | 0.4–3.6 |

participation in the study. Thus, a possible systematic selection out of the cohort would most probably lead to a differential loss of healthy workers, which could have resulted in somewhat inflated SIR estimates. To further explore this possibility, we analyzed the SIR of lung cancer with follow-up ending in 1996 and compared the results with that of the previous cohort follow-up (12), removing those who declined participation in the present cohort. We found similar SIR between the two cohorts, indicating that non-participation of <5% of the cohort had not introduced any selection bias of importance. In a further sensitivity analysis with follow-up to 2005, in adding the employment periods of the individuals who declined inclusion (assuming none had developed cancer), we observed a slight reduction in the observed SIR, but the associations were still statistically significant, both in the total cohort (SIR of lung cancer 1.9, 95% CI 1.5–2.3, compared with SIR 2.0, 95% CI 1.6–2.4 in the present study), and in the sub-cohorts of short- and long-term workers. We, therefore, presume that our results are valid with respect to selection bias from this source.

### Comparing results with earlier studies

Two previous cohort studies among SiC workers have shown an increased risk of lung cancer in this industry (11, 12). Both studies concluded that the risk seemed to increase with higher levels of exposure, a criterion usually considered in favor of causality (19). In the present study, using employment duration as an indicator of exposure, we could not confirm a corresponding pattern between increasing SIR of lung cancer and the duration of exposure.

Both Infante-Rivard et al (11) and Romundstad et al (12) addressed stomach cancer in their papers on the SiC industry. In the Canadian study, the increased stomach cancer incidence was non-significant (7 cases, SIR 2.18, 95% CI 0.88–4.51). In the Norwegian study, the SIR of stomach cancer was 1.5 (95% CI 1.1–2.0), but the authors found only weak evidence for a causal association with the working environment. The overall SIR of stomach cancer in the present study was 1.3 (95% CI 1.0–1.8). No new stomach cancers were diagnosed during the additional nine years of follow-up time. Even though exposure to dust and silica are mentioned as suspected risk factors for stomach cancer (20), the most important etiologic factor for this cancer is infection by *Helicobacter pylori* (21). There was little indication that stomach cancer was associated with occupational factors in our study.

Romundstad et al (12) also observed borderline increases of lip and non-melanoma skin cancers. In our study, the incidence of lip cancer was increased among both long- and short-term workers, although non-significantly in the latter group. The incidence of non-melanoma skin cancer was non-significantly increased among long-term workers and significantly increased among short-term workers. Earlier studies have shown strong associations between lip cancer and smoking, especially in combination with outdoor work (exposure to sunshine) (22). Similarly, non-melanoma skin cancer is primarily associated with sunshine, although association with non-solar (including some occupational) exposures have been discussed, among them exposure to PAH (23). Previous measurements of PAH in the SiC industry have indicated low levels (9), but we cannot exclude that skin exposure to PAH may have contributed to the observed excess of non-melanoma skin cancer among the workers.

### Lung cancer

Lung cancer risk was significantly elevated for workers employed in all periods since the first plant started in 1913, except for those employed in 1980 or later, where only one case of lung cancer was observed. The SIR seem to decrease by period of first employment, indicating that the lung cancer risk actually may be reduced in later years compared to the earliest years of production. On the other hand, the latency period for developing lung cancer is so long that most lung cancer cases caused by exposure in this last period would not yet be evident.

The analyses stratified by time since first employment showed an increased lung cancer incidence ≥20 years after first employment, among both short- and long-term workers. As in the other analyses, the SIR level of short-term workers was higher than that of long-term workers. Among long-term workers, stratifying employment duration in periods of <10 years and ≥10 years showed no difference between the groups. The increased SIR ≥20 years after first employment is in accordance with knowledge of the latency time for development of lung cancer, given exposure to relevant carcinogens in the SiC industry.

However, a high lung cancer risk with short employment duration indicates additional exposure to carcinogens outside the SiC industry. In addition to tobacco use, the finding of three pleural cancers, two of which are classified as mesotheliomas and the third as "malignant tumor, uncertain mesothelioma", indicates some asbestos exposure among the employees. All three smelters in question are located on the Norwegian coast, and we know that many seamen were recruited for employment, particularly in the oldest plant under study. There was also some exchange of workers between these plants and other polluted industries in the study regions, but we have no further information about previous or later jobs. Thus, apart from asbestos exposure in the SiC industry, exposure to asbestos from time spent in other dusty industries or during machine room work on ships is likely to have occurred.

The smoking data available from the main part of the cohort were limited to "non-smokers", "smokers" and "ex-smokers". As we did not have information on duration of smoking and dates of quitting, the ex-smoker data were impossible to utilize in the time-dependent analyses. Altogether, 60% were registered as "ever smokers", 20% as "never smokers" and 20% as unknown smoking status. According to Axelson (24), the fraction of smokers in industrial populations seldom exceeds 70%. Using this estimate, he found that excess smoking among industrial workers relative to the general population could increase the incidence of lung cancer with a rate ratio of 1.43 (24). The SIR for lung cancer found in the present study were considerably higher than 1.43. Based on the same, sparse smoking data, Romundstad et al (12) found that the excess incidence of lung cancer in the previous Norwegian SiC cohort study did not seem to be confounded by smoking.

### Short- and long-term workers

The highest SIR for lung cancer were seen among the short-term workers, and among the long-term workers the SIR were fairly stable with increasing employment duration. Ideally, for a causal association, one would have expected an increasing trend in risk with increasing duration of employment, but as employment duration is an imperfect exposure indicator, results should be interpreted with caution.

Several authors have addressed the fact that cancer incidence is often increased among short-term workers, and many occupational epidemiologic studies show increased cancer risk in this group only (13, 14). Only a few authors, however, have thoroughly studied short-term workers per se and tried to investigate the reasons why this group shows both a higher cancer incidence and a higher total mortality than long-term workers (15–17). Gubéran & Usel (15) found that the prevalence of smoking, exposure to asbestos, and occupational accidents in later work were higher among workers employed for <2 months in the Geneva perfumery industry than among a reference population. Lamm et al (16) reviewed past working histories in a cohort of 741 New York State tremolitic talc workers and concluded that an increase in lung cancer mortality among the short-term employed most likely was due to exposure elsewhere (prior employment, smoking, other factors). The authors argued that the inclusion of short-term employees in epidemiologic studies may sometimes have a magnifying effect on the association between work environment and risk, whereas the traditional argument for excluding short-term employees has been the risk of diluting the association. Stewart et al (17) performed an occupational hygiene study comparing the jobs, exposures, and mortality experience of workers employed ≤1 year to workers employed >1 year in formaldehyde plants. They showed that short-term workers had no greater exposure to formaldehyde, but that they were more likely to be in jobs exposed to particulates than long-term workers. The short-term workers had greater overall mortality risks than their long-term counterparts.

In this study, we have performed analyses stratified on short- and long-term employees, where the cut-off point, a priori, was set to three years, in accordance with the previous cohort study (25). Many authors have suggested that short-term workers should be treated as a special group, and that a study including both short- and long-term workers will give biased results (13, 14). This view is supported by the results from the present study, indicating that the short-term workers in fact may be a group with high risk of cancer, either from occupational exposure or from exposure to other risk factors. In our study, follow-up of the short-term workers started one year after the end of last employment, in order to minimize any effect of employment being terminated due to illness. During this period, 19 workers died or emigrated and were, consequently, excluded from the study.

In our study, we observed an excess of several cancers which are associated with lifestyle factors among short-term workers. In addition to lung cancer, which is associated with smoking, we found an excess of OCP cancers. The most important risk factors for OCP cancers are tobacco and alcohol (26). Both factors separately elevate the risk of OCP cancer, while tobacco and alcohol use together seem to act synergistically. Several studies have examined the role of occupation in the etiology of OCP cancers, and excess risk has been observed among blue-collar workers with exposure to dust, inhaled organic agents, or inhaled inorganic agents. There is little consistency to these findings, however, and it has been difficult to isolate occupational exposures from the effects of smoking and drinking (26). Also, we observed an excess of (i) lung cancer with no specific histological diagnosis ("other" lung cancers) and (ii) cancers at unspecified sites, both of which have been associated with low socioeconomic status (27). The risk of other smoking-related cancers (eg, cancers of the bladder, pancreas, and larynx) showed a non-significant increase. In the short-term worker group, we observed an excess incidence of thyroid cancer (SIR 5.8) and Hodgkin's lymphoma (SIR 5.2), both based on a small number (four cases each). Fillmore et al (28) reported an increased risk of thyroid cancer among women exposed to silica, but no such increased risk among men. We have not found any other evidence in support of associations between occupational exposures in the SiC industry and these types of cancer.

Moreover, there was an increased incidence of lung and OCP cancers among the long-term workers but no excess of other smoking and lifestyle-associated cancers. In addition to the already discussed lip, skin, and stomach cancers, there was increased incidence of leukemia. The subtypes showed great variation, with the six cases comprising two acute lymphatic leukemia, one chronic lymphatic leukemia, two chronic myelomonocyte leukemia, and one unspecified leukemia. This great diversity argues against a common cause.

Lifestyle factors, smoking in particular, could thus be the main reasons for the excess cancer incidence observed among short-term workers in this study. However, Gubéran & Usel (15) and Stewart et al (17) showed that short-term workers have a higher tendency to be employed in dusty and unhealthy jobs, indicating that work environmental factors may contribute to the excess lung cancer risk also among short-term workers. The results indicate that differential selection bias and confounding between short- and long-term workers may distort the assessment of exposure–response relationships in cohorts of occupationally exposed workers.

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