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Cancer incidence among Finnish ferrochromium and stainless steel production workers in 1967–2011: a cohort study

Markku Huvinen,[1] Eero Pukkala[2,3]

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[1]Occupational Health, Outokumpu Oyj, Espoo, Finland
[2]Finnish Cancer Registry, Institute for Statistical and Epidemiological Cancer Research, Helsinki, Finland
[3]School of Health Sciences, University of Tampere, Tampere, Finland

Correspondence to
Dr Markku Huvinen; markku.huvinen@outokumpu.com

ABSTRACT

Objectives: The aim of the study was to assess the risk of cancer among workers employed in the Finnish ferrochromium and stainless steel industry since the beginning of production in 1967.

Methods: The study cohort was made up of all persons employed by the Finnish stainless steel production chain from chromite mining to cold rolling of stainless steel during the period 1967–2004, and it was divided into subcohorts by production units with specific exposure patterns of the subcohorts assessed in previous studies. Follow-up for cancer through the files of the Finnish Cancer Registry was performed using the personal identity code as key. Standardised incidence ratios (SIRs) were calculated as the ratios of observed numbers of cancer cases and numbers expected on the basis of incidence rates in the population of the same region.

Results: The overall cancer incidence was at the expected level. The lung cancer risk was decreased in the whole cohort (SIR 0.79; 95% CI 0.65 to 1.08). The incidence of prostate cancer was significantly increased (1.31; 1.05 to 1.61) and that for kidney cancer was significantly decreased (0.38; 0.14 to 0.82). None of the department-specific SIRs for lung cancer were significantly different from 1.0. No cancers of the nose and nasal sinuses were observed among workers in the ferrochromium smelter or the stainless steel melting shop.

Conclusions: It is not likely that the occupational exposures in the Finnish ferrochromium and stainless steel industry would have increased the risk of cancer.

Strengths and limitations of this study

- The study was based on non-selected national registers with good data accuracy and coverage.
- Long follow-up and complete information on cancer.
- Information on cofactors was not systematically available.

INTRODUCTION

Stainless steels are defined according to the European Standard EN 10088 as iron-based alloys containing at least 10.5% chromium and a maximum of 1.2% carbon. Stainless steels can contain nickel as another major alloying element, with a content of up to 38%. Other possible alloying elements include molybdenum, manganese, silicon and copper.[1]

Chromium is encountered mainly in the following three oxidation states: metallic (Cr^0), trivalent (Cr^{3+}) and hexavalent (Cr^{6+}). According to the evaluation of the International Agency for Research on Cancer (IARC), metallic chromium and trivalent chromium compounds are not classifiable as to their carcinogenicity to humans.[2] In 2011, IARC stated that there is sufficient evidence in humans for the carcinogenicity of Cr^{6+} compounds (group 1). They cause cancer of the lung.[3] Positive associations have also been observed between exposure to Cr^{6+} compounds and cancer of the nose and nasal sinuses. Exposure to Cr^{6+} compounds may occur in certain phases in stainless steel production: in ferrochromium smelting, in stainless steel melting and in the annealing and pickling of cold-rolled stainless steel.

According to IARC evaluation, there is sufficient evidence in humans for the carcinogenicity of mixtures that include nickel compounds and nickel metal.[4] The evidence is strongest for soluble nickel compounds; there is also independent evidence for the carcinogenicity of oxidic and sulfidic nickel compounds. These agents cause cancers of the lung and of the nose and nasal sinuses. Nickel compounds are carcinogenic to humans (group 1). Exposure to nickel-containing fumes and dusts may occur mainly in the melting shop stage of stainless steel production.

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The main aim of this study was to assess the risk of cancer, with special reference to cancers of the nose and lung among workers employed in the Finnish ferrochromium and stainless steel industry since the beginning of production in 1967.

SUBJECTS AND METHODS

Study design

The study cohort was made up of all persons employed at the Kemi mine and Tornio production units of Outokumpu Group (called Tornio Works) during the period 1967–2004. The cohort was identified from the company's employment records. An extensive search of the population registers traced the correct personal identity code (PIC), possible emigration date and vital status for all but 9 (0.1%) of the cohort members. Non-residents of Finland were excluded. After the exclusions, the cohort included a total of 8146 workers (table 1). All Finnish residents have had a unique PIC since 1967 that is used in all main registers in Finland. PIC enables reliable automatic record linkage.

Follow-up for cancer through the files of the population-based countrywide Finnish Cancer Registry was performed using PIC as key. Follow-up for cancer started at the date of first employment at Tornio Works, and ended at emigration, death or 31 December 2011, whichever was first. Further division was made by the time elapsed since the first employment.

The cohort was divided into subcohorts by production departments (table 1). Analyses stratified by department were performed in two ways. First, we counted the overall cancer risk starting from first employment in a given department. Second, the follow-up was started from the date when a person had worked for 5 years in a given department.

The numbers of observed cases and person-years at risk were counted, by 5-year age groups, separately for men and women and for nine 5-year calendar periods during 1967–2011. The expected numbers of cases for total cancer and for specific cancer types were calculated by multiplying the number of person-years in each stratum by the corresponding average cancer incidence in the catchment area of Oulu University Hospital in Northern Finland. For comparison purposes, we also calculated SIRs based on expected rates based on reference rates of the whole of Finland.

To calculate SIR, the observed number of cases was divided by the expected number. The 95% CIs for SIR were based on the assumption that the number of observed cases followed a Poisson distribution.

Exposures

At the chromite mine in the 1980s, the average exposure to total dust was 1 mg/m^3. The highest personal exposures were found in the crushing plant (1.4–4.9 mg/m^3). The chromium content of the dust was 1–5%, which indicates that the median personal exposure to chromium was 22 µg/m^3. Cr^{6+} was not detected in any of the samples from the mine.[5]

In the furnace department of the ferrochromium smelter, the median personal dust exposure was 1.5 mg/m^3. The median chromium concentration was 143 µg/m^3. The median personal workplace air concentration of Cr^{6+} was below the detection limit of the method (0.5 µg/m^3, maximum 2.4 µg/m^3). The highest concentrations were detected during tapping in the vicinity of the tap hole, where the proportion of Cr^{6+} was 10-fold that of other areas.[5] In an analysis using a field emission scanning electron microscope, the aerosols from the ferrochromium smelter were observed to contain agglomerates of particles

Table 1 Number of persons (N) at Tornio works, and person-years at follow-up during 1967–2011, by work department, age and gender

	Men		Women		Total	
	N*	Person-years	N*	Person-years	N*	Person-years
Total	6330	156 296	1816	40 188	8146	196 484
Department						
Chromite mine	335	8894	31	697	366	9591
Ferrochromium plant	820	23 705	28	770	848	24 475
Stainless steel melting shop	682	13 755	21	367	703	14 122
Hot rolling mill	189	3329	27	435	216	3764
Cold rolling mill	1648	34 115	262	5198	1910	39 312
Maintenance and services	2132	58 856	852	18 606	2984	77 462
Metallurgical laboratory	303	7824	147	3269	450	11 093
Office	221	5818	448	10 847	669	16 665
Age						
<30	5400	43 922	1536	14 178	6936	58 099
30–44	829	66 155	227	15 602	1056	81 756
45–59	98	36 434	52	7944	150	44 378
60–74	3	9085	1	2097	4	11 182
75+	–	700	–	369	–	1069

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with a diameter of less than 1 µm. Chromium seemed to be dissolved in a silica matrix. Most of the particles were covered with a thin layer of zinc oxide. Zinc originates from the ore. Owing to its low melting point, zinc is the last condensate on the surface of the particles.[6]

The average exposure to total dust in the stainless steel melting shop was 1.8 mg/m^3. The dust contained 2–4% chromium. The median content of total chromium in the personal samples collected from the breathing zone was 30 µg/m^3. The median Cr^{6+} level was 0.5 µg/m^3. The highest figures of Cr^{6+} among personal samples were detected in the handling of molten metal by the arc furnace (6.6 µg/m^3). Although Cr^{6+} seemed to be present at low concentrations almost all over the steel melting shop, it exceeded the detection limit of 0.5 µg/m^3 only in some of the personal samples. The particles in the aerosols encountered in the stainless steel melting shop were predominantly metal alloys. No pure chromium or nickel particles were observed. The particles had an iron core surrounded by chromium and nickel as alloys and silicates and oxides.[6] In an analysis using scanning electron microscopy, energy-dispersive X-ray spectroscopy and X-ray diffraction, the composition of the metal particles generated in the melting process and released to the ambient air were observed to resemble stainless steel.[7]

In the grinding shop, the average exposure to total dust was 0.8 mg/m^3. The median chromium content was 66 µg/m^3. The median Cr^{6+} level was below 0.5 µg/m^3 (maximum 0.6 µg/m^3).

The total dust content was low throughout the cold rolling mill, averaging 0.3–0.5 mg/m^3, and the highest measured single concentration was 1.8 mg/m^3. In general, the content of chromium in the air in the cold rolling mill was lower than the detection limit of the measurement method. Cr^{6+} was found only in the annealing and pickling line, in the neutralisation and acid regeneration shop and near some automatic welding machines. The median Cr^{6+} concentration was below 0.5 µg/m^3 (maximum 6.6 µg/m^3).

The continuous monitoring system for dust exposure has shown that the concentrations of chromium-containing dusts in the workplace air decreased at a rate of 17% from 1970 to the early 1990s in the mine, the ferrochromium works and the stainless steel melting shop. In the cold rolling mill, the concentrations have always been very low.

In the stainless steel melting shop, nickel and molybdenum are added as alloying metals. The median ambient air concentration of nickel was 1.8 µg/m^3 (maximum 9.4 µg/m^3) in the personal samples and 3.1 µg/m^3 (maximum 30.0 µg/m^3) in the stationary samples.[8]

The Finnish Meteorological Institute carried out an outdoor air quality monitoring programme within the industrial area of Outokumpu Tornio Works. The continuous programme covered 4 months in 2011. The mean concentration of chromium in the respirable particles (PM_{10}) was 181 ng/m^3. The respective figure for nickel was 77 ng/m^3.[9]

Asbestos, crystalline silica. polycyclic aromatic hydrocarbons and ionising radiation have also been classified as carcinogenic to humans.[10–13]

Asbestos containing materials were used in thermal insulators and in construction materials in the early decades of production. Limited areas in the ore body and the waste rock of the chromite mine contained crevices filled with chrysotile in the 1980s. Thus, sporadic exposure peaks among workers have been possible. Exposure to quartz and benzo(a)pyrene (PAHs) may occur in the ferrochromium smelter.

The main raw material in the stainless steel melting shop is recycled steel, which may include radioactive material. Despite strict online radiation security screening, some small sources of radiation may accidentally, but rarely, enter the melting process. A typical example of radioactive materials is americium, which is used in industrial measuring devices and smoke detectors. Americium ends up in the stainless steel melting shop ambient air via slag. In the conducted individual measurements, not a single incidental personal radiation dose has, however, exceeded the limit level given by the national radiation authorities.

RESULTS

There were 6330 men and 1816 women under follow-up in the cohort. The numbers of person-years were 156 000 and 40 000, respectively (table 1). The mean length of follow-up of a person was thus 24.1 years.

During the follow-up period, of the 408 cases of cancer that were diagnosed, the expected number was 396 (table 2). The SIR of cancer was 1.03 (95% CI 0.93 to 1.13) using people living in Northern Finland as the reference population. The SIR was 0.94 (95% CI 0.86 to 1.03) when the expected number of cancer cases (432) for the whole country was used as reference.

Among the total cohort members, the observed number of lung cancer cases was 37 (SIR 0.79, 95% CI 0.65 to 1.08). Among those members of the cohort who had been working in the same department for more than 5 years, the SIR was 0.72 (95% CI 0.44 to 1.12) (table 3). None of the department-specific SIRs for lung cancer was significantly different from 1.0 (table 3).

Two cancers of the nose were observed (SIR 2.05, 95% CI 0.25 to 7.42), both among men. One of them had been working in the concentration department of the chromite mine for 9 months, and the other in the sintering plant for 3 months in the 1970s.

There were no cases of mesothelioma. The expected number for the whole cohort was 0.37.

From the other sites, only the incidence of prostate cancer was significantly increased (SIR 1.31, 95% CI 1.05 to 1.61), and only the incidence of kidney cancer was significantly decreased (SIR 0.38, 95% CI 0.14 to 0.82) (table 2).

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Table 2 Observed (Obs) and expected (Exp) numbers of cancer cases and standardised incidence ratios (SIR) with 95% CIs among workers at Tornio Works during 1967–2011, by site

Primary site Exp SIR 95% CI	Obs	Exp	SIR	95% CI
All sites	408	395.8	1.03	0.93 to 1.13
Mouth, pharynx	12	10.3	1.16	0.60 to 2.03
Oesophagus	4	4.6	0.86	0.24 to 2.20
Stomach	12	14.9	0.80	0.42 to 1.40
Colon	22	16.8	1.30	0.82 to 1.97
Rectum	14	13.3	1.06	0.58 to 1.77
Liver	4	5.2	0.78	0.21 to 1.98
Gallbladder	4	2.5	1.58	0.43 to 4.03
Pancreas	16	13.1	1.22	0.70 to 1.98
Nose, sinuses	2	1.0	2.05	0.25 to 7.42
Larynx	4	3.4	1.19	0.33 to 3.05
Lung, bronchus	37	47.0	0.79	0.55 to 1.08
Breast	31	30.8	1.01	0.68 to 1.42
Cervix uteri	20	16.7	1.20	0.73 to 1.85
Corpus uteri	7	4.5	1.54	0.62 to 3.18
Ovary	2	4.0	0.50	0.06 to 1.81
Prostate	89	67.8	1.31	1.05 to 1.61*
Testis	5	6.4	0.78	0.25 to 1.83
Kidney	6	15.8	0.38	0.14 to 0.82**
Bladder	14	14.0	1.00	0.55 to 1.67
Skin melanoma	24	16.7	1.44	0.92 to 2.14
Other skin	5	7.6	0.66	0.21 to 1.53
Brain/nervous system	18	19.3	0.93	0.55 to 1.47
Thyroid	10	13.7	0.73	0.35 to 1.34
Soft tissue	3	3.7	0.82	0.17 to 2.40
Hodgkin lymphoma	3	5.8	0.52	0.11 to 1.50
Non-Hodgkin lymphoma	24	19.1	1.26	0.81 to 1.87
Multiple myeloma	6	4.6	1.32	0.48 to 2.86
Leukaemia	15	11.5	1.31	0.73 to 2.15
Not included above: skin, basal cell carcinoma	88	70.3	1.25	1.00 to 1.54*

Included are sites with Exp>2, and nasal cancer because of a priori interest.
*p<0.05.
**p<0.01.

The only department which showed increased cancer incidence was the chromite mine. The overall cancer incidence among those with at least 5 years of employment at the chromite mine was non-significantly increased (SIR 1.48, 95% CI 0.88 to 2.33; table 3), but the SIR for those with less than 5 years of employment had an SIR of 1.84 (95% CI 1.09 to 2.90, p<0.05; 18 observed cases) and raised the SIR for all workers who had ever worked at the chromite mine to 1.64 (95% CI 1.15 to 2.26, p<0.01). There were altogether five cases of alcohol-related cancers (tongue, mouth, pharynx, liver and pancreas)[14] versus 1.4 expected (SIR 3.57, 95% CI 1.16 to 8.33). The incidence of rectal cancer was also significantly increased (SIR 5.06, 95% CI 1.38 to 12.9), while there was only one case of lung cancer (SIR 0.33, 95% CI 0.01 to 1.84).

DISCUSSION

Our cohort consisted of all employees who had been working at the integrated production unit of Tornio Works during 1967–2004. Identification of cohort members and follow-up for deaths and emigration are complete for the period of this study. The completeness of cancer registration in Finland is at least 99%,[15] and the computerised record linkage procedure precise.[16] Therefore, technical incompleteness does not cause bias in the results.

Overall cancer

The overall cancer incidence was not elevated in the present study. We used as the main reference the incidence rates of the population of Northern Finland because the incidence rates vary geographically. Cancer incidence also varies according to socioeconomic position. The majority of the workers in the departments at Tornio Works belong to the category of skilled blue-collar workers who have an average or slightly elevated overall cancer incidence as compared to the average population.[17]

A slightly increased incidence of cancer (SIR 1.16) was observed in a Norwegian study among ferrochromium workers.[18] Decreased cancer mortality was observed in a Swedish study in ferrochromium production[19] and studies in the French stainless steel industry.[20–22]

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Table 3 Observed (Obs) and expected (Exp) numbers of cancer cases (all sites, lung and nasal cancer) and standardised incidence ratios (SIR) with 95% CI during 1967–2011 among workers at Tornio Works with employment >5 years, by department

	All sites				Lung cancer				Nasal cancer			
Department	Obs	Exp	SIR	95% CI	Obs	Exp	SIR	95% CI	Obs	Exp	SIR	95% CI
Chromite mine	18	12.2	1.48	0.88 to 2.33	1	1.8	0.55	0.01 to 3.04	0	0.03	0.00	0.00 to 137
Sintering plant	9	11.0	0.82	0.37 to 1.55	1	1.8	0.57	0.01 to 3.17	0	0.03	0.00	0.00 to 145
Ferrochromium smelter	17	17.9	0.95	0.55 to 1.52	4	2.8	1.41	0.38 to 3.61	0	0.04	0.00	0.00 to 89.2
Stainless steel melting shop	20	19.3	1.03	0.63 to 1.59	2	2.6	0.76	0.09 to 2.76	0	0.05	0.00	0.00 to 72.2
Hot rolling mill	3	4.4	0.68	0.14 to 1.98	1	0.5	1.95	0.05 to 10.9	0	0.01	0.00	0.00 to 272
Cold rolling mill	42	43.4	0.97	0.70 to 1.30	2	5.1	0.39	0.05 to 1.40	0	0.01	0.00	0.00 to 34.6
Maintenance	31	33.2	0.93	0.64 to 1.32	2	5.2	0.39	0.05 to 1.39	0	0.07	0.00	0.00 to 50.0
Total	207	202.6	1.02	0.89 to 1.16	19	26.3	0.72	0.44 to 1.12	0	0.44	0.00	0.00 to 8.37

The only department with an increased cancer incidence was the chromite mine, but the excess was mainly seen among the short-term workers. Such a finding is common in the industrial worker cohorts and has been interpreted to reflect a general lifestyle with negative health habits.[23] There was a significant excess of alcohol-related cancers among workers in the chromite mine in our study. Among the mine workers there is no exposure to Cr^{6+} or special chemicals. The concentration process is based on the specific gravity of various minerals in the ore body. It seems unlikely that the cancer risk pattern would be strongly associated with occupational exposures at the chromite mine.

Lung cancer

In the present study the incidence of lung cancer cases was decreased by one-fifth, and even more among those cohort members who had been working in the same department for more than 5 years.

No excess of respiratory cancer mortality was found among men who had been employed in a Swedish ferrochromium plant for at least 1 year during 1930–1974, with an estimated exposure to Cr^{6+} of 0.25 mg/m^3 near the electric arc furnaces. The incidence of cancer of the trachea, bronchus, lung and pleura was not elevated among workers at the arc furnaces, but the incidence of these respiratory cancers was significantly increased among maintenance workers.[19]

Low proportional mortality from lung cancer was reported from US stainless steel production workers by Cornell[24] in 1984.

A statistically significant increase in lung cancer incidence was observed among Finnish nickel smelter workers exposed to insoluble nickel compounds, with a latency of 20 years.[25] In that cohort, the mean personal levels of exposure to nickel varied between 0.02 and 0.2 mg/m^3. Exposure to nickel is encountered at Tornio Works only in the stainless steel melting shop, where the median exposure level in the 1990s was 0.002 mg/m^3.[8]

A mortality study at a French plant producing ferrochromium and stainless steel (2269 men employed for at least 1 year from 1952 to 1982) showed a non-significant excess of lung cancer mortality (SMR 1.40, 95% CI 0.72 to 2.45).[20] In another stainless steel plant with 4227 workers who had been employed for at least 3 years during 1968–1984, there was a small increase of lung cancer mortality, which was due to a significant increase among the foundry workers (SMR 2.3, 95% CI 1.1 to 4.1).[21] Lung cancer mortality among ferroalloy production workers and among workers involved in stainless steel melting and casting was close to expectation.[21]

In a third French cohort with workers exposed to metals in the production of stainless steel and metal alloys during 1968–1992, the mortality from lung cancer was slightly elevated.[22] A case-control study nested within this cohort failed to detect any relationship between lung cancer and exposure to iron, chromium, nickel and/or their compounds, while high and statistically significant relative risks, along with increasing trends, were observed for simultaneous exposure to PAHs and silica.

In a Norwegian ferrochromium plant, the incidence of lung cancer showed a non-significant, at least, 1.5-fold excess.[18] The ferrochromium furnace operators worked in an atmosphere with from 0.04 to 24 mg/m^3 total chromium. The proportion of Cr^{6+} was estimated to be 11–33%. The exposure levels to Cr^{6+} in the Norwegian ferrochromium smelter were up to 40-fold higher compared to the Finnish smelter.

There are several reasons why the results on lung cancer risk may vary between the cohorts. One of the reasons may be the registration of lung cancer. Registration of cancer in the Nordic countries is on such a high level[26] that we can assume that the events on cancer incidence in the Finnish, Norwegian and Swedish studies are recorded correctly. When it comes to cancer incidence in other countries, or cancer mortality statistics in any country, the possibility of incomplete registration and inaccurate disease classification increases.

The most important source for incomparability between the cohorts is confounding due to smoking, which has not been controlled for in most studies and may lead to a bias to different direction, depending on whether smoking in the cohort is lower or higher than

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in the reference population. The prevalence of smokers among the male employees of Tornio Works in 1993 varied from 28% in the ferrochromium smelter and stainless steel melting shop to 58% in the chromite mine[27] and in 1998 from 27% in the ferrochromium smelter and the stainless steel melting shop to 43% in the cold rolling mill.[8] The prevalence of smokers in the male population in the province of Lapland in Northern Finland in 1990–2005 varied from 20% in the highest educational class to 42% in the lowest one.[28] Hence, the confounding due to smoking should not be large in our study.

Finally, the industrial processes and true exposures may vary. For instance, the ferrochromium electric arc furnaces in Norway were either open or semiclosed furnaces while the Finnish furnaces are fully closed ones with reducing conditions within the furnace. This technological feature explains why the exposure levels to Cr^{6+} were substantially higher in the Norwegian cohorts (variation 13–8000 μg/m^3) compared to the Finnish one (median below 0.05 μg/m^3 and maximum 2.4 μg/m^3).

Cancer of the nose and nasal sinuses

We observed two cases of nasal cancer, both among persons with no exposure to nickel or Cr^{6+}. Hence, these cases cannot be linked to occupational exposures at Tornio Works. As a comparison, among workers in a Finnish nickel refinery who were exposed primarily to nickel sulfate at levels below 0.5 mg/m^3 as well as to low concentrations of other nickel compounds, there were also two cases of nasal cancer (40-fold increased risk), both of them after a latency of >20 years and long duration of employment.[25]

Other cancers

In the present study we did not see an excess risk of stomach cancer, similar to the one seen in the French study among ferrochromium and stainless steel workers (SMR 1.57, 95% CI 0.43 to 4.03)[20] and the Finnish nickel refinery cohort (SIR 5.0, 95% CI 1.6 to 11.6).[25]

In the Norwegian study,[18] a 60% non-significant excess was observed for kidney cancer. The present study, instead, showed a significantly decreased risk for cancer of the kidney. A low risk of kidney cancer was also reported for the US stainless steel production workers in the proportional mortality analysis by Cornell[24] in 1984. There is no evident explanation for the low risk of kidney cancer, but it is worth mentioning that the work in most departments of Tornio Works some decades ago included much physical activity, and high physical activity has been sometimes connected with a very low risk of kidney cancer.[29]

In the Norwegian study, a 56% excess was observed for prostate cancer.[18] The present study showed a significant 30% increased incidence of prostate cancer. This could be explained by intensified screening and improved early diagnostic methods. Prostate-specific antigen testing in the Nordic countries started in the 1990s in Sweden, and in Finland it first became common in the Tornio region next to the Swedish border,[30] which may well have lead to an increased incidence of prostate cancer diagnoses.

As a conclusion, the exposure levels are low, and it is not likely that the occupational exposures in the Finnish ferrochromium and stainless steel industry would have increased the risk of cancer.

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Contributors MH coordinated the collection of cohort personal data. EP performed the statistical analyses. Both authors interpreted the data and approved the final manuscript. EP is the guarantor.

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Markku Huvinen and Eero Pukkala

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