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**Incidence of cancer among workers in Norwegian hydroelectric power companies.**

by Tynes T, Reitan JB, Andersen A

**Affiliation:** Cancer Registry of Norway, Institute of Epidemiological Cancer Research, Oslo.

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Incidence of cancer among workers in Norwegian hydroelectric power companies

by Tore Tynes, MD, 1 Jon B Reitan, MD, 2 Aage Andersen 1

TYNES T, REITAN JB, ANDERSEN A. Incidence of cancer among workers in Norwegian hydroelectric power companies. Scand J Work Environ Health 1994;20:339-44.

OBJECTIVES — The goal of this study was to examine whether exposure to electric or magnetic fields is related to cancer.

METHODS — The study cohort consisted of 5088 men who had worked for at least one year between 1920 and 1991 for any of eight participating companies which produce and distribute hydroelectric power in Norway. The occupational exposure of these workers included extremely low-frequency electromagnetic fields. Incident cancer cases identified from the Cancer Registry of Norway were analyzed on the basis of the standardized incidence ratio with the Norwegian male population as reference.

RESULTS — The incidence of cancer was close to unity for the cohort. The standardized incidence ratio for lymphoma was below unity, whereas those for leukemia and brain tumors were similar to those expected. Calculated cumulative exposure to electric or magnetic fields was not associated with the incidence of leukemia or brain tumors, but an excess of malignant melanoma was shown for the highest category of magnetic field exposure. An analysis of combined possible exposure to oils containing polychlorinated biphenyls and exposures to magnetic fields or possible exposure to electric sparks gave standardized incidence ratios of 265 and 280, respectively, for the higher exposure category.

CONCLUSIONS — These results do not support the assumption of a possible association between exposure to electromagnetic fields and leukemia and brain tumors. The possible association between exposure to polychlorinated biphenyls or magnetic fields and risk of malignant melanoma should be further evaluated in future studies.

KEY TERMS — brain tumor, cohort, electromagnetic fields, leukemia, malignant melanoma, occupational exposure.

Public interest in a possible association between exposure to extremely low-frequency (ELF) electromagnetic (EM) fields and cancer has increased over the last decade. Several epidemiologic studies have suggested an increased risk for cancer, particularly leukemia and brain tumors, in various categories of "electrical occupations."

Interpreting studies of workers exposed to EM fields has been especially difficult because of the lack of historical exposure data and biological support for the hypothesis that occupational exposure to ELF fields in the 50–60 Hz range can enhance cancer development. Furthermore, the respective roles of electric and magnetic fields have not been established, the results show no homogeneous pattern, and reviewers have suggested confounding factors and publication bias as explanations for the observed excess risks (1, 2). Currently, there is no clear experimental evidence to support any single interaction mechanism through which ELF fields could influence cell membrane properties (3, 4). It is not known whether peak field strength, cumulative exposure, or relative orientation of the field is important.

Two earlier Norwegian studies on cancer and exposure to EM fields have been carried out (5, 6). A study on cancer incidence among workers with potential exposure to EM fields showed an excess risk for leukemia for those who had been employed for long periods, but no excess risk for brain tumors was seen (5). A nested case-referent study of railroad workers gave no support to the hypothesis that EM fields can promote cancer (6). The purpose of the present study was to use calculated cumulative exposure to magnetic fields to determine whether exposure to EM fields during the production and distribution of hydroelectric power is associated with cancer.

Subjects and methods

The study cohort consisted of 5088 male workers in eight large Norwegian hydroelectric power companies. Their job title indicated exposure to electric and magnetic fields, they had been employed for at least one year, and they had been first employed between 1 January 1920 and 31 December 1985. The cohort was established from employment records available
at each company. The completeness was not guaranteed for employees dead or retired before 1950. The two largest companies contributed more than 50% of the cohort. The records varied greatly from company to company but generally included the following information: name, personal identification number, gender, date of birth, date of leaving, and summary of work history. For some employees information on jobs held before hire at the present company were also available. Information on whether a man had ever smoked was also collected, although this information was not available for 12% of the cohort. Among the cohort members with such information available, 70% were smokers or ex-smokers and 30% had never smoked.

All new cases of cancer in Norway have been recorded by the Cancer Registry since 1953 (7). The system is based on compulsory reporting by hospital departments and histopathological laboratories. All causes of death on death certificates are coded by the Central Bureau of Statistics and reported regularly to the Cancer Registry. Cancers are coded according to the International Classification of Diseases, seventh revision. Site 193 (brain tumors) includes all tumors of the central nervous system and malignant tumors of the peripheral nervous system.

The cohort was followed from 1953 to the end of 1991 by use of the personal identification number given to all citizens alive at the census in 1960 or who were born in or immigrated to Norway later. The date of death or emigration and details of any cancer diagnosis were obtained for each individual. Only five (0.1%) of the workers were lost to follow-up; six workers emigrated during the follow-up period.

Table 1. Exposure to magnetic fields during an 8-h workday (typical value) for various worksites in power production and distribution, based on results of spot measurements (root mean square).

| Worksite       | Minimum (µT) | Maximum (µT) | Typical value, (µT) | Time spent at site (%) |
|----------------|--------------|--------------|---------------------|-----------------------|
| Power stations |              |              |                     |                       |
| Control room   | 0.3          | 126          | 2                   |                       |
| Repair room    | 0.5          | 20           | 1                   |                       |
| Outdoor station| 0.5          | 10           | 3                   |                       |
| Lunchroom      | 0.3          | 200          | 5                   |                       |
| Office         | 0.5          | 40           | 2                   |                       |
| Under electric lines | | | | |
| 0—13 kV       | 0.1          | 3            | 0.5                 | 60                    |
| 14—47 kV      | 0.5          | 10           | 5                   | 40                    |
| 50—420 kV     | 1            | 20           | 8                   | 20                    |
| Other installations | | | | |
| Transformer    | 1            | 100          | 10                  | 70                    |
| Cable          | 0.1          | 20           | 0.8                 | 50                    |
| Road lights    | 0.1          | 0.5          | 0.2                 |                       |
| Central switch | 0.1          | 5            | 1                   |                       |

The basic unit of statistical computation was the number of years each employee was followed from the date of first employment to the end of the study period or death. Each year contributed by each cohort member was classified by age and calendar year, and the person-years of all workers were then summed by age and calendar year. In the cohort analysis, the standardized incidence ratio (SIR) for total cancer is given with the national male population as the reference entity. The expected number of cancer cases was calculated from the five-year, age-specific incidence rates for the reference entity for each year of follow-up (1953—1991). Ninety-five percent con-
Results

Total cohort
During the follow-up period 1953—1991 (116 930 person-years), 486 new cases of cancer were observed (table 2). No significant change in risk was seen for cancer at any site. The standardized incidence ratio was lower than unity for malignant lymphoma and greater than unity for stomach cancer and nonmelanoma skin cancer.

Analysis by time since first employment and duration of employment
An analysis of all cancers, brain tumors, and leukemia by time since first employment (data not shown) showed no change in incidence. For stomach cancer an excess risk was shown for workers with more than 30 years since first employment, and a rise in the standardized incidence ratio was detected for malignant melanoma (the SIR rose from 73 in the category <20 years since first employment to 131 in the category >30 years since first employment). An analysis by duration of employment (table 3) showed a rise in the standardized incidence ratio for all cancers combined, cancer of the pancreas, lung (significant linear trend, Poisson trend statistics) and kidney, malignant melanoma, nonmelanoma, and lymphoma.

Analysis by longest held job
Table 4 shows the number of cases of all cancer and the number for selected sites for groups of job categories. The excess risk for cancer at all sites for in- stallation electricians was not associated with duration of employment (data not shown). Two of the three cases of leukemia among the installation electricians occurred in workers who had been employed for less than 20 years. An elevated risk for nonmelanoma skin cancer was seen for installation electricians (data not shown, 3 observed, SIR 197) and for the “other worker” group (7 observed, SIR 175).

Analysis by cumulative exposure
Table 5 shows the number of observed cases of cancer and the standardized incidence ratios for selected cancer sites by calculated levels of exposure to cumulative magnetic fields. An excess risk was seen for malignant melanoma at cumulative exposures above 35 μT-years, although the data showed no continuous exposure-response trend. No association with magnetic fields was seen for leukemia, and brain tumor showed a tendency towards a negative correlation. An analysis by calculated levels of exposure to electric fields showed no association for any site (data not shown). The cumulative categorized data on workers possibly exposed to electric discharges showed no association for either leukemia or brain tumors (data not shown). The evaluation of risk for malignant melanoma and combined exposures to magnetic fields and possible exposure to electric discharges or to oils contaminated with polychlorinated biphenyls (PCB) showed a tendency towards an effect (table 6). The standardized incidence ratio for lung cancer was analyzed...
Table 4. Numbers of observed (O) cases of cancer at selected sites among 5088 Norwegian power plant workers and the standardized incidence ratios (SIR) by longest job held — follow-up from 1953 to 1991.

| Job title                            | All sites | Lung (162) | Malignant melanoma (190) | Brain tumors (193) | Lymphoma (200—2) | Leukemia (204) |
|--------------------------------------|-----------|------------|--------------------------|-------------------|------------------|---------------|
|                                      | O SIR     | O SIR     | O SIR                   | O SIR             | O SIR            | O SIR         |
| Electrician, installation            | 78 140*   | 13 188*   | 2 103                   | 2 111             | 1 48             | 3 200         |
| Electrician, power supply            | 129 98    | 13 79     | 11 208*                 | 4 89              | 4 77             | 3 88          |
| Electric line worker                 | 46 67*    | 1 74      | 2 91                    | 1 53              | 1 42             | 0 0           |
| Power plant operator                 | 49 88     | 10 137    | 2 100                   | 2 118             | 2 100            | 1 71          |
| Engineer                             | 42 116    | 4 91      | 2 182                   | 0 0               | 0 0              | 0 0           |
| Other worker                         | 142 103   | 21 117    | 2 47                    | 2 53              | 4 87             | 4 121         |

* P < 0.05.

Table 5. Numbers of observed (O) cases of cancer at selected sites among 5088 Norwegian power plant workers and the standardized incidence ratios (SIR) by exposure to cumulative magnetic fields — follow-up from 1953 to 1991.

| Site of cancer | Cumulative exposure to magnetic fields | O SIR | O SIR | O SIR | O SIR | O SIR | O SIR |
|---------------|---------------------------------------|-------|-------|-------|-------|-------|-------|
|               | <5 µT-years                           |       |       |       |       |       |       |
|               | 5—35 µT-years                         |       |       |       |       |       |       |
|               | >35 µT-years                          |       |       |       |       |       |       |
| Stomach (151) | 11 177                                 | 24 129| 22 116|       |       |       |       |
| Colon (153)   | 8 119                                  | 16 102| 15 97 |       |       |       |       |
| Pancreas (157)| 4 145                                  | 5 68  | 10 135|       |       |       |       |
| Lung (162)    | 11 101                                 | 25 97 | 32 128|       |       |       |       |
| Prostate (177)| 11 86                                 | 38 116| 41 108|       |       |       |       |
| Kidney (180)  | 6 188                                 | 5 67  | 8 116 |       |       |       |       |
| Bladder (181) | 3 52                                  | 15 112| 9 67  |       |       |       |       |
| Malignant melanoma (190) | 3 71 | 5 63 | 11 224* |       |       |       |       |
| Nonmelanoma (191) | 5 192 | 4 73 | 9 155 |       |       |       |       |
| Brain tumors (183) | 6 182 | 5 71 | 2 44 |       |       |       |       |
| Lymphoma (200—2) | 1 26 | 4 50 | 7 121 |       |       |       |       |
| Leukemia (204) | 2 95                                 | 4 74  | 5 104 |       |       |       |       |

* Code of International Classification of Diseases, seventh revision, in parentheses.

Discussion

The present study showed no association between the occurrence of leukemia or brain tumors and exposure to electrical or magnetic fields in hydroelectric power companies. No exposure-response trend was shown for cancer at any site in relation to cumulative exposures to magnetic fields, although there was an excess risk for malignant melanoma in the highest exposure category. For brain tumors, a tendency was seen towards a negative correlation with magnetic fields.

This study had the following strengths: (i) complete data with detailed job histories from employment records from the eight participating power companies and (ii) cancer incidence data from a high-quality national cancer register. Exposure was determined on the basis of job title and department, however, and not from direct recordings for each individual; historical records do not give information on differences among workers within the same job category. The calculated cumulative exposure to magnetic and electric fields is, at best, a qualified estimate and may have introduced misclassification that is nondifferential (ie, independent of the end point) and in practice may have a magnitude and direction such that a linear, true exposure-response relationship would be distorted so as to appear inconsistent with causation (ie, to bias the risk estimates towards unity) (9).

Magnetic fields near high-voltage power distribution systems change less over time than those associated with other electric installations (eg, railroads and some electric appliances). Very few of the workers (less than 10%) in our study had exposure to magnetic fields greater than 2 µT. An earlier study of leukemia and brain tumors in Norwegian railroad line for combined exposure to asbestos and oil-impregnated cables. No significant association was seen, although there was an increased standardized incidence ratio for the combination more than 20 years of exposure to asbestos and more than 30 years of exposure to oil-impregnated cable (20 observed, SIR 163). The observed number of cases of lung cancer among ever smokers was 55 (SIR 137, 95% CI 103—178). Neither bladder cancer nor leukemia showed any association with smoking.
workers, who experience an average 8-h time-weighted exposure to magnetic fields of 20 μT (frequency 16 2/3 Hz), showed no association (6). Workers in power companies are exposed to a varying degree to electrical shocks or electrical spark discharges. Discharges have been suggested to be associated with an increased frequency of chromosome aberrations (10, 11). In our study, however, no association was seen for either leukemia or brain tumor with categorized data on the possibility of such exposure. Although we controlled for categorized exposures to solvents, herbicides, and cable oils in our analysis, a potential confounding effect of these parameters cannot be excluded. As the exposure data were based on information from experienced current and retired workers and no historical measurements were available, misclassification may have occurred.

The selection of reference rates in occupational epidemiologic cohort studies may be problematic when cancer incidence at selected sites has a geographic gradient. The incidence of cancer in urban areas in Norway is 20% higher than in rural areas (12). The fraction of urban residency in this cohort was 10% higher than that of the general male Norwegian population. A deficit of total cancer would therefore appear in our cohort if residency were taken into consideration. The null effect in our study may reflect a possible “healthy worker effect” for selection into exposed occupations, for an incidence study on cancer this is, however, not very likely, especially not for leukemia and brain tumors.

Previous epidemiologic studies on leukemia risk among electrical workers have shown an association with such work, but most studies have not provided any evidence of a quantitative exposure-response relationship between risk and the level of EM field exposure (13—16). An exception is a Swedish case-referent study of leukemia and brain tumor, which showed an association between magnetic field measurements (dosimeter) and leukemia; for chronic lymphocytic leukemia in particular, a clear association with exposure intensity was observed (17). A recent cohort and nested-case referent study of electric utility workers, however, showed no consistent association between such work and leukemia, brain cancer, or lymphoma (18). The Norwegian census study of the incidence of cancer among workers potentially exposed to EM fields showed a 40% excess risk for leukemia in workers with a long duration of employment (5). The finding that electricians in power supply and electric line workers show elevated risks was not confirmed in the present study. Our cohort was relatively young, and at the end of the observation period (31 December 1991) 4099 (80.5%) cohort members were still alive. The census cohort was, on the average, older (72% still alive at the end of the observation period), but the excess leukemia risk was not restricted to the older cohort members. Our cohort covers the largest Norwegian hydroelectric power producers and distributors, presumably with a more specialized work force than the census cohort. In addition only a smaller fraction of the workers in our cohort was present in the census cohort, which had only 20% of the power supply electricians, 15% of the power plant operators, and 5% of the installation electricians and electric line workers. The excess risk seen previously for leukemia may therefore have occurred in similar jobs in smaller companies where there is possibly higher exposure to other factors that contribute to leukemia risk, such as, for example, solvents.

An association between electrical work and brain tumors has also been reported in previous epidemiologic studies (14—16, 19—21) although negative results have also emerged (22, 23). The Norwegian census cohort study (5) showed no excess risk for brain tumors among electrical workers, and our findings do not support the hypothesis that exposure to electric or magnetic fields in power companies enhances the risk for brain tumor.

Previous studies have drawn attention to the possibility that melanoma might be related to EM fields. Studies in telecommunications and the electronic and electrical manufacturing industry have shown excess risks for malignant melanoma (24—27). Exposure to magnetic fields has been associated with changes in the diurnal pattern of the pineal hormone melatonin (4). The patterns for malignant melanoma in our data may indicate a tendency towards an interaction between exposure to polychlorinated biphenyls and other exposures, in particular exposure to electric sparks and magnetic fields (table 6). Nine of 11 cases among electricians in power supply were possibly exposed to polychlorinated biphenyls. As polychlorinated biphenyls were used as dielectric fluids in electrical capacitors until 1977, accidental exposure may have occurred owing to explosions or the destruction of old equipment. An association between exposure to polychlorinated biphenyls and mortality from malignant melanoma has been suggested previously (28). The creation of polychlorinated dibenzofurans or other organochlorine compounds from combined exposure to polychlorinated biphenyls and electric sparks may be a mechanism of interest (table 6).

An association has been reported between lung cancer and exposure to mineral oils (29). Our data gave no opportunity to confirm this finding, although a tendency towards an association was seen.

Concluding remarks

In summary, the results of this study give no support to previous findings of a possible association between exposure to electrical and magnetic fields and leukemia and brain tumors. The results for malignant melanoma should be evaluated in future studies. Our results are based on a combination of data from a high-quality national cancer register and detailed job histories obtained from employment
records. These advantages must be weighed against the limitations of lack of historical dosimeter data for relevant exposures and limited knowledge about the biological effects of EM fields. As the classification of cumulative exposure to magnetic fields in this study may be an imprecise surrogate for a true biologically effective exposure, the results should be interpreted with caution.

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