Magnetic fields and brain tumour risks in UK electricity supply workers

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Magnetic field exposures and brain tumour risks in UK electricity generation and transmission workers, 1973-2010

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Abstract

Objective- To investigate whether brain tumour risks are related to occupational exposure to low-frequency magnetic fields.

Methods- Brain tumour risks experienced by 73 051 employees of the former Central Electricity Generating Board of England and Wales were investigated for the period 1973-2010. All employees were hired in the period 1952-82 and were employed for at least six months with some employment in the period 1973-82. Detailed calculations had been performed by others to enable an assessment to be made of exposures to magnetic fields. Poisson regression was used to calculate relative risks (rate ratios) of developing a brain tumour (or glioma or meningioma) for categories of lifetime, distant (lagged) and recent (lugged) exposure.

Results- Findings for glioma and for the generality of all brain tumours were unexceptional; risks were close to (or below) unity for all exposure categories and there was no suggestion of risks increasing with cumulative (or recent or distant) magnetic field exposures. There were no statistically significant dose-response effects shown for meningioma, but there was some evidence of elevated risks in the three highest exposure categories for exposures received more than ten years ago.

Conclusions- This study found no evidence to support the hypothesis that exposure to magnetic fields is a risk factor for gliomas, and the findings are consistent with the hypotheses that both distant and recent magnetic field exposures are not causally related to gliomas. The limited positive findings for meningioma may be chance findings; national comparisons argue against a causal interpretation.

KEYWORDS: glioma, meningioma, electricity supply industry, cohort study

Introduction

There have been many epidemiological studies into brain tumour risks (including other tumours of the central nervous system) in relation to occupational exposures to low-frequency electric and magnetic fields (EMF), and Kheifets et al published a meta-analysis of 48 such cohort and case-control studies in 2008 [1]. These reviewers found a small (14%) but significant excess risk (different summary measures from the various studies) but concluded that "the apparent lack of a clear pattern of exposure and risk substantially detracts from the hypothesis that measured magnetic fields in the work environment are responsible for the observed excess risk of … brain cancer". Other narrative reviews have come to similar conclusions [2][3]. The more important of these 48 studies are the five cohort studies of electric utility workers that present findings in relation to quantitative estimates of magnetic field exposure [4-8]. The Southern California Edison Study [4] presented unexceptional findings for all brain cancers combined. The United States Five Utility Study [5] presented significant trends for brain cancer risks in relation to estimated cumulative exposure to magnetic fields. The Canada-France study [6] presented some positive findings for malignant brain cancer particularly for astrocytoma (but not for glioblastoma). The Danish utility workers study [7] presented unexceptional findings for all brain tumours combined. Earlier analyses of the UK cohort found no positive association between brain cancer risks and magnetic field exposure; these earlier findings did not show separate results for gliomas and meningiomas [8].

The purpose of this paper is to present updated findings for the UK study of cancer risks in employees of the former Central Electricity Generating Board (CEGB). An additional thirteen years of mortality data are now available together with cancer registration (incidence) data for the whole period under study (1973-2010); the analysis commenced without strong prior evidence of any association between the risk of brain tumour or its subtypes and magnetic field exposure.

Materials and methods

The full cohort comprises 83 997 employees (72 954 men and 11 043 women) at power stations, sub-stations and non-operational sites of the CEGB. All employees were employed for at least six months with some period of employment in the period 1973-82. The study computer files include 347 832 work history records (variable number per study subject) showing dates of working and coded entries for job title, region, facility/plant and negotiating body (pay and conditions) for employment in the period 1971-1993. Later dates of leaving employment (1994-99) were obtained from requests to employers. The current analysis proceeded on the basis of those 73 051 study subjects (62 825 men, 10 226 women) first employed in the period 1952-82 for whom a detailed work history (1971-93) was available.

There were five negotiating bodies representing managers, engineers and scientists, administrative and clerical workers, industrial workers, and construction and building workers. It was unusual for employees to change negotiating body. Consequently, for individuals with missing codes, known codes for later periods of working were assumed to apply. Facility codes (specific power stations, transmission districts etc.) were problematic in that each region had its own set of codes, codes changed over time and complete contemporaneous lists were no longer available. Satisfactory recoding was possible and this has been described previously [9].

The study received follow-up particulars from the National Health Service Central Register (NHSCR) of the Office for National Statistics (ONS) for the period 1973-2010. Underlying cause and multiple-cause coding had been supplied for all deaths. For the study subjects under analysis, 1025 (1.4%) subjects had emigrated and 1194 (1.6%) were untraced. Details of cancer registrations (date of diagnosis, site of cancer and morphology code) had also been supplied for the same period.

The exposure protocol used to translate work histories into histories of magnetic field exposures has been summarised previously [9], and a full account by its original authors is available [10]. Renew et al state that the main sources of magnetic fields in the electricity supply industry are the large electric currents that flow in the generator main connections in power stations, the power lines leaving the stations, the busbars around transmission substations, and the power lines entering the substations [10]. 'Background' exposures from other occupational sources of magnetic fields and non-occupational sources are not evaluated. Exposure assessments for the larger power stations were based on the maximum output from each station, annual load factors, typical working patterns, and proximity of departments to the main generator connections. Exposure assessments for the smaller stations assumed a standard site design and less detailed assessments were available for transmission workers. The coded job histories of each study subject were cross-referenced with the exposure assessments (time-weighted average of the root-mean-square power-frequency magnetic field) in order to obtain individual assessments of magnetic field exposure for the period 1952-1994. For subjects with pre-1971 employment, the first known employment details were assumed to apply to the earlier employment. Cumulative occupational lifetime exposures together with exposures received more than ten years ago (lagged exposures) and those received less than ten years ago (lugged exposures) were developed for each study subject, as time dependent variables. A study subject can receive the same level of cumulative exposure by very different routes (eg 10 μT.y can be a consequence of 10 years of employment at 1μt. or one year of employment at 10μT). Software, written in BASIC, was developed to calculate, for each study subject, if and when any of the predetermined 'cut-off' values for exposure levels were reached. The selected cut-off values were the same convenient multiples of 2.5μT.y and 0.5μT.y used in earlier analyses [7]; these values had been selected so that similar proportions of deaths from all causes were in each of the four higher exposure categories, and had been selected before the calculation of any relative risks.

Seven variables were considered to have the potential for influencing cancer risk: attained age, sex, calendar year, estimated cumulative occupational exposure to magnetic fields, exposure to magnetic fields in the most recent ten years, exposure to magnetic fields received more ten years ago, and negotiating body (surrogate for socio-economic group). These variables were not treated as continuous variables, but were categorised into a number of levels. In constructing the models, it was necessary to ensure that there was at least one case observed at each level of each variable. All adjustments were made before any statistical modelling was carried out.

Individuals enter the person-years-at-risk (pyr) at the end of the first six months of employment or the date of computerisation for the relevant region whichever is the later. Individuals leave the pyr on the date of death, date of embarkation, date last known alive or the closing date of the study (31st December, 2010), whichever is the earlier. Individuals were "censored" on reaching their 85th birthday - that is, they make no further contributions to expected or observed numbers past this age. The EPICURE computer program [11] was used to provide both pyr and numbers of cases of primary brain tumours (cancer registration, or any mention on the death certificate if there was no cancer registration), for all combinations of all levels of the variables under study. The EPICURE program was also used to carry out statistical modelling by means of Poisson regression [12], providing point estimates of rate ratios (relative risks) for each category of magnetic field exposure compared with the baseline (lowest) category, with and without adjustment for other variables. More importantly, the statistical significance of any trend in risk across the exposure categories was also assessed. The exposure distributions (total, lagged and lugged exposures) of all deaths were used to calculate mean exposures in each exposure category. (Similar means were obtained for all study subjects at the end of follow-up.) These mean exposures were then used to calculate a dose-weighted P-value for trend, by assigning these mean exposures as scores for the five exposure categories and treating exposure as an unfactored variable. These analyses also provided relative risks per ten microtesla-years of occupational exposure.

This study was established with the approval of the Central Ethical Committee of the British Medical Association, and the author is currently accredited by the ONS as the "Approved Researcher" of this study.

Results

Relative risks (rate ratios) for any notification of a primary brain tumour (cancer registration or mention on death certificate: 372 cases in total) are shown in Table 1 for four categories of estimated cumulative occupational exposure to magnetic fields relative to the corresponding rates in the lowest (baseline) category of exposure (model 1). Corresponding relative risks are also shown for a simultaneous analysis of distant (lagged) and recent (lugged) exposures (model 2). Rate ratios in the left hand side of the Table were adjusted for age and sex. Rate ratios in the right hand side of the Table were additionally adjusted for calendar period, and socio-economic status (three categories: managers, scientists and engineers; administrative and clerical workers; industrial and construction workers). To be concrete, the Table summarises four separate analyses. None of the individual point estimates of risk are significantly different from unity and there is no suggestion that risks increase with increasing exposure. Findings were little different with or without adjustment for calendar period and socio-economic status.

Findings for glioma risks are shown in Table 2. This analysis did not make use of death certificates because these do not routinely distinguish between gliomas and other types of brain tumour but is based on 225 incident cases of glioma (gliomas, astrocytomas, glioblastomas) identified from cancer registration particulars. None of the individual point estimates of risk are significantly different from unity and there is no suggestion that risks increase with increasing exposure. Findings were little different with or without adjustment for calendar period and socio-economic status.

Findings for meningioma risks are shown in Table 3. This is based on 41 incident cases of meningioma. There are no statistically significant positive trends of disease risk with exposure, but point estimates of risk are somewhat raised for the three highest exposure categories, both for lifetime and distant exposures. In addition, a significant doubling of risk is shown in an intermediate exposure category for distant exposures. Findings were little different with or without adjustment for calendar period and socio-economic status. Standardised registration ratios (SRR) (not shown in Table) were also computed for meningiomas for the five exposure categories under investigation, using cancer registration rates (based on recorded morphology codes) for England and Wales. The overall SRR was non-significantly reduced (Obs 41, SRR 90, 95% CI 64 to 122). There was no significant trend with SRRs by exposure category and there was an unusually low SRR in the lowest exposure group (0-2.4 μT.y: Obs 17, SRR 63; 2.5-4.9 μT.y: Obs 3, SRR 69; 5-9 μT.y: Obs 10, SRR 159; 10-19 μT.y: Obs 8, SRR 151; ≥20 μT.y: Obs 3, SRR 117). A fuller tabulation is shown in the Supplementary Table S1.

The analyses summarised in Tables 1-3 were then repeated for the sub-cohort of those 48 768 employees first employed in power stations; these analyses were carried out because the exposure assessments for power station workers are more detailed than for other groups of workers. Relative risks (rate ratios) for any notification of a primary brain tumour (cancer registration or any mention on the death certificate if there was no cancer registration: 254 cases in total) are shown in Table 4. None of the individual point estimates of risk are significantly different from unity and there is no suggestion that risks increase with increasing exposure. Findings were little different with or without adjustment for calendar period and socio-economic status.

Findings for glioma risks in power station workers are shown in Table 5. This analysis is based on 152 incident cases of glioma (gliomas, astrocytomas, glioblastomas) identified from cancer registration particulars. None of the individual point estimates of risk are significantly different from unity and there is no suggestion that risks increase with increasing exposure. Findings were little different with or without adjustment for calendar period and socio-economic status.

Findings for meningioma risks in power station workers are shown in Table 6. This analysis is based on 34 incident cases of meningioma. There are no statistically significant positive trends of disease risk with exposure, but point estimates of risk for distant exposures are somewhat raised for the three highest exposure categories. Findings were little different with or without adjustment for calendar period and socio-economic status.

Discussion

This study found no evidence to support the hypothesis that exposure to magnetic fields is a risk factor for gliomas, and the findings are consistent with the hypotheses that both distant and recent magnetic field exposures are not causally related to gliomas. The same statements could be made for the generality of tumours of the central nervous system considered as a single entity, and these statements are not dependent on the selection of co-variates in the analysis or on the selection of sub-cohorts for analysis (all employees or power station workers only). It is not possible, however, to be as confident for the findings for meningioma, because whilst there were no statistically significant dose-response effects shown, some suggestion of elevated risks were shown in the three higher exposure categories. However the latter findings were much diminished in the analysis of power station workers only and may well be no more than chance findings based on multiple testing of brain neoplasm sub-types.

A key issue in the interpretation of the limited positive findings for meningioma is whether the elevated point estimates of risk in the higher exposure categories are based on unusually low risks in the lowest exposure category or unusually high risks in the higher exposure categories, or both. The comparisons with national cancer registration rates suggest that the former is at least partly responsible, and taken together with the lower than average rates of meningioma in the total cohort under study, these findings argue against a causative explanation for the elevated risks obtained from the Poisson regression (internal) analyses.

The study has many strengths including its large size, long period of follow-up, availability of cancer registration as well as mortality data, large number of glioma cases available for analysis, and detailed exposure assessments that used the physics of exposure to magnetic fields as a starting point.[10] However, there are limitations to be attached to the work. Most notably it was necessary to assume that for those workers hired before 1973, job and place of work in the 1950s and 1960s were the same as those pursued in the early 1970s, and it was also assumed that working patterns (time spent by different groups of workers in different parts of power stations) are the same in different power stations. These assumptions will have introduced errors into the exposure assessments but we remain confident that the exposure assessments have value particularly if we accept the relative rankings of the five exposure categories and do not attach overwhelming importance to the their absolute values. It must be the case, however, that the current exposure estimates fall short of an ideal survey that would include measured individual exposures over time.

Earlier published comparisons with national mortality rates (total cohort and males and females combined) are consistent with the absence of occupational risk factors for the generality of brain tumours (Obs 202, SMR 107, 95% CI 93 to 123).[13] Likewise, earlier comparisons with national incidence rates (total cohort and males and females combined) are also consistent with the absence of occupational risk factors for the generality of malignant brain tumours (Obs 278, SRR 100, 95% CI 88 to 114) and for the generality of other brain tumours (benign, in situ, unspecified behaviour) (Obs 93, SRR 93, 95% CI 75 to 114) [14]. These SRRS are similar to the published findings for all malignant neoplasms (Obs 15 103, SRR 96,95% CI 95 to 98) [14], and to the overall SRR for meningioma shown in this report (Obs 41, SRR 90, 95% CI 64 to 122). National comparisons will be subject to many influences including regional and socio-economic effects and employment selection effects such as the healthy worker effect, although the latter would be expected to have more influence on mortality than cancer incidence. The overall SRR for all malignant neoplasms suggests, however, that national comparisons are meaningful for this cohort; the low SRR for meningioma in the baseline group may well be no more than a chance finding.

This study was designed to carry out the minimum of multiple testing; there was one set of cut-off points for each of the three exposure metrics, and the principle test was a single test for trend across all exposure categories. These analyses do not consider the possible role of threshold effects (no effects at lower exposures) or saturation effects (same effects at moderate and higher exposures) and it is possible that, in the course of time, physiological considerations might lead to very different exposures metrics being investigated. The overall comparisons with national data suggest, however, that any occupational effect on brain tumour risks in this cohort must be relatively small.

Further national comparisons can usefully be made for the United States Five Utility Study [5]. Although significant trends for brain cancer risks were found in relation to estimated cumulative exposure to magnetic fields, calculations carried out by the current author suggest that the SMR for brain tumours in the baseline category was about 44 and that SMRs were never more than 100 in any of the higher exposue categories (the overall SMR for brain neoplasms in the total cohort was 95 (95% CI 81 to 112)). Some or all of the trend reported by the US study must be due to unusually low rates of brain neoplasms in the baseline exposure category.

In conclusion, the current UK study indicates that neither recent nor distant magnetic field exposures are a risk factor for gliomas. There were limited positive findings for meningioma but national comparisons argue against a causal interpretation. Nevertheless, findings for such tumours could be examined in other cohorts of electric utility workers.

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Key Messages

1. This large UK study study found no evidence to support the hypothesis that exposure to magnetic fields is a risk factor for gliomas.

2. The findings are consistent with the hypotheses that both distant and recent magnetic field exposures are not causally related to gliomas.

3. The limited positive findings for meningioma may be chance findings; national

comparisons argue against a causal interpretation.

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Table 1. Relative risks of brain tumours[a] by levels of estimated cumulative magnetic field exposure (four separate analyses), total cohort under study (73 051 workers first employed in period 1952-82), 1973-2010.

Exposure to magnetic fields (μT.y)[b]	N	RR[c]	(95 % CI)	RR[d]	(95% CI)
Model 1.Occupational cumulative lifetime exposure to magnetic field.					
0-	205	1.0		1.0	
2.5-	41	1.01	(0.72 to 1.41)	1.04	(0.74 to 1.47)
5.0-	59	0.97	(0.72 to 1.30)	1.00	(0.74 to 1.36)
10.0-	47	0.91	(0.66 to 1.25)	0.94	(0.68 to 1.31)
≥20.0	20	0.81	(0.51 to 1.29)	0.85	(0.53 to 1.35)
RR per 10 μT.y[e]		0.94	(0.84 to 1.06)	0.96	(0.85 to 1.07)
Model 2.Occupational exposure to magnetic fields received more than ten years ago (lagged exposure)					
0-	224	1.0		1.0	
2.5-	44	1.12	(0.80 to 1.56)	1.17	(0.83 to 1.64)
5.0-	50	0.93	(0.68 to 1.29)	0.97	(0.70 to 1.36)
10.0-	36	0.89	(0.61 to 1.28)	0.92	(0.63 to 1.35)
≥20.0	18	1.01	(0.62 to 1.67)	1.10	(0.66 to 1.84)
RR per 10 μT.y[f]		0.99	(0.88 to 1.12)	1.01	(0.89 to 1.15)
Occupational exposure to magnetic fields received less than ten years ago (lugged exposure)					
Zero	232	1.0		1.0	
0.01-	61	1.09	(0.81 to 1.47)	1.07	(0.79 to 1.46)
0.5-	28	0.88	(0.59 to 1.32)	0.86	(0.56 to 1.32)
2.0-	31	1.08	(0.73 to 1.60)	1.05	(0.68 to 1.62)
≥5.0	20	0.79	(0.49 to 1.28)	0.76	(0.45 to 1.27)
RR per 10 μT.y[g]		0.82	(0.56 to 1.21)	0.80	(0.53 to 1.20)

a. cancer registration or any part of death certificate coded to ICD-9 191,192, 225, 237.5 or 237.6.
b. one year refers to a working year, approx. 250 8-hour shifts.
c. analysed simultaneously with sex and attained age (5 year age groups)
d. analysed simultaneously with sex, attained age, calendar period (5 year periods), and negotiating body (NJM + NJB, NJC, NJIC + NJ(B+C)E).
e. five exposure categories scored by the mean value in each category, namely 0.47, 3.71, 7.26, 13.97, 38.60 μT.y.
f. five exposure categories scored by the mean value in each category, namely 0.45, 3.69, 7.24, 13.82, 38.27 μT.y.
g. five exposure categories scored by the mean value in each category, namely zero, 0.19, 1.11, 3.31, 12.01 μT.y.

Table 2. Relative risks of astrocytoma/glioma[a] by levels of estimated cumulative magnetic field exposure (four separate analyses), total cohort under study (73 051 workers first employed in period 1952-82), 1973-2010.

Exposure to magnetic fields (μT.y)[b]	n	RR[c]	(95 % CI)	RR[d]	(95% CI)
Model 1. Occupational cumulative lifetime exposure to magnetic field.					
0-	129	1.0		1.0	
2.5-	24	0.91	(0.59 to 1.41)	0.92	(0.59 to 1.43)
5.0-	30	0.77	(0.51 to 1.15)	0.77	(0.51 to 1.16)
10.0-	28	0.85	(0.56 to 1.28)	0.85	(0.56 to 1.29)
≥20.0	14	0.88	(0.50 to 1.53)	0.90	(0.52 to 1.59)
RR per 10 μT.y[e]		0.95	(0.82 to 1.10)	0.96	(0.83 to 1.11)
Model 2. Occupational exposure to magnetic fields received more than ten years ago (lagged exposure)					
0-	143	1.0		1.0	
2.5-	28	1.12	(0.74 to 1.70)	1.17	(0.77 to 1.79)
5.0-	22	0.66	(0.41 to 1.05)	0.69	(0.43 to 1.11)
10.0-	20	0.80	(0.49 to 1.30)	0.85	(0.51 to 1.40)
≥20.0	12	1.08	(0.58 to 1.99)	1.24	(0.66 to 2.32)
RR per 10 μT.y[f]		0.98	(0.83 to 1.15)	1.00	(0.84 to 1.19)
Occupational exposure to magnetic fields received less than ten years ago (lugged exposure)					
zero	143	1.0		1.0	
0.01-	34	0.97	(0.66 to 1.44)	0.88	(0.59 to 1.32)
0.5-	15	0.71	(0.41 to 1.23)	0.61	(0.35 to 1.09)
2.0-	19	1.00	(0.60 to 1.64)	0.86	(0.50 to 1.49)
≥5.0	14	0.83	(0.46 to 1.48)	0.70	(0.38 to 1.31)
RR per 10 μT.y[g]		0.84	(0.53 to 1.34)	0.78	(0.47 to 1.29)

a. cancer registration with morphology code ICD-0 938-948.
b. one year refers to a working year, approx. 250 8-hour shifts.
c. analysed simultaneously with sex and attained age (5 year age groups)
d. analysed simultaneously with sex, attained age, calendar period (5 year periods), and negotiating body (NJM + NJB, NJC, NJIC + NJ (B+C)E).
e. five exposure categories scored by the mean value in each category, namely 0.47, 3.71, 7.26, 13.97, 38.60 μT.y.
f. five exposure categories scored by the mean value in each category, namely 0.45, 3.69, 7.24, 13.82, 38.27 μT.y.
g. five exposure categories scored by the mean value in each category, namely zero, 0.19, 1.11, 3.31, 12.01 μT.y.

Table 3. Relative risks of meningioma[a] by levels of estimated cumulative magnetic field exposure (four separate analyses), total cohort under study (73 051 workers first employed in period 1952-82), 1973-2010.

Exposure to magnetic fields (μT.y)[b]	n	RR[c]	(95 % CI)	RR[d]	(95% CI)
Model 1. Occupational cumulative lifetime exposure to magnetic field.					
0-	17	1.0		1.0	
2.5-	3	0.90	(0.26 to 3.09)	0.84	(0.24 to 2.95)
5.0-	10	1.98	(0.89 to 4.41)	1.82	(0.79 to 4.18)
10.0-	8	1.83	(0.77 to 4.34)	1.70	(0.70 to 4.15)
≥20.0	3	1.41	(0.41 to 4.89)	1.28	(0.36 to 4.53)
RR per 10 μT.y[e]		1.14	(0.86 to 1.49)	1.10	(0.83 to 1.46)
Model 2. Occupational exposure to magnetic fields received more than ten years ago (lagged exposure)					
0-	17	1.0		1.0	
2.5-	4	1.22	(0.40 to 3.72)	1.11	(0.36 to 3.45)
5.0-	11	2.35	(1.03 to 5.34)	2.08	(0.88 to 4.91)
10.0-	6	1.64	(0.60 to 4.44)	1.44	(0.51 to 4.10)
≥20.0	3	1.79	(0.49 to 6.50)	1.62	(0.42 to 6.30)
RR per 10 μT.y[f]		1.23	(0.92 to 1.63)	1.20	(0.89 to 1.63)
Occupational exposure to magnetic fields received less than ten years ago (lugged exposure)					
Zero	19	1.0		1.0	
0.01-	11	1.92	(0.88 to 4.19)	1.92	(0.84 to 4.36)
0.5-	4	1.30	(0.43 to 3.97)	1.44	(0.42 to 4.91)
2.0-	4	1.40	(0.45 to 4.36)	1.67	(0.47 to 5.91)
≥5.0	3	1.17	(0.32 to 4.27)	1.30	(0.31 to 5.37)
RR per 10 μT.y[g]		1.07	(0.40 to 2.86)	1.02	(0.36 to 2.93)

a. cancer registration with morphology code ICD-0 953.
b. one year refers to a working year, approx. 250 8-hour shifts.
c. analysed simultaneously with sex and attained age (5 year age groups)
d. analysed simultaneously with sex, attained age, calendar period (5 year periods), and negotiating body (NJM + NJB, NJC, NJIC + NJ(B+C)E).
e. five exposure categories scored by the mean value in each category, namely 0.47, 3.71, 7.26, 13.97, 38.60 μT.y.
f. five exposure categories scored by the mean value in each category, namely 0.45, 3.69, 7.24, 13.82, 38.27 μT.y.
g. five exposure categories scored by the mean value in each category, namely zero, 0.19, 1.11, 3.31, 12.01 μT.y.

Table 4. Relative risks of brain tumours[a] by levels of estimated cumulative magnetic field exposure (four separate analyses), 48 768 employees first hired in power stations in period 1952-82, 1973-2010.

Exposure to magnetic fields (μT.y)[b]	n	RR[c]	(95 % CI)	RR[d]	(95% CI)
Model 1. Occupational cumulative lifetime exposure to magnetic field.					
0-	97	1.0		1.0	
2.5-	41	1.17	(0.81 to 1.68)	1.16	(0.80 to 1.67)
5.0-	57	1.05	(0.76 to 1.47)	1.06	(0.76 to 1.47)
10.0-	41	0.95	(0.66 to 1.38)	0.95	(0.66 to 1.38)
≥20.0	18	0.94	(0.57 to 1.56)	0.94	(0.56 to 1.56)
RR per 10 μT.y[e]		0.97	(0.85 to 1.10)	0.97	(0.85 to 1.10)
Model 2. Occupational exposure to magnetic fields received more than ten years ago (lagged exposure)					
0-	115	1.0		1.0	
2.5-	44	1.25	(0.87 to 1.78)	1.25	(0.87 to 1.78)
5.0-	46	0.93	(0.65 to 1.33)	0.93	(0.65 to 1.34)
10.0-	33	0.93	(0.62 to 1.40)	0.92	(0.60 to 1.40)
≥20.0	16	1.11	(0.65 to 1.91)	1.11	(0.63 to 1.96)
RR per 10 μT.y[f]		1.02	(0.89 to 1.17)	1.03	(0.89 to 1.19)
Occupational exposure to magnetic fields received less than ten years ago (lugged exposure)					
Zero	123	1.0		1.0	
0.01-	60	1.22	(0.88 to 1.67)	1.22	(0.87 to 1.71)
0.5-	27	1.02	(0.66 to 1.58)	1.06	(0.65 to 1.73)
2.0-	28	1.18	(0.76 to 1.83)	1.22	(0.73 to 2.02)
≥5.0	16	0.82	(0.47 to 1.43)	0.83	(0.45 to 1.53)
RR per 10 μT.y[g]		0.83	(0.54 to 1.26)	0.79	(0.50 to 1.25)

a. cancer registration or any part of death certificate coded to ICD-9 191,192, 225, 237.5 or 237.6.
b. one year refers to a working year, approx. 250 8-hour shifts.
c. analysed simultaneously with sex and attained age (5 year age groups)
d. analysed simultaneously with sex, attained age, calendar period (5 year periods), and negotiating body (NJM + NJB, NJC, NJIC + NJ(B+C)E).
e. five exposure categories scored by the mean value in each category, namely 0.76, 3.72, 7.27, 13.92, 38.50 μT.y.
f. five exposure categories scored by the mean value in each category, namely 0.71, 3.70, 7.25, 13.75, 37.82 μT.y.
g. five exposure categories scored by the mean value in each category, namely zero, 0.19, 1.11, 3.29, 12.26 μT.y.

Table 5. Relative risks of astrocytoma/glioma[a] by levels of estimated cumulative magnetic field exposure (four separate analyses), 48 768 employees first hired in power stations in period 1952-82, 1973-2010.

Exposure to magnetic fields (μT.y)[b]	n	RR[c]	(95 % CI)	RR[d]	(95% CI)
Model 1. Occupational cumulative lifetime exposure to magnetic field.					
0-	64	1.0		1.0	
2.5-	24	1.05	(0.65 to 1.68)	1.04	(0.65 to 1.67)
5.0-	28	0.81	(0.52 to 1.27)	0.81	(0.52 to 1.27)
10.0-	23	0.85	(0.52 to 1.37)	0.84	(0.52 to 1.37)
≥20.0	13	1.07	(0.59 to 1.95)	1.07	(0.58 to 1.96)
RR per 10 μT.y[e]		1.00	(0.85 to 1.18)	1.00	(0.85 to 1.18)
Model 2. Occupational exposure to magnetic fields received more than ten years ago (lagged exposure)					
0-	77	1.0		1.0	
2.5-	28	1.24	(0.80 to 1.93)	1.26	(0.80 to 1.96)
5.0-	18	0.59	(0.35 to 1.00)	0.60	(0.35 to 1.03)
10.0-	18	0.84	(0.49 to 1.43)	0.85	(0.49 to 1.49)
≥20.0	11	1.25	(0.65 to 2.41)	1.33	(0.67 to 2.65)
RR per 10 μT.y[f]		1.03	(0.86 to 1.24)	1.04	(0.86 to 1.26)
Occupational exposure to magnetic fields received less than ten years ago (lugged exposure)					
Zero	76	1.0		1.0	
0.01-	34	1.07	(0.70 to 1.63)	1.01	(0.65 to 1.58)
0.5-	13	0.71	(0.39 to 1.31)	0.67	(0.34 to 1.31)
2.0-	18	1.10	(0.64 to 1.90)	1.03	(0.54 to 1.94)
≥5.0	11	0.81	(0.41 to 1.58)	0.74	(0.35 to 1.56)
RR per 10 μT.y[g]		0.84	(0.50 to 1.41)	0.80	(0.46 to 1.40)

a. cancer registration with morphology code ICD-0 938-948.
b. one year refers to a working year, approx. 250 8-hour shifts.
c. analysed simultaneously with sex and attained age (5 year age groups)
d. analysed simultaneously with sex, attained age, calendar period (5 year periods), and negotiating body (NJM + NJB, NJC, NJIC + NJ(B+C)E).
e. five exposure categories scored by the mean value in each category, namely 0.76, 3.72, 7.27, 13.92, 38.50 μT.y.
f. five exposure categories scored by the mean value in each category, namely 0.71, 3.70, 7.25, 13.75, 37.82 μT.y.
g. five exposure categories scored by the mean value in each category, namely zero, 0.19, 1.11, 3.29, 12.26 μT.y.

Table 6. Relative risks of meningioma[a] by levels of estimated cumulative magnetic field exposure (four separate analyses), 48 768 employees first hired in power stations in period 1952-82, 1973-2010.

Exposure to magnetic fields (μT.y)[b]	n	RR[c]	(95 % CI)	RR[d]	(95% CI)
Model 1.Occupational cumulative lifetime exposure to magnetic field.					
0-	12	1.0		1.0	
2.5-	3	0.69	(0.19 to 2.44)	0.72	(0.20 to 2.55)
5.0-	10	1.48	(0.63 to 3.46)	1.54	(0.65 to 3.63)
10.0-	7	1.28	(0.50 to 3.30)	1.33	(0.51 to 3.47)
≥20.0	2	0.80	(0.18 to 3.61)	0.81	(0.18 to 3.68)
RR per 10 μT.y[e]		0.99	(0.71 to 1.39)	0.99	(0.71 to 1.39)
Model 2.Occupational exposure to magnetic fields received more than ten years ago (lagged exposure)					
0-	12	1.0		1.0	
2.5-	4	1.07	(0.34 to 3.38)	1.04	(0.33 to 3.29)
5.0-	11	2.07	(0.88 to 4.87)	1.94	(0.80 to 4.73)
10.0-	5	1.29	(0.43 to 3.84)	1.20	(0.38 to 3.74)
≥20.0	2	1.23	(0.26 to 5.72)	1.18	(0.23 to 5.92)
RR per 10 μT.y[f]		1.11	(0.78 to 1.57)	1.12	(0.78 to 1.62)
Occupational exposure to magnetic fields received less than ten years ago (lugged exposure)					
Zero	13	1.0		1.0	
0.01-	11	1.83	(0.80 to 4.17)	1.93	(0.80 to 4.63)
0.5-	4	1.20	(0.38 to 3.78)	1.42	(0.39 to 5.17)
2.0-	4	1.32	(0.41 to 4.23)	1.67	(0.44 to 6.39)
≥5.0	2	0.80	(0.17 to 3.78)	0.94	(0.17 to 5.10)
RR per 10 μT.y[g]		0.75	(0.24 to 2.35)	0.75	(0.22 to 2.52)

a. cancer registration with morphology code ICD-0 953.
b. one year refers to a working year, approx. 250 8-hour shifts.
c. analysed simultaneously with sex and attained age (5 year age groups)
d. analysed simultaneously with sex, attained age, calendar period (5 year periods), and negotiating body (NJM + NJB, NJC, NJIC + NJ(B+C)E).
e. five exposure categories scored by the mean value in each category, namely 0.76, 3.72, 7.27, 13.92, 38.50 μT.y.
f. five exposure categories scored by the mean value in each category, namely 0.71, 3.70, 7.25, 13.75, 37.82 μT.y.
g. five exposure categories scored by the mean value in each category, namely zero, 0.19, 1.11, 3.29, 12.26 μT.y.