Occupational exposure to magnetic fields relative to mortality from brain tumours: updated and revised findings from a study of United Kingdom electricity generation and transmission workers, 1973–97

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Abstract

***Objective*—To investigate whether risk of brain tumour is related to occupational exposure to magnetic fields.**

***Methods*—The mortality experienced by a cohort of 83 997 employees of the former Central Electricity Generating Board of England and Wales was investigated for the period 1973–97. All workers were employed for at least 6 months with some employment in the period 1973–82. Computerised work histories were available for 79 972 study subjects for the period 1971–93. Detailed calculations had been performed by others to enable a novel assessment to be made of exposures to magnetic fields. Two analytical approaches were used, indirect standardisation (n=83 997) and Poisson regression (n=79 972).**

***Results*—Based on serial mortalities for England and Wales, deaths from brain cancer were close to expectation (observed 158, expected 146.4). No significant positive trends were shown for risks of brain tumours either with lifetime cumulative exposure to magnetic fields or with such exposures received in the most recent 5 years.**

***Conclusions*—There are no discernible excess risks of brain tumours as a consequence of occupational exposure to magnetic fields in United Kingdom electricity generation and transmission workers.**

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Keywords: magnetic fields; brain tumours; electricity generation and transmission; cohort mortality study

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Concerns about possible risks of malignancy associated with occupational exposure to extremely low frequency electromagnetic fields (ELF/EMF) have been reviewed by others.[1–3] These concerns related, in the main, to findings for leukaemia and brain cancer. The study described in this report seeks to obtain important new information on the topic of occupational exposure to magnetic fields and risks of brain tumour by examining data from an ongoing epidemiological study of electricity generation and transmission workers from the former Central Electricity Generating Board (CEGB) of England and Wales. The mortality study (based on the National Epidemiology File or NEF) was initiated by the CEGB in 1975; responsibility for maintaining and analysing the study passed to the successor companies of the CEGB which came into being after the privatisation of the industry in 1990. The study has been used previously to investigate occupational exposure to magnetic fields relative to mortality from brain tumours[4] and leukaemia.[5] The leukaemia report made use of a much more detailed exposure assessment than did the earlier report and a further analysis of risks of brain tumour is reported here to take advantage of the new exposure assessment protocol and to introduce a further 6 years of follow up data (1992–7) into the data available for analysis.

Materials and methods

The study population and computerised database have been described previously.[5] The cohort made available for analysis comprised 83 997 employees (72 954 men and 11 043 women) of the former CEGB for whom computerised information was available. All employees were known to have been employed for at least 6 months with some period of employment in the period 1973–82. Work history records were available for 79 972 study subjects.

The study received follow up particulars from the National Health Service Central Register of the Office for National Statistics. Underlying cause and multiple cause coding had been supplied by the Office for National Statistics for all deaths (ICD-8 1973–78, ICD-9 1979–97). A total of 834 (1.0%) subjects had emigrated and 1720 (2.1%) were untraced. For decedents with any mention of a brain tumour on the death certificate (secondaries excluded), confirmation of diagnosis was sought from corresponding cancer registration data obtained from the Office for National Statistics.

The exposure protocol used to translate work histories into histories of exposures to magnetic fields has already been described.[5 6] 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. The coded job histories of each study subject were cross referenced with the exposure assessments to obtain

Table 1 Study of United Kingdom electricity generation and transmission workers: distribution of deaths and person-years at risk, 1973–97

	*Brain tumours**	*All other causes†*	*Person-years at risk*
Estimated cumulative exposure to magnetic fields (μT.y):‡			
0–2.4	95	6055	930589
2.5–4.9	18	1581	164656
5.0–9.9	22	2568	220076
10.0–19.9	20	2243	174386
≥20.0	8	702	73404
Estimated cumulative exposure to magnetic fields received in the preceding 5 years (μT.y):‡§			
Zero	86	7503	837344
0.01–0.49	17	1159	184546
0.5–1.9	13	668	138453
2.0–4.9	6	374	102799
≥5.0	2	187	52472
Attained age:			
15–19	0	22	15176
20–24	0	28	54700
25–29	2	42	98219
30–34	4	79	140873
35–39	8	147	167227
40–44	11	226	177060
45–49	8	455	182771
50–54	20	849	186126
55–59	30	1519	181532
60–64	38	2343	156070
65–69	19	2904	112349
70–74	19	2495	62212
75–79	4	1485	23429
80–84	0	555	5367
Sex:			
Male	157	12491	1363200
Female	6	658	199911
Calendar period:			
1973–9	23	1249	277664
1980–4	31	2214	375844
1985–9	31	3126	366254
1990–7	78	6560	543349
Year of starting employment:			
<1946	4	742	31667
1946–64	74	6372	458199
1965–72	44	4110	486891
≥1973	41	1925	586354
Period from first employment (y):			
0–9	10	748	351041
10–19	60	2938	568945
20–29	45	4384	398686
≥30	48	5079	244439
Employment:¶			
Still employed	40	2155	674132
Left employment	123	10994	888979
Negotiating body (pay and conditions):			
NJM	5	129	10960
NJB	40	1801	354839
NJC	13	1205	252053
NJIC	105	9784	929972
NJ(B + C)E	0	213	13725
Not known	0	17	1562
Total	163	13149	1563111

*Any part of death certificate coded to ICD-9 191,192, 225, 237.5 or 237.6.
†No part of death certificate coded to ICD-9 191,192, 225, 237.5 or 237.6.
‡1 year refers to a working year, about 250 8 hour shifts.
§Follow up to 31 March 1994.
¶Subjects enter person-years at risk for left employment category 3 months after date of leaving.

individual assessments of exposure to magnetic fields for the period April 1952 to March 1994. Cumulative occupational lifetime exposures and cumulative exposures in the most recent 5 years were developed for each study subject, as time dependent variables. 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 two sets of four cut off values had been selected after reviewing the cumulative exposure distributions for deaths from all causes, and before the calculation of any relative risks. Lifetime and recent exposure categories were based on the same convenient multiples of 2.5 μT.y and 0.5 μT.y used in recent analyses.[5] For subjects with employment before 1971, the first known employment details were assumed to apply to the earlier employment.

EXTERNAL STANDARD: STANDARDISED MORTALITY RATIO

The mortality experience of the total study cohort (n=83 997) from both all causes and brain cancer was compared with that which might have been expected to occur if mortalities for the general population of England and Wales had been operating on the study cohort, having due regard to the composition of the study cohort by sex, age (5 year age groups), and calendar year (5 year calendar periods). Expectations based on person-years at risk were calculated with the PERSONYEARS computer program.[7] People entered the person-years at risk at the end of the first 6 months of employment or the date of computerisation for the relevant region,[5] whichever was the later. People left the person-years at risk on the date of death, date of embarkation, date last known alive, or the closing date of the study (31 December 1997), whichever was the earlier. People were censored on reaching their 85th birthday—that is, they make no further contributions to expected or observed numbers past this age.

Standardised mortality ratios (SMRs) were calculated as the ratio of observed to expected numbers of deaths expressed as a percentage. In calculating p values and 95% confidence intervals (95% CIs), it was assumed that deaths occur as a Poisson process. Any significance tests are two tailed.

INTERNAL STANDARD: POISSON REGRESSION

Nine variables were considered to have the potential for influencing mortality within the subcohort for which work history data were available (n=79 972): attained age, sex, calendar year, year of starting employment with the CEGB, employment (still employed or left employment), estimated cumulative occupational exposure to magnetic fields, estimated occupational exposure to magnetic fields in the preceding 5 years, period from first employment, and negotiating body (surrogate for socioeconomic group). These variables were not treated as continuous variables, but rather each variable was categorised into several levels (table 1). In constructing the models, it was necessary to ensure that there was at least one death observed at each level of each variable. All adjustments were made before any statistical modelling was carried out. The analysis allowed for subjects to contribute person-years at risk to contemporaneous categories.

The EPICURE computer program[8] was used to provide both person-years at risk, numbers of deaths for primary brain tumours (any mention on the death certificate), and for all other causes, for all combinations of all levels of the variables already mentioned (table 1). This classification of brain tumours introduced a further five cases unavailable to the SMR analysis. The EPICURE program was also used to carry out statistical modelling by means of Poisson regression.[9] The purpose of the modelling was to provide point estimates of

Table 2 Standardised mortality ratios (SMRs) by period from starting employment and by year of death, study of United Kingdom electricity generation and transmission workers, 1973–97

	Brain cancer†			All causes		
	Obs	Exp	SMR (95% CI)	Obs	Exp	SMR (95% CI)
Period from starting employment (y):						
0–9	10	14.6	68 (33 to 126)	829	1133.1	73*** (68 to 78)
10–19	57	42.6	134* (101 to 173)	3326	4024.7	83*** (80 to 85)
20–29	42	47.1	89 (64 to 121)	4864	5688.9	86*** (83 to 88)
⩾30	49	42.1	116 (86 to 154)	5826	7071.8	82*** (80 to 85)
p Value for trend‡		p=0.74			p=0.09	
Year of death:						
1973–80	28	24.7	113 (75 to 164)	1947	2467.3	79*** (75 to 82)
1981–1985	31	29.8	104 (71 to 148)	2794	3301.6	85*** (82 to 88)
1986–1990	35	37.2	94 (66 to 131)	3617	4312.5	84*** (81 to 87)
1991–1997	64	54.7	117 (90 to 149)	6487	7837.0	83*** (81 to 85)
p Value for trend‡		p=0.81			p=0.32	
Total	158	146.4	108 (92 to 126)	14845	17918.4	83*** (82 to 84)

*p<0.05; ***p<0.001.
†ICD-9 codes 191–192.
‡Four categories scored 1–4.

rate ratios (relative risks) for each category of exposure to magnetic fields compared with the baseline (lowest) category, with and without adjustment for other variables. More importantly, the significance of any trend in risk across the exposure categories was assessed. Information on the estimated cumulative exposure for each study subject at the end of each financial year was used to calculate mean exposures for the person-years at risk in each of the five exposure categories (carried out separately for the two exposure metrics). 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 for each 10 microtesla-years of occupational exposure (/1 μT.y for recent exposures).

Results

Observed and expected numbers of deaths for all brain cancer and for all causes are shown by period from first employment and by year of death in table 2. The SMR for all cause mortality in the most recent period of follow up (1991–7, SMR 83) was similar to that in preceding periods, indicating that inadequate tracing of deaths is not an issue in this study. The deficit in overall mortality from all causes was highly significant (observed 14 845, expected 17 918.4, SMR 83, 95% CI 82 to 84). Compared with national rates, overall mortality from brain cancer was close to expectation (observed 158, expected 146.4, SMR 108, 95% CI 92 to 126). There was no important pattern in the brain cancer SMRs for period from start of employment.

Mortalities for brain tumours and all other causes are shown in table 3 for four categories of estimated cumulative occupational exposure to magnetic fields relative to the corresponding rates in the lowest (baseline) category of exposure (<2.5 μT.y). Rate ratios (relative risks) in the left hand side of the table were obtained from two analyses (one analysis for each cause of death), each of which was adjusted for age and sex. Rate ratios in the right hand side of the table were obtained from a further two analyses, each of which was adjusted for age, sex, calendar period, year of starting employment, and negotiating body. None of the point estimates of risk shown for brain tumours was significantly different from unity. There was a non-significant trend of risk decreasing with exposure when adjusted for age and sex only (p=0.12) and when further adjustments were carried out (p=0.19). When adjusted for age and sex only, there was no significant trend (p>0.50) for risks from all causes other than brain tumours increasing with exposure to magnetic fields. Further adjustment produced a highly significant negative trend (p<0.001), although most point estimates of risk were close to unity. Negotiating body (an indicator of socioeconomic status) was an important predictor of general mortality (not shown in table 3) and further analyses (also not shown) indicated that it was the inclusion of this variable in the model which was having most influence on the differences between the two sets of relative risks for all causes other than brain tumours. Further adjustment for employment (still employed or left employment) and period of follow up did not eliminate the highly significant negative trend shown for all causes other than brain tumours (not shown in table 3). This negative trend was not dependent on a single category of deaths as earlier analyses showed negative trends for diseases of the circulatory system, all neoplasms, accidents and suicide, and for all other causes combined.[5]

Mortalities for brain tumours and all other causes are shown in table 4 for four categories of estimated cumulative occupational exposure to magnetic fields received in the most recent 5 years relative to the corresponding rates in the lowest (baseline) category of zero exposure. The presentation of results follows the style of table 3, although the closing date of the survey is now placed at 31 March 1994 (end of exposure assessments). None of the point estimates of risk shown for brain tumours was significantly different from unity. There was a non-significant trend of risk decreasing with exposure when adjusted for age and sex only (p=0.13) and when further adjustments were carried out (p=0.15). A highly significant negative trend (p<0.001) was found for risks from all causes other than brain tumours and recent exposure to magnetic fields, both when

Table 3 Relative risks of mortality from brain tumours and all other causes by levels of estimated cumulative exposure to magnetic fields (four separate analyses), study of United Kingdom electricity generation and transmission workers, 1973–97

Cumulative exposure to magnetic fields (µT.y)†	*n*	*RR‡*	*(95% CI)*	*RR§*	*(95% CI)*
Brain tumours:¶					
0–2.4	95	1.0		1.0	
2.5–4.9	18	0.88	(0.53 to 1.45)	0.90	(0.54 to 1.51)
5.0–9.9	22	0.65	(0.41 to 1.04)	0.67	(0.41 to 1.10)
10.0–19.9	20	0.68	(0.42 to 1.11)	0.69	(0.41 to 1.15)
⩾20.0	8	0.68	(0.33 to 1.40)	0.69	(0.33 to 1.44)
RR/10 µT.y††		0.86	(0.71 to 1.04)	0.88	(0.72 to 1.07)
All other causes:‡‡					
0–2.4	6055	1.0		1.0	
2.5–4.9	1581	1.20***	(1.14 to 1.27)	1.07*	(1.01 to 1.14)
5.0–9.9	2568	1.11***	(1.06 to 1.16)	0.97	(0.92 to 1.02)
10.0–19.9	2243	1.10***	(1.04 to 1.15)	0.96	(0.91 to 1.01)
⩾20.0	702	0.95	(0.88 to 1.03)	0.88**	(0.82 to 0.96)
RR/10 µT.y††		1.00	(0.98 to 1.01)	0.96***	(0.95 to 0.98)

*p<0.05; **p<0.01; ***p<0.001.
†1 Year refers to a working year, approx. 250 8 hour shifts.
‡Analysed simultaneously with sex and attained age.
§Analysed simultaneously with sex, attained age, calendar period, year of starting employment, and negotiating body. For levels, see table 1.
¶Any part of death certificate coded to ICD-9 191,192, 225, 237.5, or 237.6.
††Five exposure categories scored by the mean value in each category, namely 0.36, 3.67, 7.24, 13.93, 38.53 µT.y. See text for details.
‡‡No part of death certificate coded to ICD-9 191,192, 225, 237.5, or 237.6.

Table 4 Relative risks of mortality from brain tumours and all other causes by levels of estimated exposure to magnetic fields received in preceding 5 years (four separate analyses), study of United Kingdom electricity generation and transmission workers, 1973–94

Exposure to magnetic field received in preceding 5 years (µT.y)†	*n*	*RR‡*	*(95% CI)*	*RR§*	*(95% CI)*
Brain tumours:¶					
Zero	86	1.0		1.0	
0.01–0.49	17	0.94	(0.56 to 1.59)	0.99	(0.58 to 1.69)
0.5–1.9	13	0.95	(0.53 to 1.72)	0.98	(0.54 to 1.81)
2.0–4.9	6	0.63	(0.27 to 1.45)	0.64	(0.28 to 1.50)
⩾5.0	2	0.40	(0.10 to 1.63)	0.42	(0.10 to 1.74)
RR/µT.y††		0.91	(0.81 to 1.03)	0.92	(0.82 to 1.03)
All other causes:‡‡					
Zero	7503	1.0		1.0	
0.01–0.49	1159	1.04	(0.97 to 1.10)	0.94	(0.88 to 1.00)
0.5–1.9	668	0.93	(0.86 to 1.01)	0.82***	(0.75 to 0.89)
2.0–4.9	374	0.82***	(0.74 to 0.91)	0.72***	(0.65 to 0.81)
⩾5.0	187	0.82**	(0.71 to 0.95)	0.72***	(0.62 to 0.83)
RR/µT.y††		0.98***	(0.96 to 0.99)	0.96***	(0.95 to 0.97)

*p<0.05; **p<0.01; ***p<0.001.
†1 Year refers to a working year, about 250 8 hour shifts.
‡Analysed simultaneously with sex and attained age.
§Analysed simultaneously with sex, attained age, calendar period, year of starting employment, and negotiating body. For levels, see table 1.
¶Any part of death certificate coded to ICD-9 191,192, 225, 237.5, or 237.6.
††Five exposure categories scored by the mean value in each category—namely, 0.0, 0.19, 1.14, 3.16, and 11.40 µT.y. See text for details.
‡‡No part of death certificate coded to ICD-9 191,192, 225, 237.5, or 237.6.

adjusted for age and sex only and when further adjustments were carried out.

Information on brain tumours obtained from the survey death certificates was compared with corresponding information obtained from cancer registration particulars. Of the 163 deaths with brain tumours, corresponding registration particulars were obtained for 158 subjects of which 152 (96%) were recorded as brain tumours.

Discussion

This large cohort of United Kingdom electricity generation and transmission workers did not have significantly increased mortalities from brain cancer, on the basis of comparisons with national mortalities. Also there were no indications of risks of brain tumour increasing with increasing exposure to magnetic fields, irrespective of whether lifetime or recent exposure was considered.

The style of exposure assessment recognises that the main source of exposure to magnetic field in a power station is proximity to the main generator connections, and consequently, that the physical layout of departments in power stations will be highly relevant. Also, the assessments recognise that exposures will depend on the variable power output of the station. In short, the assessments have used the physics of exposure to magnetic fields as a starting point. Some early validation work on the power station model has already been completed (D C Renew, personal communication). Some 4200 personal full shift magnetic field measurements were taken in the period January to July 1999 for employees at three power stations. Mean measured exposures to magnetic fields were then calculated from these data for 29 job-facility combinations. Corresponding predicted values were obtained from the exposure model; there was a significant correlation (p<0.05) between the predicted and measured mean fields. It is recognised that the exposure assessments for transmission workers (5.7% of the cohort) do not involve a similar degree of complexity, although treating non-operational jobs as unexposed should not have introduced bias into the study because it is only unusual (or non-background) exposures which are being considered for the operational jobs. Some limitations have to be attached, however, to our use of the exposure assessments and these have been described previously.[5]

The study cohort comprised an entry (inception) cohort and a survivor population. Although it would have been preferable to have had a study in which the entry cohort dominated the study findings, the survivor population subcohort currently contributes some 85% of the deaths from all causes currently available for analysis. Poisson regression analyses for all causes of death other than brain tumours were carried out so that the usefulness of the explanatory variables could be assessed. It seemed highly unlikely that exposure to magnetic fields could have a discernible influence on mortality in general, so that a significant negative or positive trend for this overall disease grouping might indicate that some selection or social class effect was not being adjusted for, although with such large numbers of deaths available for this analysis, small differences in risk ratios can be highly significant. The negative trend shown for this disease grouping and lifetime occupational exposure to magnetic fields after adjustment for socioeconomic category (negotiating body) is probably due to a selection effect. A particular form of the survivor population effect may be present. Perhaps workers who stay in the industry doing jobs with higher exposures have to be fitter than workers remaining in other jobs. Alternatively, there may be residual negative confounding from social class effects.

Risks of brain tumour relative to estimated cumulative exposure to magnetic fields have been studied in other cohorts of electric utility workers. The Southern California Edison study[10] and the Canada-France study[11] both provided findings consistent with those reported here. The United States five utility study[12] provided positive findings; but given the results from the other studies, these positive findings may well be due to chance. The unexceptional SMR of 95 shown for brain cancer in the United States cohort is consistent with such an assessment.

In conclusion, this large cohort study provides no evidence that United Kingdom electricity generation and transmission workers have an excess risk of brain tumours as a consequence of occupational exposure to magnetic fields.

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