C A N A D A

PROVINCE OF QUEBEC

DISTRICT OF MONTREAL

DOCKET No. R-3770-2011

RÉGIE DE L'ÉNERGIE / ENERGY BOARD

AUTHORIZATION OF AN INVESTMENT BY HYDRO-QUEBEC DISTRIBUTION – ADVANCED METERING PROJECT PHASE 1

HYDRO-QUEBEC
As Electricity Distributor

Petitioner

-and-

STRATEGIES ENERGETIQUES (S.E.) / ENERGY STRATEGIES (E.S.)

ASSOCIATION QUEBECOISE DE LUTTE CONTRE LA POLLUTION ATMOSPHERIQUE (AQLPA) / QUEBEC ASSOCIATION TO FIGHT AGAINST AIR POLLUTION

Interveners

H. DOLK, G. SHADDICK, P. WALLS, C. GRUNDY, B. THAKRAR, I. KLEINSCHMIDT, P. ELLIOTT

Cancer Incidence near radio and television transmitters in Great Britain. I – Sutton-Colfield transmitter, and II. Al high-power transmitters, Am J Epidemiol 1997; 145(1):1-9 and 10-17

Part I : http://aje.oxfordjournals.org/content/145/1/1.full.pdf

Part II: http://aje.oxfordjournals.org/content/145/1/10.full.pdf

In the first study, there was a statistically significant increase in cancer; in the second, a small but significant increase in adult leukemia.

Referred to in **David O. CARPENTER**, *Expert Report*, Revised on May 14, 2012, C-SE-AQLPA-0072, SE-AQLPA-7, Doc. 1.1, parag. 38.
Filed on May 14, 2012

American Journal of
EPIDEMIOLOGY

Volume 145
Number 1
January 1, 1997

Copyright © 1997 by The Johns Hopkins University
School of Hygiene and Public Health

Sponsored by the Society for Epidemiologic Research

ORIGINAL CONTRIBUTIONS

Cancer Incidence near Radio and Television Transmitters in Great Britain

I. Sutton Coldfield Transmitter

Helen Dolk,[1] Gavin Shaddick,[1] Peter Walls,[1] Chris Grundy,[1] Bharat Thakrar,[1] Immo Kleinschmidt,[1] and Paul Elliott[2]

A small area study of cancer incidence in 1974–1986 was carried out to investigate an unconfirmed report of a "cluster" of leukemias and lymphomas near the Sutton Coldfield television (TV) and frequency modulation (FM) radio transmitter in the West Midlands, England. The study used a national database of postcoded cancer registrations, and population and socioeconomic data from the 1981 census. Selected cancers were hematopoietic and lymphatic, brain, skin, eye, male breast, female breast, lung, colorectal, stomach, prostate, and bladder. Expected numbers of cancers in small areas were calculated by indirect standardization, with stratification for a small area socioeconomic index. The study area was defined as a 10 km radius circle around the transmitter, within which 10 bands of increasing distance from the transmitter were defined as a basis for testing for a decline in risk with distance, and an inner area was arbitrarily defined for descriptive purposes as a 2 km radius circle. The risk of adult leukemia within 2 km was 1.83 (95% confidence interval 1.22–2.74), and there was a significant decline in risk with distance from the transmitter ($p = 0.001$). These findings appeared to be consistent over the periods 1974–1980 and 1981–1986, and were probably largely independent of the initially reported cluster, which appeared to concern mainly a later period. In the context of variability of leukemia risk across census wards in the West Midlands as a whole, the Sutton Coldfield findings were unusual. A significant decline in risk with distance was also found for skin cancer, possibly related to residual socioeconomic confounding, and for bladder cancer. Study of other radio and TV transmitters in Great Britain is required to put the present results in wider context. No causal implications can be made from a single cluster investigation of this kind. *Am J Epidemiol* 1997;145:1–9.

electromagnetic fields; leukemia; neoplasms; radio waves

There has been considerable public and scientific debate concerning the possible adverse health effects associated with environmental exposure to extremely low frequency (0–300 Hz) non-ionizing radiation, as emitted by power cables and electric substations (1–5). Exposure to extremely low frequency radiation has most commonly been associated with leukemia, particularly acute myeloid and childhood leukemia, and also brain cancer, male breast cancer, and skin and eye melanoma (1, 3, 6–12), although there is currently no agreement as to causality (2–5).

Far less attention has been paid to environmental

Received for publication December 13, 1995, and accepted for publication August 12, 1996.

Abbreviations: CI, confidence interval; erp, effective radiated power; FM, frequency modulation; ICD, *International Classification of Diseases*; O/E ratio, observed/expected ratio; TV, television.

[1] Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, London, England.

[2] Small Area Health Statistics Unit, Department of Epidemiology and Public Health, Imperial College of Science, Technology and Medicine, Imperial College School of Medicine at St Mary's, London, England.

Reprint requests to Dr. Helen Dolk, Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1 7HT, England.

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

exposure to radiation in the radiofrequency range (100 kHz to 300 GHz), including television (TV) and frequency modulation (FM) broadcast frequencies (30 MHz to 1 GHz), at field strengths below those required to produce thermal effects. The few epidemiologic studies that have reported on cancer incidence in relation to radiofrequency radiation (mainly from occupational exposure including microwave and radar) have generally presented negative or inconsistent results, or were subject to possible confounding from other exposures (2, 13–22). A study of residential exposure in Hawaii examined cancer incidence for census tracts with broadcasting antennae (22). A significantly increased relative risk of all cancers was found (standard incidence ratio (SIR) = 1.36 based on 905 cases, $p < 0.01$), and there was a nonsignificant excess of leukemias (SIR = 1.56 based on 23 cases, $p > 0.01$). However, there was only limited control for possible confounding.

Nevertheless, concerns have been expressed about the possible health effects of living near high power radio transmitters. Following a claim (see Appendix) of an excess of cases of leukemia and lymphoma near the Sutton Coldfield radio and television transmitter in the West Midlands, England, the Small Area Health Statistics Unit in the United Kingdom (23) was asked to investigate the incidence of selected cancers in the vicinity. The results of those analyses are reported here.

MATERIALS AND METHODS

The Sutton Coldfield transmitter is sited at the northern edge of the city of Birmingham. It first came into service in 1949 for television. High power transmission at 1 megawatt effective radiated power (erp) per frequency began with one frequency in 1964, rose to 3 frequencies in 1969, and then 4 frequencies in 1982. Three frequencies of very high frequency (VHF) radio began in 1957, at 250 kW erp per frequency. The mast is 240 m high. There are no big hills (above the height of the transmitter) in the study area. Nearby industrial processes registered with Her Majesty's Inspectorate of Pollution include a mineral works 3 km east, a copper works 6.5 km west, and a lead works 7 km west (Department of the Environment, personal communication, 1993).

Cancer incidence data postcoded to address at diagnosis were examined from 1974 to 1986. Population statistics were from the 1981 census enumeration districts and wards. The study area was defined by a circle of 10 km radius centered on the transmitter, grid reference SK 113003 (figure 1). The population within 10 km was around 408,000. Within the study area, ten bands of outer radius 0.5, 1, 2, 3, 4.9, 6.3, 7.4, 8.3, 9.2, and 10 km were defined (giving equal areas beyond 3 km). Populations and cases were located in the study area via the postcode of residence (which refers to an average of 14 households in Great Britain) according to methods described elsewhere (23). The completeness of postcoding of cancer registrations is high both nationally (96.6 percent) and in the West Midlands region (98.7 percent).

The following cancers at ages 15 years and over were considered as a priori groupings according to the 8th and 9th revisions of the *International Classification of Diseases* (ICD):

1) all cancers, excluding non-melanoma skin cancer (ICD-8/9 code 173);

2) cancers of the type stated in the initial cluster report, i.e., hematopoietic and lymphatic cancers: all leukemias (ICD-8/9 code 204–207 + ICD-9 code 208); multiple myeloma (ICD-8/9 code 203 + ICD-9 code 238.6), non-Hodgkin's lymphoma (ICD-8/9 code 200 + ICD-8 code 202 + ICD-9 codes 202.0, 201.1, 202.8); all hematopoietic and lymphatic (all leukemias, multiple myeloma, non-Hodgkin's lymphoma and ICD-8/9 code 201); all leukemias and non-Hodgkin's lymphoma combined; all leukemias; acute leukemia, i.e., acute myeloid leukemia (205.0) and acute lymphatic leukemia (204.0) separately, and combined with ICD-8/9 code 206.0 + ICD-9 codes 204.2, 205.2, 206.2, 208.0, 208.2 + ICD-8 code 207.0; chronic myeloid leukemia (205.1); chronic lymphatic leukemia (204.1);

3) cancers possibly associated with non-ionizing radiation (1, 3, 6–12), i.e., malignant brain and nervous system cancers (ICD-8/9 codes 191, 192); brain and nervous system cancers of malignant, benign, and uncertain behavior (ICD-8/9 codes 191, 192 + ICD-8/9 code 225 + ICD-9 codes 237.5, 237.6, 237.9); skin melanoma (ICD-8/9 code 172); eye (mainly melanoma) (ICD-8/9 code 190); male breast (ICD-8 codes 174.0–2, ICD-9 code 175);

4) common cancers (examined separately), i.e., lung (162), colon (ICD-8 codes 153.0–3, 153.7–8, ICD-9 code 153), rectal (154), colorectal (colon + rectal), stomach (ICD-8/9 code 151), bladder (ICD-8/9 code 188), prostate (ICD-8/9 code 185), female breast (ICD-8 codes 174.0–2, ICD-9 code 174).

Childhood cancer (0–14 years) was restricted to all cancers and all leukemias.

To allow for possible socioeconomic confounding, a deprivation score, shown elsewhere to be a powerful predictor of cancer rates (24), was calculated for each census enumeration district in Great Britain using 1981 census data on unemployment, overcrowding, and social class of head of household. The scores were grouped into quintiles, with a small sixth category for unclassifiable enumeration districts, mostly with institutional populations. According to this deprivation score, the areas closer to the transmitter were more affluent than those further away, i.e., at 1–2 km, 67 percent of the population was in the two most affluent

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

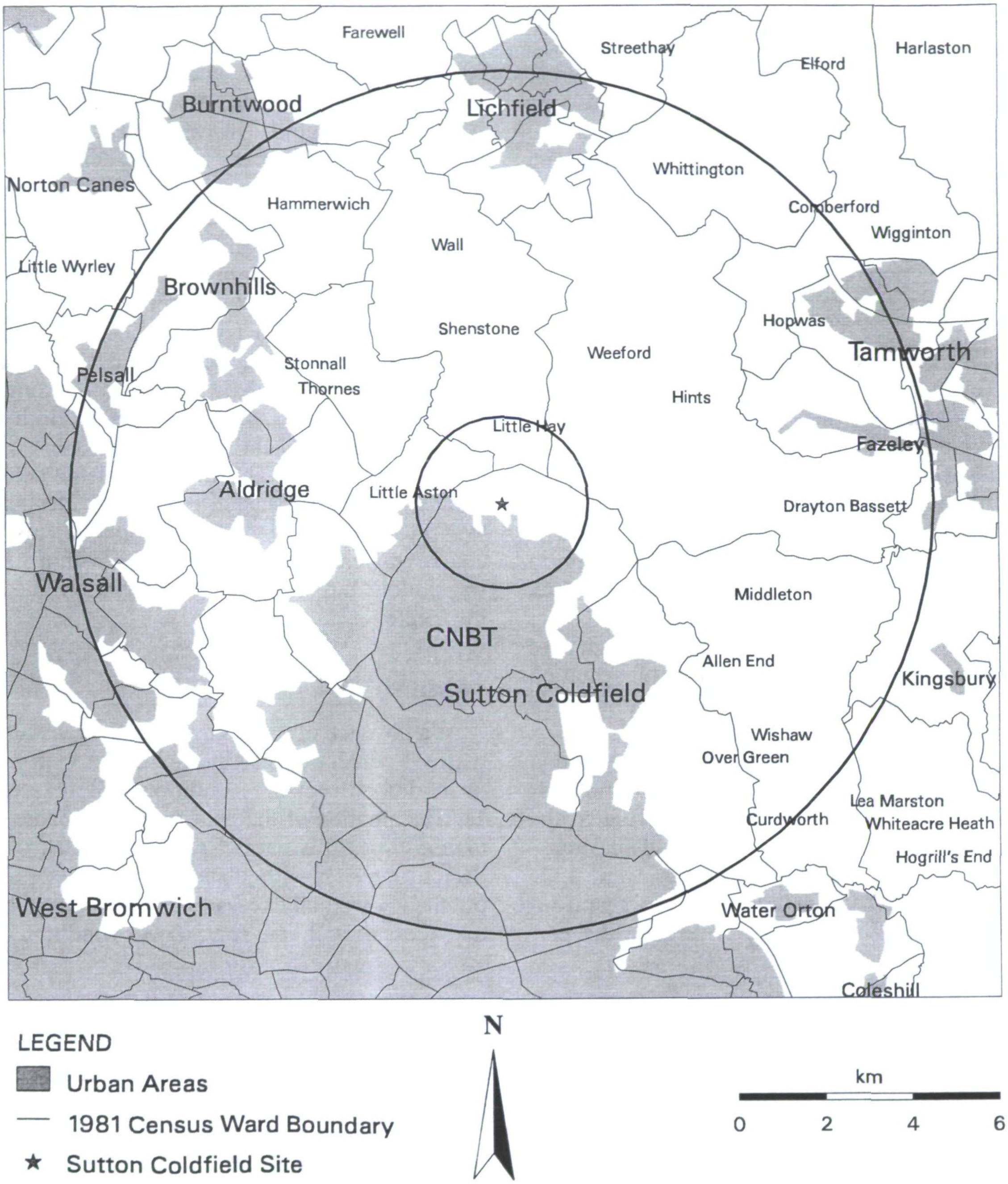

FIGURE 1. Map of 2 and 10 km circles surrounding Sutton Coldfield television and FM radio transmitter, showing position of census ward "CNBT." (Map data copyright Automobile Association.)

quintiles, compared with 28 percent at 9.2–10 km. For many cancers (e.g., lung), lower incidence rates would be expected in the more affluent areas; for some other cancers (e.g., leukemia), there is essentially no relation between incidence and deprivation thus measured, whereas for others (e.g., skin melanoma), higher disease rates are found in the more affluent areas (24).

Statistical analysis was based on the comparison of observed and expected numbers of cancer cases; the expected numbers were calculated from national incidence rates stratified by 5-year age group, sex, year, and deprivation quintile, and regionally adjusted, as described in detail elsewhere (25). Compared with national rates, the West Midlands region had standardized incidence ratios of 0.95 for all cancers and 0.80 for leukemias (0.65 for chronic lymphatic leukemia).

For descriptive purposes, observed and expected values, observed/expected (O/E) ratios, and their 95

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

percent confidence intervals (calculated assuming a Poisson distribution) are reported for the entire study area (0–10 km) and for an area close to the source, arbitrarily chosen to be 0–2 km. Formal tests of significance were based on those proposed by Stone (26) for isotonic decline in risk with distance from the source. These tests give due weight to the smaller populations near the site, and do not prespecify the shape of the decline, or boundaries between "exposed" and "unexposed" populations. Both an unconditional and a conditional test were performed (25, 27, 28). For the unconditional test, the null hypothesis is that the relative risk is one in each of the bands. An isotonic alternative includes any pattern of non-increasing risk over the study area. The data were further explored by use of the conditional test that corrects for the overall level of risk over the 10 km study area, thereby specifying a null hypothesis where all relative risks are equal to a constant, not necessarily one (25, 27). Significance levels were obtained by Monte Carlo methods based on 999 simulations and the nominal statistical significance level taken to be $p = 0.05$. Stone's tests were in all cases performed on the data in the ten predefined distance bands. For presentation purposes only, we give some data collapsed into four distance bands.

A geographic analysis to investigate the background variability of leukemia incidence in the West Midlands region was also done, in order to place in context the size of any excess found in the vicinity of the transmitter. This analysis was done at census ward level relating to around 10,000 people on average and included supplementary postcoding to reduce the percentage of unpostcoded cases of leukemias from 2.5 percent to 0.3 percent. Observed and expected numbers per ward were calculated as for the main analysis. Departure from Poisson variability was tested by the Pothoff-Whittinghill test (29) and a 5th to 95th percentile range in O/E ratios was calculated using a likelihood method that removes the random component of variability (30). O/E ratios were "smoothed" using an empirical Bayesian method (31). This method produces a set of smoothed estimates on the basis of a compromise between the observed relative risks and the overall regional mean, with the amount of "shrinkage to the mean" being determined by the population size of each ward, thereby removing variability in O/E ratios due to small population sizes. Both raw and smoothed values of the O/E ratio for each of the 832 wards were ranked, and the rank of the census ward containing the transmitter (ward designated as "CNBT" in figure 1) was determined. This ward included 90 percent of the population within 2 km of the transmitter, but with half its population outside the 2 km circle.

RESULTS

At a distance of 0–10 km from the transmitter, there was a 3 percent excess in all cancers with significant unconditional but not conditional Stone's test (table 1). Examination of the data for all ten bands (table 2) demonstrates this overall excess but lack of trend of decreasing risk with distance. Non-Hodgkin's lymphoma showed an excess from 0–10 km (table 1) but no excess at 0–2 km. The Stone's conditional test and

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

TABLE 1. Selected cancers near the Sutton Coldfield transmitter, West Midlands, England: observed and expected numbers of cases, observed/expected (O/E) ratios, and 95% confidence intervals (CI), by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Type of cancer	Distance from transmitter (km) 0–2				0–10				Stone's p value*	
	Observed	Expected	O/E ratio	95% CI	Observed	Expected	O/E ratio	95% CI	U	C
All cancers†	703	647.49	1.09	1.01–1.17	17,409	16,861.22	1.03	1.02–1.05	0.001	0.462
Hematopoietic and lymphatic	45	37.08	1.21	0.91–1.62	935	895.83	1.04	0.98–1.11	0.153	
All leukemias and non-Hodgkin's lymphomas	31	24.76	1.25	0.88–1.78	661	592.84	1.11	1.03–1.20	0.018	0.161
All leukemias	23	12.59	1.83	1.22–2.74	304	302.34	1.01	0.90–1.13	0.001	0.001
All acute	10	5.38	1.86	0.89–3.42	116	131.75	0.88	0.73–1.06	0.003	0.004
Acute myeloid	4	3.94	1.02	0.28–2.60	81	95.60	0.85	0.68–1.05	0.024	0.045
Acute lymphatic	3	0.84	3.57	0.74–10.43	21	20.62	1.02	0.67–1.56	0.201	
Chronic myeloid	2	1.63	1.23	0.15–4.43	42	39.95	1.05	0.78–1.42	0.257	
Chronic lymphatic	8	3.12	2.56	1.11–5.05	96	72.56	1.32	1.08–1.62	0.002	0.007
Non-Hodgkin's lymphomas	8	12.17	0.66	0.28–1.30	357	290.50	1.23	1.11–1.36	0.005	0.958
Multiple myeloma	10	6.51	1.54	0.74–2.83	174	154.52	1.13	0.97–1.31	0.156	

* p values given by Stone's unconditional (U) and conditional (C) tests.
† All cancers excluding non-melanoma skin cancer.

TABLE 2. All cancers, all leukemias, and non-Hodgkin's lymphomas near the Sutton Coldfield transmitter, West Midlands, England: observed and expected numbers of cases, observed/expected (O/E) ratios, and cumulative O/E ratios, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Distance from transmitter (km)	All cancers*				All leukemias				Non-Hodgkin's lymphomas			
	Observed	Expected	O/E ratio	Cumulative O/E ratio	Observed	Expected	O/E ratio	Cumulative O/E ratio	Observed	Expected	O/E ratio	Cumulative O/E ratio
0–0.5	2	5.61	0.36	0.36	1	0.11	9.09	9.09	0	0.11	0.00	0.00
0.5–1.0	96	137.19	0.70	0.69	5	2.72	1.84	2.12	3	2.60	1.15	1.11
1.0–2.0	605	504.59	1.20	1.09	17	9.76	1.74	1.83	5	9.46	0.53	0.66
2.0–3.0	282	279.01	1.01	1.06	9	5.56	1.62	1.76	9	5.76	1.56	0.95
3.0–4.9	1,002	1,050.86	0.95	1.00	25	20.22	1.24	1.49	20	20.25	0.99	0.97
4.9–6.3	2,414	2,301.25	1.05	1.03	54	41.96	1.29	1.38	45	40.60	1.11	1.04
6.3–7.4	2,734	2,650.62	1.03	1.03	48	46.54	1.03	1.25	57	43.95	1.30	1.13
7.4–8.3	2,827	2,798.65	1.01	1.02	51	49.22	1.04	1.19	52	47.19	1.10	1.12
8.3–9.2	3,363	3,213.75	1.05	1.03	40	57.35	0.70	1.07	80	54.56	1.47	1.21
9.2–10	4,084	3,919.59	1.04	1.03	54	68.90	0.78	1.01	86	66.02	1.30	1.23

* All cancers excluding non-melanoma skin cancer.

examination of the data over the ten bands (table 2) do not indicate a decline in risk with distance. Excesses within 2 or 10 km of the transmitter for hematopoietic and lymphatic cancers and multiple myeloma, were not statistically significant (table 1), nor was there evidence of a significant decline in risk with distance.

For adult leukemias from 0–2 km, the O/E ratio was 1.83 (95 percent confidence interval (CI) 1.22–2.74), based on 23 cases (table 1). The Stone's tests indicated a significant ($p = 0.001$) decline in risk with distance; data for all ten bands (table 2) were consistent with a decline in risk extending over the entire 10 km. Risk fell below 1.0 in the outer bands so that there was no overall excess over the 10 km area (O/E ratio = 1.01, 95 percent CI 0.90–1.13) (table 1). A pattern of decline with significant Stone's conditional tests was also found at ages 15–64 and ≥65 years, and for each sex separately (table 3). Acute leukemias, acute myeloid leukemia, and chronic lymphatic leukemia showed significant declines in risk with distance, as indicated by Stone's tests (table 1) and inspection of the data (table 4).

The leukemia excess at 0–2 km was apparent in both the earlier (1974–1980) and later (1981–1986) periods; there were 11 leukemia cases in the first period and 12 leukemia cases in the second period, and O/E ratios of 1.80 and 1.85, respectively. Stone's tests were significant in both periods. Twenty-one of the 23 cases within 2 km are known to have died, as verified by death certificates, and all but one had died by 1988. The stated occupations at diagnosis of the 23 adult leukemia cases were as follows: of 10 females, 4 housewives, 1 clerk/cashier, and 5 unstated; of 13 males, 2 clerk/cashiers, 3 managers, 1 printer, 1 gardener, 1 teacher, 1 farmer, 1 driver/foreman of roads goods vehicles, 1 inadequately described, and 2 unstated.

Among children, there were 97 cancers within 0–10 km of the transmitter (106.1 expected), including 34 leukemia cases (29.7 expected), of which 2 cases were at 0–2 km (1.1 expected); Stone's tests were not significant (leukemia conditional test $p = 0.173$).

Among other adult cancers, there was a significant decline in risk for skin melanoma and for bladder

TABLE 3. Leukemia near the Sutton Coldfield transmitter, West Midlands, England, by age and sex: observed and expected numbers of cases, observed/expected (O/E) ratios, and 95% confidence intervals (CI), by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Sex and age (years)	Distance from transmitter (km): 0–2				Distance from transmitter (km): 0–10				Stone's p value*	
	Observed	Expected	O/E ratio	95% CI	Observed	Expected	O/E ratio	95% CI	U	C
Both sexes										
15–64	10	4.75	2.11	1.01–3.87	132	121.71	1.08	0.91–1.29	0.003	0.001
≥65	13	7.84	1.66	0.97–2.84	172	180.63	0.95	0.82–1.11	0.009	0.008
Males										
≥15	13	6.72	1.93	1.13–3.31	162	164.72	0.98	0.84–1.15	0.002	0.000
Females										
≥15	10	5.86	1.71	0.82–3.14	142	137.60	1.03	0.88–1.22	0.014	0.006

* p values given by Stone's unconditional (U) and conditional (C) tests.

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

TABLE 4. Acute leukemias and acute myeloid, acute lymphatic, chronic myeloid, and chronic lymphatic leukemias near the Sutton Coldfield transmitter, West Midlands, England: observed numbers of cases and observed/expected (O/E) ratios, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Leukemia subtype	Distance from transmitter (km)							
	0–2		2–4.9		4.9–7.4		7.4–10	
	Observed	O/E ratio	Observed	O/E ratio	Observed	O/E ratio	Observed	O/E ratio
Acute leukemias	10	1.86	11	0.95	38	0.99	57	0.75
Acute myeloid	4	1.02	8	0.97	28	1.00	41	0.74
Acute lymphatic	3	3.57	3	1.52	5	0.83	10	0.85
Chronic myeloid	2	1.23	3	0.87	19	1.62	18	0.78
Chronic lymphatic	8	2.56	14	2.31	27	1.27	47	1.12

cancer (table 5), although point estimates of O/E ratios were not in excess within 1 km for these cancers (table 6); none of the other Stone's tests were significant.

The ward level geographic analysis of adult leukemia in the West Midlands region showed significant extra-Poisson variability (Pothoff-Whittinghill z = 2.67, p = 0.004). The 5th to 95th percentile range of O/E ratios was estimated as 0.70 to 1.35 after removing random fluctuation. Census ward "CNBT," containing 90 percent of the population within 2 km of the transmitter, had a raw O/E ratio of 1.55, which ranked 154 out of 832 wards. After smoothing, the ratio was 1.25, ranking second. The highest ranking ward for smoothed values had 26 observed cases and a raw O/E ratio of 1.74, which after smoothing was reduced to 1.26. This analysis therefore indicates that the excess in the 0–2 km circle around Sutton Coldfield, with 23 cases observed and 12.6 expected, was unusual, even in the presence of significant geographic variation in leukemia incidence in the West Midlands region. However, the magnitude of excess was not much greater than that found elsewhere in the region.

DISCUSSION

The main finding was the confirmation of a reported excess of leukemias near the Sutton Coldfield radio and television transmitter, and a decline in risk with distance from the site. Because all but one of the leukemia cases included in our study had died by 1988, this would seem to be independent of the seven apparently current cases reported in the media in 1992, although unfortunately further details of those cases were not made available to us or to the health authorities. Our findings appear to be consistent over two independent time periods (1974–1980 and 1981–

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

TABLE 5. Other cancers near the Sutton Coldfield transmitter, West Midlands, England: observed and expected numbers of cases, observed/expected (O/E) ratios, and 95% confidence intervals (CI), by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Type of cancer	Distance from transmitter (km)								Stone's p value*	
	0–2				0–10					
	Observed	Expected	O/E ratio	95% CI	Observed	Expected	O/E ratio	95% CI	U	C
Cancers possibly associated with non-ionizing radiation										
Brain										
Malignant and benign	17	13.20	1.29	0.80–2.06	332	317.74	1.04	0.94–1.16	0.612	
Malignant	12	9.18	1.31	0.75–2.29	218	223.27	0.98	0.86–1.11	0.717	
Skin melanoma	13	9.10	1.43	0.83–2.44	189	196.53	0.96	0.83–1.11	0.027	0.018
Eye melanoma	0	0.71	0	0–4.22	20	17.19	1.16	0.75–1.80	0.849	
Male breast	1	0.61	1.64	0.04–9.13	15	15.08	0.99	0.60–1.64	0.889	
Common cancers										
Female breast	107	98.67	1.08	0.90–1.31	2,412	2,288.30	1.05	1.01–1.10	0.131	
Lung	113	112.31	1.01	0.84–1.21	3,466	3,418.60	1.01	0.98–1.05	0.875	
Colorectal	112	99.48	1.13	0.94–1.35	2,529	2,454.93	1.03	0.99–1.07	0.330	
Stomach	33	43.75	0.75	0.54–1.06	1,326	1,248.40	1.06	1.01–1.12	0.246	
Prostate	37	32.81	1.13	0.82–1.55	785	760.45	1.03	0.96–1.11	0.466	
Bladder	43	28.37	1.52	1.13–2.04	788	728.96	1.08	1.01–1.16	0.008	0.040

* p values given by Stone's unconditional (U) and conditional (C) tests.

TABLE 6. Skin melanoma and bladder cancers in the vicinity of the Sutton Coldfield transmitter, West Midlands, England: observed and expected numbers of cases, observed/expected (O/E) ratios, and cumulative O/E ratios, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Distance from transmitter (km)	Skin melanoma				Bladder cancer			
	Observed	Expected	O/E ratio	Cumulative O/E ratio	Observed	Expected	O/E ratio	Cumulative O/E ratio
0–0.5	0	0.09	0.00	0.00	0	0.24	0.00	0.00
0.5–1.0	2	2.02	0.99	0.95	4	5.96	0.67	0.65
1.0–2.0	11	6.99	1.57	1.43	39	22.17	1.76	1.52
2.0–3.0	12	5.03	2.39	1.77	11	11.94	0.92	1.34
3.0–4.9	16	16.16	0.99	1.35	43	45.27	0.95	1.13
4.9–6.3	26	28.77	0.90	1.13	119	100.31	1.19	1.16
6.3–7.4	28	27.93	1.00	1.09	131	114.85	1.14	1.15
7.4–8.3	32	30.90	1.04	1.08	117	120.64	0.97	1.10
8.3–9.2	28	35.66	0.79	1.01	169	140.13	1.21	1.13
9.2–10	34	43.08	0.79	0.96	155	167.45	0.93	1.08

1986). Within the context of some unexplained variability in leukemia incidence across census wards in the West Midlands region, the excess near Sutton Coldfield can be considered unusual.

Possible methodological artefacts to explain the leukemia findings were explored. First, the lower registration of cancers, and particularly leukemias, in West Midlands relative to the country as a whole, is unexplained, but there was no suggestion that the level of registration varied systematically within the region; nor would it seem likely that any such registration artefact could produce local trends in risk of the order seen around Sutton Coldfield. Second, there are known problems of leukemia diagnosis and registration, particularly at older ages, but we found similar results in the younger and older age groups. Third, the study spanned 1974–1986, but relied on population data from the 1981 census, i.e., around the midpoint of the study period. Estimates were made of the extent to which population change over the period (including ageing of the population) may have led to bias in the calculation of the expected numbers of cancers. Based on data from the 1971 and 1991 censuses, there appeared to be a tendency for overestimation of the O/E ratios close to the site (within 2 km), but the bias, estimated at less than 5 percent, was not sufficient to explain the excesses of leukemia observed.

Secondary findings of the study were declines in skin melanoma and bladder cancer with distance from the transmitter site. Because skin melanoma is strongly inversely related to level of deprivation (24), and because this transmitter is located in a relatively affluent area, control for socioeconomic confounding, as expected, reduced the size of the excess—by 11 percent within 2 km. However, it is possible that further socioeconomic confounding could explain at least part of the residual excess of skin melanoma near the site. Bladder cancer was examined along with other causes to explore the small general excess in all cancers, and there was no a priori hypothesis linking it to the exposure under consideration. The results should be viewed in the context of the large number of statistical tests performed and hence may be chance findings.

Field strength measurements have been made in the vicinity of the transmitter (British Broadcasting Corporation, internal report, 1994). In general, both measured and predicted field strength values tended to show a decline in average field strength or power density with distance from the transmitter, although there are undulations in predicted field strength up to distances of about 6 km from the transmitter resulting from the vertical radiation pattern. The maximum total power density equivalent summed across frequencies at any one measurement point (at 2.5 m above ground) was 0.013 W/m^2 for TV, and 0.057 W/m^2 for FM. However, there was considerable variability between different measurement points at any one distance from the transmitter, as would be expected from the impact of reflections from the ground and buildings, and this variability was as great as that related to distance. Power density on average declines by a factor of at least 5 to 10 over 10 km. Field strength varies as the square root of power density, thus declining less steeply, and it is not clear which exposure measure would be biologically more relevant for athermal effects. These measurements cannot of course be converted to personal dose to residents, which depends on numerous factors, including building type, the amount of time spent inside the home as well as away from home, and the number of years spent at the residence. It can nevertheless be assumed that, on average, residents in higher exposure areas receive higher doses unless this is obscured by the combination of patterns

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

of population density and of variable field strengths at any one distance from the transmitter. The exposures near Sutton Coldfield appear to be much lower than those in other epidemiologic studies where the health effects of radiofrequency exposure have been examined (2, 13, 14, 22). They are well within current guidelines based on the thermal effects of radiofrequency exposure (15, 32).

In conclusion, the results of this study confirm that there was an excess of adult leukemia within the vicinity of the Sutton Coldfield TV/FM transmitter in the period 1974–1986, accompanied by a decline in risk with distance from the transmitter. Further monitoring of cancer statistics in the area appears warranted. No causal implications regarding radio and TV transmitters can be drawn from this finding, based as it is on a single "cluster" investigation. Results of a study of cancer incidence around all other high power radio and TV transmitters in Great Britain are given in the accompanying paper (33) in order to put the present results in wider context.

ACKNOWLEDGMENTS

The Small Area Health Statistics Unit is funded by grants from the Department of Health, Department of the Environment, Health and Safety Executive, Scottish Office Home and Health Department, Welsh Office, and Northern Ireland Department of Health and Social Services.

The authors thank the Office of Population Censuses and Surveys (OPCS) (now the Office of National Statistics) and the Information and Statistics Division of the Scottish Health Service, who made the postcoded cancer data available. They also thank OPCS for checking registration details of specific cases and for providing copies of death certificates. They are grateful to the West Midlands cancer registry for checking individual cases. In addition, they acknowledge the cooperation of the British Broadcasting Corporation for providing field measurements and predicted field strengths in the area of the Sutton Coldfield transmitter.

REFERENCES

1. Electromagnetic fields and the risk of cancer. Report of an advisory group on non-ionising radiation. Documents of the NRPB. Vol 3, no. 1. London: National Radiation Protection Board, 1992.
2. Dennis JA, Muirhead CR, Ennis JR. Human health and exposure to electromagnetic radiation. National Radiation Protection Board, Report NRPB-R241, July 1992.
3. Thériault GP. Health effects of electromagnetic radiation on workers: epidemiologic studies. In: Bierbaum PJ, Peters JM, eds. Proceedings of the Scientific Workshop on the Health Effects of Electric and Magnetic Fields on Workers, January 30–31, 1991. Cincinnati, OH: US Department of Health and Human Services, 1991. (DHHS (NIOSH) publication no. 91-111):91–124.
4. Cartwright RA. Low frequency alternating electromagnetic fields and leukaemia: the saga so far. Br J Cancer 1989;60: 649–51.
5. Coleman B, Beral V. A review of epidemiological studies of the health effects of living near or working with electricity generation and transmission equipment. Int J Epidemiol 1988; 17:1–13.
6. Guénel P, Raskmark P, Anderson JB, et al. Incidence of cancer in persons with occupational exposure to electromagnetic fields in Denmark. Br J Ind Med 1993;50:758–64.
7. Demers PA, Thomas DB, Rosenblatt KA, et al. Occupational exposure to electromagnetic fields and breast cancer in men. Am J Epidemiol 1991;134:340–7.
8. Törnqvist A, Knave B, Ahlbom A, et al. Incidence of leukaemia and brain tumours in some "electrical occupations." Br J Ind Med 1991;48:597–603.
9. Savitz DA, Calle EE. Leukaemia and occupational exposure to electromagnetic fields: review of epidemiologic surveys. J Occup Med 1987;29:47–51.
10. Feychting M, Ahlbom A. Magnetic fields and cancer in children residing near Swedish high-voltage power lines. Am J Epidemiol 1993;138:467–81.
11. Savitz DA, Wachtel H, Barnes FA, et al. Case-control study of childhood cancer and exposure to 60-Hz magnetic fields. Am J Epidemiol 1988;128:21–38.
12. Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol 1979;109:273–84.
13. Pollack H. Epidemiological data on American personnel in the Moscow Embassy. Bull NY Acad Med 1979;55:1182–6.
14. Silvermann C. Epidemiologic studies of microwave effects. Proceedings of the IEEE 1980;68:78–84.
15. World Health Organization. Electromagnetic fields (300 Hz to 300 GHz). Environmental Health Criteria 137. Geneva: World Health Organization, 1993.
16. Robinette CD, Silverman C, Jablon S. Effects upon health of occupational exposure to microwave radiation (radar). Am J Epidemiol 1980;112:39–53.
17. Lester JR, Moore DF. Cancer mortality and Air Force bases. J Bioelectricity 1982;1:77–82.
18. Polsen P, Merritt JH. Cancer mortality and Air Force bases: a re-evaluation. J Bioelectricity 1985;4:121–7.
19. Lester JR. Reply to "Cancer Mortality and Air Force Bases: a re-evaluation." J Bioelectricity 1985;4:129–31.
20. Milham S Jr. Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies. Am J Epidemiol 1988;127:50–4.
21. Kraut A, Chan E, Lioy PJ, et al. Epidemiologic investigation of a cancer cluster in professional football players. Environ Res 1991;56:131–43.
22. Cancer incidence in census tracts with broadcasting towers in Honolulu, Hawaii. Report submitted to the Honolulu City Council. Honolulu, HI: Environmental Epidemiology Program, Hawaii, October 1986.
23. Elliott P, Westlake AJ, Kleinschmidt I, et al. The Small Area Health Statistics Unit: a national facility for investigating health around point sources of environmental pollution in the United Kingdom. J Epidemiol Community Health 1992;46: 345–9.
24. Elliott P. Small area studies. In: Bertollini R, Lebovitz MD, Saracci R, et al. Environmental epidemiology: exposure and disease. Boca Raton, FL: CRC Press, 1996:187–99.
25. Shaddick G, Elliott P. Use of Stone's method in studies of disease risk around point sources of environmental pollution. Stat Med 1996;15:1927–34.
26. Stone RA. Investigations of excess environmental risks

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

around putative sources: statistical problems and a proposed test. Stat Med 1988;7:649–60.
27. Hills M. Some comments on methods for investigating disease risk around a point source. In: Elliott P, Cuzick J, English D, et al, eds. Geographical and environmental epidemiology: methods for small-area studies. Oxford: Oxford University Press, 1992:231–7.
28. Bithell JF, Stone RA. On statistical methods for analysing the geographical distribution of cancer cases near nuclear installations. J Epidemiol Community Health 1989;43:79–85.
29. Pothoff RF, Whittinghill M. Testing for homogeneity. II. The Poisson distribution. Biometrika 1966;53:183–90.
30. Martuzzi M, Hills M. Estimating the degree of heterogeneity between event rates using likelihood. Am J Epidemiol 1995; 141:369–74.
31. Clayton D, Kaldor J. Empirical Bayes estimates of age-standardised relative risks for use in disease mapping. Biometrics 1987;43:671–81.
32. Guidance on standards. Guidance as to restrictions on exposures to time varying electromagnetic fields and the 1988 recommendations of the International Non-Ionizing Radiation Committee Report NRPB-GS11. London: National Radiation Protection Board, May 1989.
33. Dolk H, Elliott P, Shaddick G, et al. Cancer incidence near radio and television transmitters in Great Britain. II. All high power transmitters. Am J Epidemiol 1997;145:10–17.
34. Cancer "link with TV transmitter." The Guardian, March 30, 1992:3.

APPENDIX

On March 30, 1992, the *Guardian* newspaper (34) reported that Dr. Mark Payne of Solihull, Birmingham, had collected data on cancer cases from a north Birmingham general practitioner with 2,600 patients. According to the report, seven existing cases of leukemia and lymphoma, five men and two women aged 18–66 years, were identified, living 400 to 1,500 m from the Sutton Coldfield transmitter. All but one of the cases had lived in the region for 14–25 years; the remaining case had lived there for only 2 years. As a rough guide, in a population with the same age structure as England and Wales, one could expect 2.5 cases per 10,000 persons per year to be newly diagnosed with leukemia or lymphoma. Dr. Payne explained later (Dr. M. Payne, Alternative Medicine Centre, Solihull, Birmingham, personal communication, 1993) that his attention had been drawn to the area because of his concerns that non-ionizing radiation is harmful to health, although it is not clear how the particular general practice was chosen for study (the practice population forms approximately 16 percent of the population within 2 km of the transmitter). Details of the study have not subsequently been published outside the popular press.

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

American Journal of Epidemiology
Vol. 145, No. 1
Printed in U.S.A.
Copyright © 1997 by The Johns Hopkins University School of Hygiene and Public Health
All rights reserved

Cancer Incidence near Radio and Television Transmitters in Great Britain

II. All High Power Transmitters

Helen Dolk,[1] Paul Elliott,[2] Gavin Shaddick,[1] Peter Walls,[1] and Bharat Thakrar[1]

A small area study of cancer incidence, 1974–1986, near 20 high power television (TV) and frequency modulation (FM) radio transmitters in Great Britain was carried out to place in context the findings of an earlier study around the Sutton Coldfield transmitter. The national database of postcoded cancer registrations was used with population and socioeconomic data from the 1981 census. Cancers examined were adult leukemias, skin melanoma, and bladder cancer, following the findings in the earlier study of significant declines in risk of these cancers with distance from the Sutton Coldfield transmitter. Childhood leukemia and brain cancer were also examined. Statistical analysis was performed for all transmitters combined, four overlapping groups of transmitters defined by their transmission characteristics, and for all transmitters separately. There were 3,305 adult leukemia cases from 0–10 km (observed/expected (O/E) ratio = 1.03, 95% confidence interval (CI) 1.00–1.07). A decline in risk of adult leukemia was found for all transmitters combined ($p = 0.05$), two of the transmitter groups, and three of the single transmitters; for all transmitters combined, observed excess risk was no more than 15% at any distance up to 10 km, and there was no observed excess within 2 km of transmitters (O/E ratio = 0.97, 95% CI 0.78–1.21). For childhood leukemia and brain cancer, and adult skin melanoma and bladder cancer, results were not indicative of a decline in risk with distance from transmitters. The magnitude and pattern of risk found in the Sutton Coldfield study did not appear to be replicated. The authors conclude that the results at most give no more than very weak support to the Sutton Coldfield findings. *Am J Epidemiol* 1997;145:10–17.

electromagnetic fields; leukemia; neoplasms; radio waves

This study of the incidence of leukemia and other selected cancers near high power frequency modulation (FM) radio and television (TV) transmitters in Great Britain follows an earlier study of the incidence of hematopoietic and selected cancers near the Sutton Coldfield transmitter (1), in order to provide an independent test of hypotheses arising from the findings of that study.

Received for publication December 13, 1995, and accepted for publication August 12, 1996.

Abbreviations: BBC, British Broadcasting Corporation; CI, confidence interval; erp, effective radiated power; FM, frequency modulation; O/E ratio, observed/expected ratio; TV, television.

[1] Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, London, England.

[2] Small Area Health Statistics Unit, Department of Epidemiology and Public Health, Imperial College of Science, Technology and Medicine, Imperial College School of Medicine at St Mary's, London, England.

Reprint requests to Dr. Helen Dolk, Environmental Epidemiology Unit, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1 7HT, England.

The Sutton Coldfield study, covering the period 1974–1986, found a decline in the ratio of observed to expected cases of adult leukemia with distance from the transmitter over a 10 km radius, with a risk within 2 km of the transmitter of 1.83 (95 percent confidence interval (CI) 1.22–2.74) relative to the West Midlands regional average. Within the range of variability of leukemia incidence across census wards in the West Midlands region, the Sutton Coldfield excess was unusual. Of a number of cancers other than leukemia studied in the Sutton Coldfield area, only skin melanoma and bladder cancer showed a decline in the ratio of observed to expected cases with distance from the transmitter.

We report here findings for adult leukemias, skin melanoma, and bladder cancer near the other 20 high power radio and TV transmitters in Great Britain. Eight of these transmit FM radio frequencies and three transmit TV frequencies at power equivalent to Sutton Coldfield (figure 1), but none transmit at exactly the same combination of frequencies and power as Sutton Coldfield. Childhood leukemias and brain cancers are also included in this

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

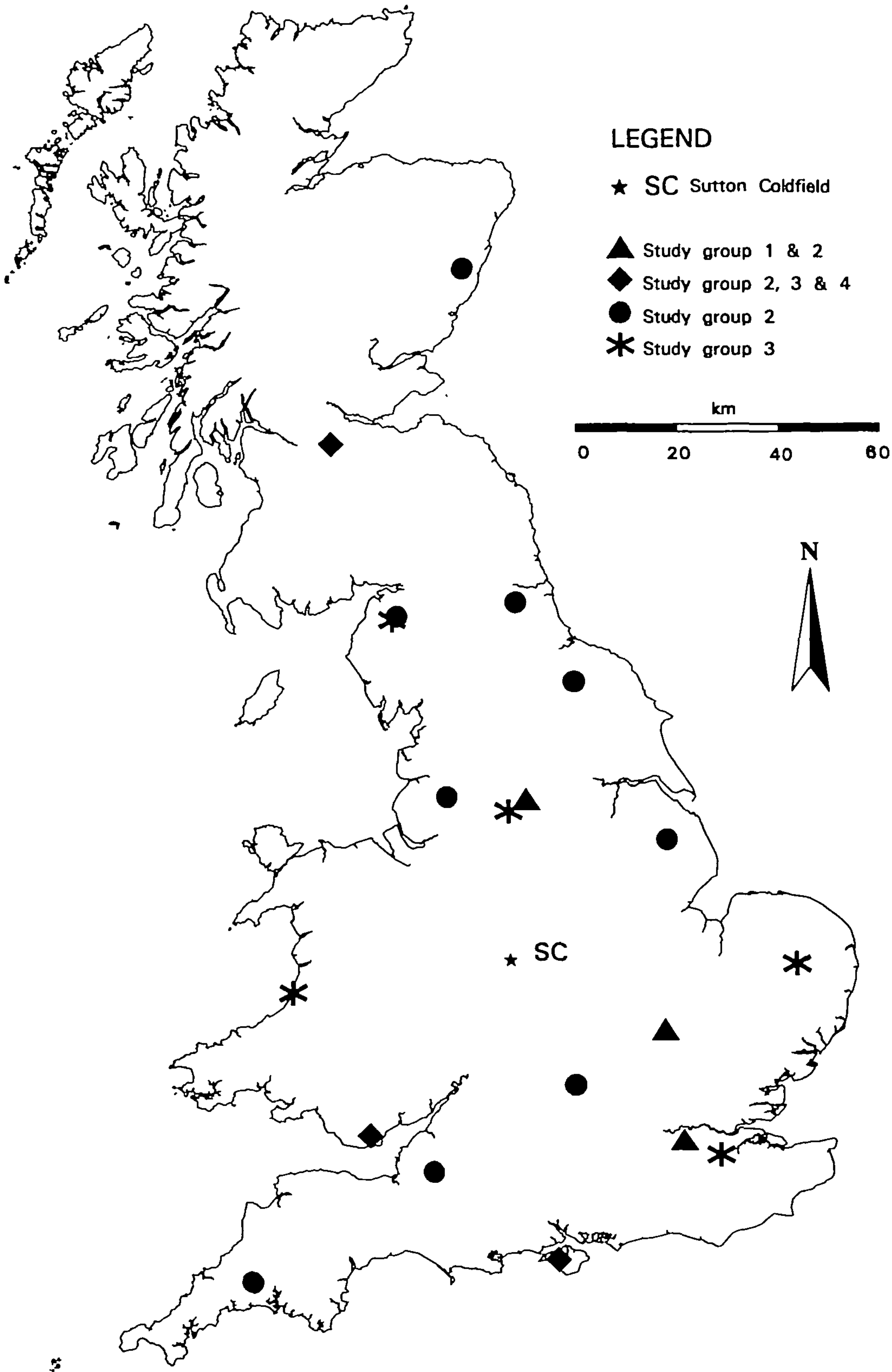

FIGURE 1. Map showing 21 television and FM radio high power transmitters (including Sutton Coldfield) in Great Britain. Definitions of transmitter groups: Group 1, highest power TV transmitters of 870–1,000 kW erp; Group 2, all TV transmitters of 500–1,000 kW erp; Group 3, all FM transmitters of 250 kW erp; Group 4, all transmitters with a combination of TV (≥500 kW erp) and FM (250 kW erp) transmission.

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

study in view of the a priori interest of these cancers in relation to electromagnetic field exposure.

MATERIALS AND METHODS

The study gives an independent test of the association found in the Sutton Coldfield study between residence near a high power radio transmitter and risk of adult leukemia, skin melanoma, and bladder cancer. The analysis was therefore done excluding the Sutton Coldfield transmitter itself. For childhood leukemia and brain cancer, which were not significantly in excess near the Sutton Coldfield transmitter, we took advantage of the larger sample size available to investigate more generally whether residence near a transmitter is associated with increased risk. Therefore, those data are analyzed with the inclusion of Sutton Coldfield.

A list of all radio and TV transmitters with transmission power of at least 500 kW effective radiated power (erp) for television and 250 kW erp for FM was supplied by the British Broadcasting Corporation (BBC), including both BBC and non-BBC transmitters (figure 1). No other transmitter resembles Sutton Coldfield exactly in its combination of both high power TV and FM transmission. In addition to the main analysis of all transmitters combined, analysis was carried out for each transmitter separately and for four groups of transmitters: Group 1, highest power TV transmitters of 870–1,000 kW erp; Group 2, all TV transmitters of 500–1,000 kW erp; Group 3, all FM transmitters of 250 kW erp; Group 4, all transmitters with a combination of TV ($\geq$500 kW erp) and FM (250 kW erp) transmission.

These groups were not mutually exclusive, because one transmitter could be in more than one group. The groups were therefore not designed to give independent tests of the hypotheses, but were chosen to allow for the possibility of a strong dose-response effect or threshold (in view of the fact that electromagnetic fields are considered to be non-genotoxic so that a threshold model is more likely to be appropriate (2–4)), and to allow for differences between FM and TV frequencies, alone or in combination. Human absorption of FM radiation is higher than that of TV radiation, but this is thought to be relevant only to thermal effects (2).

Most transmitters started with ultra high frequency (UHF) TV transmission in 1965 with one frequency, adding two further frequencies in 1969, and one more in 1982. All transmitters had three frequencies by 1971. Three FM channels began in 1955–1958 (except at Black Hill and Blaenplwyf, where one of these was added in 1988–1989), and one further frequency was added between 1988 and 1990.

The study areas were defined by circles of radius 10 km from each transmitter. The total study population was around 3.39 million persons. Two pairs of transmitters were closer than 20 km to each other—Emley Moor and Holme Moss, which were 15.4 km apart, and Sandale and Calbeck, which were 4.3 km apart. Their populations were assigned to the nearest transmitter.

Cancer registration data were used, with the data postcoded to address at diagnosis for 1974–1986 for England, 1974–1984 for Wales, and 1975–1986 for Scotland. The selected cancers studied were all leukemias, all acute leukemias, acute lymphocytic leukemia, acute myelocytic leukemia, chronic lymphocytic leukemia, chronic myelocytic leukemia, skin melanoma, and bladder cancer, and in children, all leukemias, brain cancers (malignant), and brain cancers (malignant and benign). *International Classification of Diseases* codes for these cancers and a description of methods are given in the accompanying paper (1). Among adults, special attention was paid to the 15–64 years age group on the basis that leukemia diagnosis and its registration are more reliable in this age group. Analysis for the four transmitter groups was restricted to all leukemias.

In brief, arbitrary circles 0.5, 1.0, 2.0, 3.0, 4.9, 6.3, 7.4, 8.3, 9.2, and 10 km from each transmitter were defined. Observed cases were allocated according to the grid reference of the postcode of residence at diagnosis. Expected cases were based on national rates (Great Britain), stratified by year, age (5-year age groups), sex, and socioeconomic deprivation quintile, and adjusted for region. Population data were from the 1981 small area census statistics.

Statistical methods, based on descriptive statistics for 0–2 and 0–10 km circles (chosen a priori), and Stone's tests (5, 6) (unconditional and conditional) for decline in risk with distance from the transmitter, have been described in the accompanying paper (1). The main test of hypothesis was for all transmitters combined. Methods of pooling results from individual point sources to give overall (studywide) p values are given elsewhere (7, 8). When combining the data from multiple point sources, the Stone's conditional method takes into account the possibility that transmitters may vary in the overall level of risk over the surrounding 10 km, as well as in the pattern of decline of risk. While Stone's method gives a significance test of decline in disease risk with distance, it does not give an estimate of the magnitude of any excess (8), therefore inspection of the ten-band data is important for its interpretation. For presentation purposes only, we have given some data collapsed into four distance bands, although

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

significance tests were based on all ten bands, chosen a priori.

RESULTS

Results are given here for both sexes combined for persons aged 15 years and over and for children aged 0–14 years. (The age-, sex-, and transmitter-specific results, as well as results for leukemia subgroups, are available on request from the first author.)

Over all 20 transmitters (excluding Sutton Coldfield), there were 3,305 adult leukemia cases from 0–10 km (observed/expected (O/E) ratio = 1.03, 95 percent CI 1.00–1.07) and 79 cases from 0–2 km (O/E ratio = 0.97, 0.78–1.21) (table 1). Although there was no excess within 2 km, Stone's tests indicated a decline in O/E ratio with distance from transmitter of borderline significance ($p = 0.001$ unconditional, $p = 0.052$ conditional, table 1). Table 2 also shows that point estimates of O/E ratios in individual bands never exceeded 1.15 (2–3 km) for all transmitters combined. Although it is not possible to use Stone's test to compare subgroups directly, the significance of the decline for the 15–64 years age group ($p = 0.028$ unconditional, $p = 0.001$ conditional, data not shown) indicates that it is not restricted to older ages.

The Stone's tests were significant for Groups 3 and 4 (table 3), but the conditional test did not reach statistical significance for Groups 1 and 2. O/E ratios by band are given in table 2 for the four transmitter groups. Groups 3 and 4 had very few expected cases within 2 km.

Results for individual transmitters (table 3) showed significant ($p < 0.05$) declines in risk with distance for Crystal Palace, Rowridge, and Wenvoe (tables 2 and 3). Around both the Rowridge and Wenvoe transmitters, the O/E ratio in the outermost bands fell well below 1.00 (table 2). There was excess leukemia risk at 0–10 km for Sandy Heath (O/E ratio = 1.38, 95 percent CI 1.05–1.81) and Winter Hill (O/E ratio = 1.16, 95 percent CI 1.04–1.29) but no significant declines in risk (table 3), and a deficit at 0–10 km for Black Hill (O/E ratio = 0.80, 95 percent CI 0.67–0.97) (table 3).

None of the leukemia subtypes on their own showed a significant decline with distance for all transmitters combined (table 1). Inspection of the data (table 4) indicates that the small excess from 2–4.9 km in all leukemias is mainly associated with acute, acute myeloid, and chronic lymphatic leukemias.

For skin melanoma (table 1), there was an overall deficit of cases from 0–10 km (O/E ratio = 0.90, 95 percent CI 0.85–0.94), reflected in a significant unconditional Stone's test. Results of the conditional Stone's test (table 1) were not indicative of decline in risk with distance, and examination of data by distance (table 4) shows only a small nonsignificant excess within 2 km followed by a steady deficit at further distances. For bladder cancer, although there was an excess risk from 0–10 km (O/E ratio = 1.09, 95 percent CI 1.06–1.11) reflected in a significant unconditional Stone's test, the conditional Stone's test did not indicate decline in risk with distance, and this was supported by examination of data over the ten bands (table 4), indicating a constant excess with distance.

For childhood leukemia and brain cancer around all 21 transmitters combined (including Sutton Coldfield), numbers were small and confidence intervals within 2 km wide (table 5), and there were no significant declines in risk with distance.

DISCUSSION

In the earlier study of the Sutton Coldfield transmitter (1), the main finding was a decline in risk of adult leukemia with distance from the transmitter, accom-

TABLE 1. Cancer incidence near 20 high power radio and TV transmitters in Great Britain (excluding Sutton Coldfield): observed and expected numbers of cases, observed/expected (O/E) ratios, and 95% confidence intervals (CI), for all transmitters combined, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Type of cancer	Distance from transmitter (km)								Stone's p value*	
	0–2				0–10					
	Observed	Expected	O/E ratio	95% CI	Observed	Expected	O/E ratio	95% CI	U	C
All leukemias	79	81.58	0.97	0.78–1.21	3,305	3,194.25	1.03	1.00–1.07	0.001	0.052
All acute	34	36.21	0.94	0.67–1.31	1,422	1,347.90	1.05	1.00–1.11	0.124	
Acute myeloid	20	26.06	0.77	0.50–1.19	1,022	964.48	1.06	1.00–1.13	0.152	
Acute lymphatic	5	5.54	0.90	0.39–2.11	204	202.63	1.00	0.88–1.15	0.500	
Chronic myeloid	7	11.19	0.63	0.30–1.29	449	448.67	1.00	0.91–1.10	0.315	
Chronic lymphatic	28	23.23	1.20	0.83–1.74	969	953.98	1.02	0.95–1.08	0.055	0.674
Skin melanoma	51	46.08	1.11	0.84–1.46	1,540	1,719.36	0.90	0.85–0.94	0.001	0.725
Bladder cancer	209	193.66	1.08	0.94–1.24	8,307	7,655.32	1.09	1.06–1.11	0.001	0.864

* p values given by Stone's unconditional (U) and conditional (C) tests.

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

TABLE 2. Cancer incidence near 20 high power radio and TV transmitters in Great Britain—all leukemias: observed (O) and expected (E) numbers of cases, O/E ratios, and cumulative O/E ratios, for all transmitters combined, for transmitter groups, and selected individual transmitters, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Distance from transmitter (km)	O	E	O/E ratio	Cumulative O/E ratio	O	E	O/E ratio	Cumulative O/E ratio	O	E	O/E ratio	Cumulative O/E ratio	O	E	O/E ratio	Cumulative O/E ratio
	All transmitters				*Group 1**				*Group 2**				*Group 3**			
0–0.5	2	2.3	0.87	0.87	2	1.9	1.08	1.08	2	2.2	0.91	0.91	0	0.2	0.0	0.00
0.5–1.0	12	13.8	0.87	0.87	11	12.0	0.92	0.94	12	13.4	0.90	0.90	0	0.6	0.0	0.00
1.0–2.0	65	65.5	0.99	0.97	53	52.6	1.01	0.99	63	63.2	1.00	0.98	6	5.8	1.03	0.90
2.0–3.0	155	135.3	1.15	1.08	125	97.1	1.29	1.17	155	132.0	1.17	1.10	11	13.9	0.79	0.82
3.0–4.9	539	494.1	1.09	1.09	377	342.7	1.10	1.12	516	476.1	1.08	1.09	78	61.0	1.28	1.16
4.9–6.3	623	589.7	1.06	1.07	376	341.0	1.10	1.11	607	562.6	1.08	1.08	103	123.3	0.84	0.97
6.3–7.4	547	518.0	1.05	1.07	315	297.1	1.06	1.10	503	484.8	1.04	1.07	134	120.7	1.11	1.02
7.4–8.3	434	453.4	0.96	1.05	220	245.0	0.90	1.06	414	429.2	0.96	1.05	83	100.0	0.83	0.98
8.3–9.2	497	493.5	1.01	1.04	304	296.8	1.02	1.06	465	458.1	1.02	1.04	83	97.5	0.85	0.95
9.2–10	431	427.9	1.01	1.03	259	254.1	1.02	1.05	393	398.7	0.99	1.04	80	96.0	0.83	0.93
	Crystal Palace				*Wenvoe*				*Rowridge*				*Group 4**			
0–0.5	1	1.6	0.62	0.62	0	0.1	0.00	0.00	0	0.02	0.00	0.00	0	0.1	0.00	0.00
0.5–1.0	11	11.7	0.94	0.90	0	0.2	0.00	0.00	0	0.02	0.00	0.00	0	0.2	0.00	0.00
1.0–2.0	50	48.5	1.03	1.00	4	2.9	1.38	1.25	0	0.1	0.00	0.00	4	3.6	1.12	1.02
2.0–3.0	116	87.4	1.33	1.19	9	9.2	0.98	1.05	1	0.5	2.08	1.54	11	10.7	1.03	1.03
3.0–4.9	343	310.4	1.10	1.13	35	27.0	1.30	1.22	12	7.9	1.52	1.52	55	42.9	1.28	1.22
4.9–6.3	346	311.2	1.11	1.12	61	54.6	1.12	1.16	17	15.6	1.09	1.24	87	96.2	0.90	1.02
6.3–7.4	273	259.2	1.05	1.11	58	51.7	1.12	1.15	3	7.2	0.42	1.05	90	86.4	1.04	1.03
7.4–8.3	184	207.1	0.89	1.07	49	48.5	1.01	1.11	1	2.8	0.35	1.00	63	75.9	0.83	0.98
8.3–9.2	244	250.4	0.97	1.05	20	36.4	0.55	1.02	2	3.4	0.58	0.96	51	62.1	0.82	0.95
9.2–10	190	185.1	1.03	1.05	16	30.3	0.53	0.97	6	10.9	0.55	0.87	42	66.8	0.63	0.91

* Group 1, highest power TV transmitters of 870–1,000 kW erp; Group 2, all TV transmitters of 500–1,000 kW erp; Group 3, all FM transmitters of 250 kW erp; Group 4, all transmitters with a combination of TV (≥500 kW erp) and FM (250 kW erp) transmission.

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

TABLE 3. Cancer incidence near 20 high power radio and TV transmitters in Great Britain—all leukemias: observed and expected numbers of cases, observed/expected (O/E) ratios, and 95% confidence intervals (CI), for individual transmitters and transmitter groups, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Site (transmitter group†)	Distance from transmitter (km)								Stone's p value*	
	0–2				0–10					
	Observed	Expected	O/E ratio	95% CI	Observed	Expected	O/E ratio	95% CI	U	C
Crystal Palace (1, 2)	62	61.78	1.00	0.78–1.29	1,758	1,672.59	1.05	1.00–1.10	0.009	0.025
Emley Moor (1, 2)	2	1.94	1.03	0.13–3.72	232	229.89	1.01	0.89–1.15	0.941	
Sandy Heath (1, 2)	2	2.70	0.74	0.09–2.68	52	37.64	1.38	1.05–1.81	0.069	0.235
Black Hill (2, 3, 4)	0	0.53	0.00	0.00–5.65	109	135.69	0.80	0.67–0.97	0.163	
Rowridge (2, 3, 4)	0	0.17	0.00	0.00–17.62	42	48.46	0.87	0.64–1.17	0.023	0.018
Wenvoe (2, 3, 4)	4	3.21	1.25	0.34–3.19	252	260.85	0.97	0.85–1.09	0.001	0.001
Belmont (2)	0	0.46	0.00	0.00–6.51	7	6.25	1.12	0.45–2.31	0.352	
Bilsdale (2)	0	0.03	0.00	0.00–99.86	3	3.53	0.85	0.18–2.48	0.867	
Calbeck (2)	0	0.06	0.00	0.00–49.93	7	8.63	0.81	0.33–1.67	0.848	
Caradon Hill (2)	1	1.51	0.66	0.02–3.69	25	27.23	0.92	0.62–1.36	0.737	
Durris (2)	0	0.00	–	–	10	7.46	1.34	0.64–2.47	0.755	
Mendip (2)	1	0.50	2.00	0.05–11.14	45	38.89	1.16	0.86–1.55	0.440	
Oxford (2)	1	0.58	1.72	0.04–9.61	160	149.04	1.07	0.92–1.25	0.453	
Pontop Pike (2)	4	5.28	0.76	0.21–1.94	101	112.37	0.90	0.74–1.09	0.734	
Winter Hill (2)	0	0.06	0.00	0.00–49.93	327	281.56	1.16	1.04–1.29	0.100	0.753
Blaenplwyf (3)	0	0.15	0.00	0.00–19.97	14	14.77	0.95	0.56–1.59	0.241	
Holme Moss (3)	0	0.03	0.00	0.00–99.86	39	36.63	1.06	0.78–1.46	0.745	
Sandale (3)	0	0.10	0.00	0.00–29.96	1	2.88	0.35	0.01–1.93	0.526	
Tacolneston (3)	0	1.12	0.00	0.00–2.67	45	43.15	1.04	0.78–1.40	0.966	
Wrotham (3)	2	1.37	1.46	0.18–5.27	76	76.74	0.99	0.79–1.24	0.395	
Group										
1	66	66.42	0.99	0.78–1.26	2,042	1,940.12	1.05	1.01–1.10	0.019	0.182
2	77	78.81	0.98	0.78–1.23	3,130	3,020.1	1.04	1.00–1.07	0.053	0.066
3	6	6.68	0.90	0.33–1.96	578	619.17	0.93	0.86–1.01	0.018	0.006
4	4	3.91	1.02	0.28–2.62	403	445.00	0.91	0.82–1.00	0.001	0.002

* *p* values given by Stone's unconditional (U) and conditional (C) tests.

† Group 1, highest power TV transmitters of 870–1,000 kW erp; Group 2, all TV transmitters of 500–1,000 kW erp; Group 3, all FM transmitters of 250 kW erp; Group 4, all transmitters with a combination of TV (≥500 kW erp) and FM (250 kW erp) transmission.

panied by an excess risk of 1.83 (95 percent CI 1.22–2.74) within 2 km. The excess leukemia risk was apparent beyond 2 km from the transmitter, with a gradual decline in risk that extended over the entire 10 km of the study area. In the present study, we sought an independent test of the hypothesis of increased leukemia risk seen near high power transmitters using data from the 20 such transmitters in Great Britain other than Sutton Coldfield. When we combined results for all 20 transmitters together, there was a significant decline in risk of leukemia with distance from transmitters, although the excess was observed only beyond 2 km and was small in comparison with that observed within 2 km of Sutton Coldfield. No clear interpretation of differences between leukemia subtypes was possible. The findings for adult leukemia were not apparent for childhood leukemia (albeit based on few cases); nor was there indication overall of a declining pattern of risk with distance for skin melanoma or bladder cancer.

The Crystal Palace transmitter contributed a large proportion of the population of this study, particularly in regard to the population closest to transmitters. A significant decline in leukemia risk with distance was demonstrated for this transmitter alone, although as in the analysis for all transmitters combined, the excess risks involved were small. There was no observed excess within 2 km, although the power of the study was not great enough to rule out a small excess or deficit in risk within this radius. Measurements taken by the BBC (British Broadcasting Corporation internal report, 1994) within a 2 km radius of Crystal Palace have confirmed that field strengths for TV frequencies are at least as great as those measured within the same radius of Sutton Coldfield. There is no high power FM transmission at Crystal Palace. The statistical power of the analysis for other single transmitters was lower, but significant declines with distance were also found for Rowridge and Wenvoe, although for those transmitters there was very little population within 5 km and the declines with distance were associated with an unexplained deficit of cases at distance from the transmitters.

Sutton Coldfield transmits both TV and FM frequencies. The analysis by transmitter group was de-

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

TABLE 4. Cancer incidence near 20 high power radio and TV transmitters in Great Britain (excluding Sutton Coldfield)—leukemia subtypes, skin melanoma, and bladder cancer: observed numbers of cases and observed/expected (O/E) ratios, for all transmitters combined, by distance of residence from transmitter, in persons aged ≥15 years, 1974–1986

Type of cancer	Distance from transmitter (km)							
	0–2		2–4.9		4.9–7.4		7.4–10	
	Observed	O/E ratio	Observed	O/E ratio	Observed	O/E ratio	Observed	O/E ratio
Leukemia								
Acute	34	0.94	302	1.12	494	1.06	585	1.03
Acute myeloid	20	0.77	227	1.17	347	1.04	424	1.04
Acute lymphatic	5	0.90	42	1.04	66	0.95	89	1.04
Chronic myeloid	7	0.63	82	0.96	177	1.16	179	0.92
Chronic lymphatic	27	1.20	208	1.13	323	0.99	401	0.97
Skin melanoma	51	1.11	297	0.86	508	0.86	673	0.94
Bladder cancer	204	1.08	1,620	1.08	2,815	1.06	3,603	1.10

TABLE 5. Childhood cancer incidence near 21 high power radio and TV transmitters in Great Britain (including Sutton Coldfield)—leukemias and brain cancers in persons aged 0–14 years: observed and expected numbers of cases, observed/expected (O/E) ratios, and 95% confidence intervals (CI), for all 21 transmitters combined, by distance of residence from transmitter, 1974–1986

Type of cancer	Distance from transmitter (km)								Stone's *p* value*	
	0–2				0–10					
	Observed	Expected	O/E ratio	95% CI	Observed	Expected	O/E ratio	95% CI	U	C
All leukemias	10	8.94	1.12	0.61–2.06	317	326.82	0.97	0.87–1.08	0.266	
Brain										
Malignant and benign	4	6.48	0.62	0.17–1.59	244	230.70	1.06	0.93–1.20	0.465	
Malignant only	3	5.99	0.50	0.10–1.46	220	213.41	1.03	0.90–1.18	0.513	

* *p* values given by Stone's unconditional (U) and conditional (C) tests.

signed to examine for any effects, if present, restricted to either the highest power TV transmission (within the high power range studied) or to either TV or FM or their combination. Significant declines in leukemia risk with distance were found for Groups 3 and 4, which transmit FM frequencies, although these groups had very little population within 2 km. The results did not reach statistical significance for TV transmitters as a whole, despite the greater population of study in Groups 1 and 2 (which include Crystal Palace). No clear interpretation seems possible as to whether the overall decline in risk with distance is associated specifically with TV or FM transmission, or a combination of the two.

The analyses presented here used population figures from the 1981 census, i.e., around the midpoint of the period. Using data from the 1971 and 1991 censuses to estimate the effects of population change, it was concluded that O/E ratios may have been overestimated by around 1.6 percent within 10 km of all 20 transmitters combined, and 4 percent for Crystal Palace. However, there is no evidence to suggest that such population artefacts occurred differentially with distance so as to generate spurious trends. No information was available concerning relative mobility of populations near different transmitters. Such mobility, i.e., migration of people away from transmitters between exposure and diagnosis, and migration toward transmitters of unexposed people, would tend to bias estimations of O/E ratios toward the null.

The Small Area Health Statistics Unit was established to examine the available routinely collected health statistics near industrial point sources. The limitations of routine cancer registry data for small area analyses have been discussed elsewhere (9), and include geographic variability in diagnostic practice as well as completeness and accuracy of data collection. Although apparent excesses and deficits may occur due to these limitations, it is less likely that a spurious pattern of decline around multiple point locations would be generated.

In conclusion, while there is evidence of a decline in leukemia risk with distance from transmitters, the pattern and magnitude of risk associated with residence near the Sutton Coldfield transmitter do not appear to be replicated around other transmitters. The only other

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012

epidemiologic study of radio transmission and cancer that we know of*, in Honolulu (10), found a relative risk of leukemia of 1.56 (99 percent CI 0.86–2.63) in census tracts with broadcasting antennae, within the context of an overall raised cancer risk in these census tracts (relative risk = 1.36, 99 percent CI 1.25–1.48). Interpretation of that study was complicated both by the ecologic nature of the design and the problem of potential confounding. We are aware of no other epidemiologic (2, 11) evidence to suggest an increased risk of leukemia from non-ionizing radiation in the radiofrequency range. The existence of biologically significant athermal effects of radiofrequency radiation in animal and in vitro experiments is a subject of research and controversy, and evidence at present is not sufficient to support a leukemogenic effect (4, 12), especially at the low field strengths to which people who reside near radio transmitters are exposed. We can consider three options. First, the apparent decline in risk may be a chance finding although statistically significant at the conventional 5 percent level. Second, there may be a shallow decline in risk with distance from the transmitters, but this does not necessarily imply any causal link with radiofrequency transmission and may reflect the geographic distribution of other unmeasured sociodemographic or environmental factors. Third, if there were a true association with radio transmission, the lack of replication of the pattern and magnitude of excesses near Sutton Coldfield may indicate that a simple radial decline exposure model is not sufficient (1). The results, at most, give no more than very weak support to the Sutton Coldfield findings.

ADDENDUM

* We have subsequently become aware of a paper about to be published in which the authors found an excess of childhood leukemia near TV towers in Sydney, Australia (13).

ACKNOWLEDGMENTS

The Small Area Health Statistics Unit is funded by grants from the Department of Health, Department of the Environment, Health and Safety Executive, Scottish Office Home and Health Department, Welsh Office, and Northern Ireland Department of Health and Social Services.

The authors thank the Office of Population Censuses and Surveys (now the Office of National Statistics) and the Information and Statistics Division of the Scottish Health Service, who made the postcoded cancer data available for use.

REFERENCES

1. Dolk H, Shaddick G, Walls P, et al. Cancer incidence near radio and television transmitters in Great Britain. I. Sutton Coldfield transmitter. Am J Epidemiol 1997;145:1–9.
2. World Health Organization. Electromagnetic fields (300 Hz to 300 GHz). Environmental Health Criteria 137. Geneva: World Health Organization, 1993.
3. Department of Health. Report on health and social subjects, no. 42. Guidelines for the evaluation of chemicals for carcinogenicity. Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment. London: HMSO, 1991.
4. Michaelson SM, Elson EC. Interaction of nonmodulated and pulsemodulated radiofrequency fields with living matter: experimental results. In: Polk C, Postow E, eds. Handbook of biological effects of electromagnetic fields. 2nd ed. Boca Raton, FL: CRC Press, 1996:441–540.
5. Stone RA. Investigations of excess environmental risks around putative sources: statistical problems and a proposed test. Stat Med 1988;7:649–60.
6. Hills M. Some comments on methods for investigating disease risk around a point source. In: Elliott P, Cuzick J, English D, et al, eds. Geographical and environmental epidemiology: methods for small area studies. Oxford: Oxford University Press, 1992:231–7.
7. Elliott P, Shaddick G, Kleinschmidt I, et al. Cancer incidence near municipal solid waste incinerators in Great Britain. Br J Cancer 1996;73:702–10.
8. Shaddick G, Elliott P. Use of Stone's method in studies of disease risk around point sources of environmental pollution. Stat Med 1996;15:1927–34.
9. Swerdlow AJ. Cancer incidence data for adults. In: Elliott P, Cuzick J, English D, et al, eds. Geographical and environmental epidemiology: methods for small area studies. Oxford: Oxford University Press, 1992:51–62.
10. Cancer incidence in census tracts with broadcasting towers in Honolulu, Hawaii. Report submitted to the Honolulu City Council. Honolulu, HI: Environmental Epidemiology Program, Hawaii, October 1986.
11. Dennis JA, Muirhead CR, Ennis JR. Human health and exposure to electromagnetic radiation. National Radiation Protection Board report no. NRPB-R241, July 1992.
12. Postow E, Swicord ML. Modulated fields and "window" effects. In: Polk C, Postow E, eds. Handbook of biological effects of electromagnetic fields. 2nd ed. Boca Raton, FL: CRC Press, 1996:541–86.
13. Hocking B, Gordon I, Grain H, et al. Cancer in proximity to TV towers. Med J Aust (in press).

Downloaded from http://aje.oxfordjournals.org/ at University at Albany on May 2, 2012