CHALMERS TEKNISKA HÖGSKOLA
GÖTEBORGS UNIVERSITET
Fysiska Institutionen
Miljöfysik
Patrik Pettersson, sept 93, okt 95

Laboration

Mi 3

Biologiska effekter av elektriska och magnetisk fält

Målsättning: Att kartlägga det magnetiska växelfältet i din omgivning, beräkna din årsexponering och bilda dig en uppfattning om den innebär någon överrisk.

INNEHÅLL

1. Inledning 2
2. Mätning av magnetfält kring en rak ledare 3
3. Mätning av elektriska och magnetiska växelfält från bildskärm 4
4. Kortfattad beskrivning av mätutrustningen 4
4. Uppskattning av magnetfältsexponering - hemlaboration 5

Bilaga A. Mätprotokoll
Bilaga B. Delpizzo V., (1989) A Model to Assess Personal Exposure to ELF Magnetic Fields from Common Household Sources. Bioeletromagnetics 11:139-147.

Namn: ____________________

Handledare: ________________

Laborationen utförd den: __________

Inlämnad den: ____________

Godgänd den: ____________ av: ________________

1. Inledning

Bakgrunden till laborationsuppgiften är misstankarna om ett samband mellan magnetfältsexponering och cancer. Under de senaste åren har det kommit allt fler undersökningar som visar på ett statiskt samband mellan exponering för lågfrekventa magnetfält och vissa cancertyper, speciellt hos barn. Exempelvis har Institutet för Miljömedicin vid Karolinska Institutet gjort en epidemiologisk studie av dem som någon gång under perioden 1960-85 bott inom 300 m från någon högspänningsledning på 400 kV eller 220 kV i Sverige. Studien visar ett samband mellan exponering för magnetfält från kraftledningar och leukemier hos barn. Vid ett årsmedelvärde av 0,2 µT eller med ses en fördubblad risk och vid 0,3 µT en drygt tredubblad risk.

Målsättningen med laborationen är att du skall kartlägga det magnetiska växelfältet i din omgivning, beräkna din årsexponering och bilda dig en uppfattning om hur stor risk den eventuellt innebär.

Laborationen är upplagd så att vi först genomför mätningar av elektriska och magnetiska växelfält i lab på Chalmers, för att ge alla tillfälle att bekanta sig med mätinstrumenten. Sedan får varje laborationsgrupp välja en egen plats att mäta upp. Förslagsvis är ni två eller tre per grupp och mäter hemma där ni bor, men ni kan också välja en annan plats. Varje grupp lämnar en skriftlig rapport som innehåller mätresultat, beräkning av årsexponering och en personlig reflektion över erfarenheter från laborationen.

Detta lab-PM bygger till viss del på material som ingår i kursen "Biologiska effekter av elektromagnetiska fält", som ges av Institutionen för teknisk elektronfysik på Chalmers. Ett varmt tack till dem för att de så generöst delat med sig av material och erfarenheter.

För att ge lite perspektiv följer här ett citat ur Yngve Hamnerius matreal om elektriska och magnetiska fält som delats ut under kursen:

> "Man måste sätta in dessa eventuella överrisker i sitt sammanhang. Vi har cirka 200 barncancerfall om året i Sverige, de uppskattningar som gjorts tyder på att kanske 5 - 10 barncancerfall skulle kunna bero på magnetfält. Antalet vuxencancerfall är ca 40 000 per år i Sverige. Utgående från Birgitta Floderus studie kan man uppskatta att ca 20 fall vardera av leukemi och hjärntumörer bland yrkesverksamma män skulle kunna bero på magnetfältsexponering. Gäller överriskerna även andra cancerformer som kvinnlig bröstcancer kan det bli tal om större antal fall. Vi ser att under förutsättningen att det verkligen finns en överrisk av magnetsfältsexponering så är denna risk liten jämfört med övriga riskfaktorer som beräknas stå för majoriteten av alla cancerfall. Man beräknar att rökning står för 15 %, dvs ca 6 000 fall årligen och kostfaktorer för dubbelt så många fall."

2. Mätning av magnetfält kring en rak ledare

Avsikten med momentet är att undersöka om mätinstrumentet är rätt kalibrerat, samt att ge en uppfattning om hur magnetfältet från en linjekälla avtar med avståndet.

Koppla upp en strömkälla bestående av en transformator (sekundär 55 V, 3A) i serie med en varierbar resistor (100 Ω, ≤ 1.2 A) och en amperemeter (AC, 0-3 A). Spänn upp en enkelledare fritt i rummet, på rejält avstånd från alla metalliska föremål. Koppla ledaren i serie med de tre komponentera ovan. Be handledaren kontrollera uppställningen innan du ansluter transformatorn till nätet.

Placera mätsonden nära ledaren och ställ in resistorn så att strömmen blir 1.0 A. Stäng av strömmen och mät upp bakgrundsnivån.

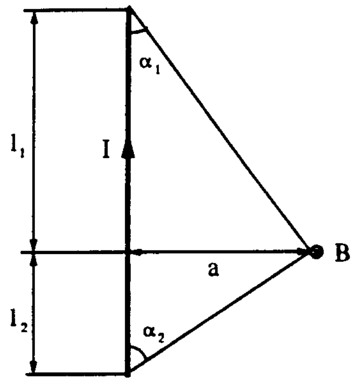
Mät upp magnetfältet i ett antal mätpunkter på olika avstånd från ledaren, exempelvis 10, 20, 30 ,40, 50, 70 och 100 cm. Subtrahera bort bakgrunden.

Enligt elektromagnetisk fältteori är magnetfältet B på avståndet a från en rak ledare med strömmen I

$$B = \frac{\mu_0 I}{4\pi a}(\cos\alpha_1 + \cos\alpha_2)$$

eller

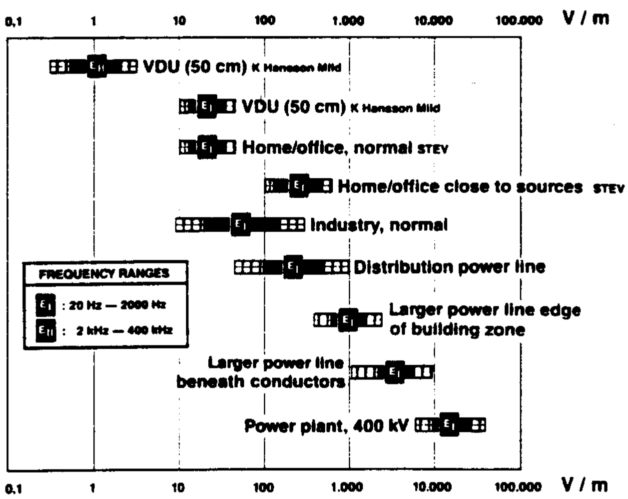
$$B = \frac{\mu_0}{4\pi}\,\frac{2I}{a}, \qquad (l_1, l_2 \gg a).$$



Stämmer detta överens med dina mätdata? Hur stor är avvikelsen? Hur förklarar du den?

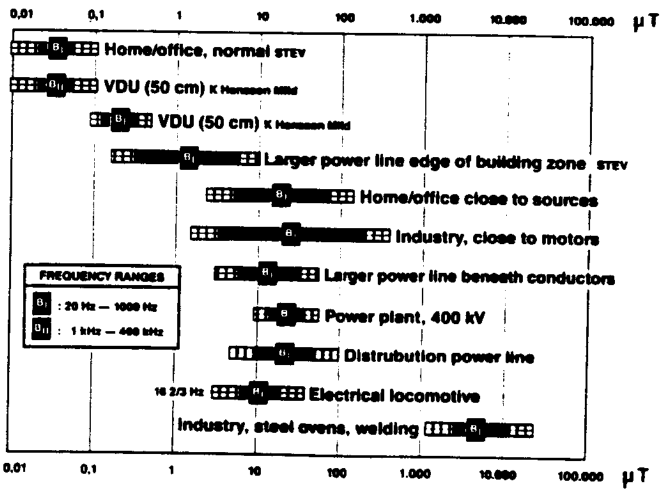
För jämförelse, se följande figurer som innehåller en sammanfattning av publicerade värden på elektriska och magnetiska växelfält uppmätta i olika miljöer.

ELECTRIC ALTERNATING FIELDS f = 20 Hz - 400 kHz



STEV = National Energy Administration

MAGNETIC ALTERNATING FIELDS f = 20 Hz - 400 kHz



STEV = National Energy Administration

3. Mätning av elektriska och magnetiska växelfält från bildskärm

Avsikten med momentet är att ge övning i mätteknik för elektriska och magnetiska växelfält som förekommer runt en bildskärm.

Ni kommer att utnyttja de normer för mätning av bildskärmar som gavs ut av SWEDAC 1990-12-01. Normerna kommer att finnas tillgängliga på labplatsen. Ett enkelt mätprotokoll finns i appendix A.

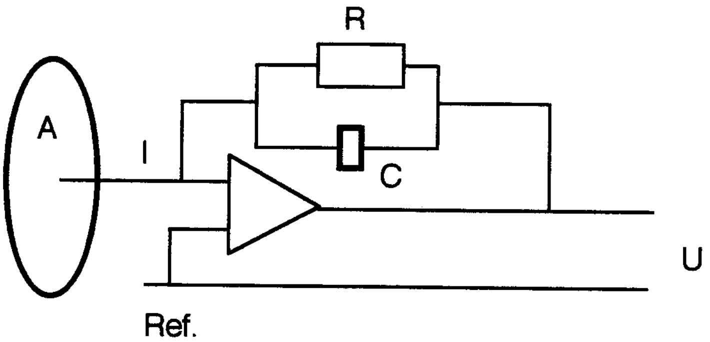
4. Kortfattad beskrivning av mätutrustningen

A. Elektriska växelfält

Det elektriska växelfältet mäts genom att mäta en förskjutningsström genom en given yta på en mätkropp. Mätkroppen är ansluten till en operationsförstärkare med kapacitiv återkoppling, se figur nedan. Utspänningen, U, orsakad av förskjutningströmmen i mätkroppen beror på styrkan hos det växelfält som mätkroppen känner, E, enligt formeln:

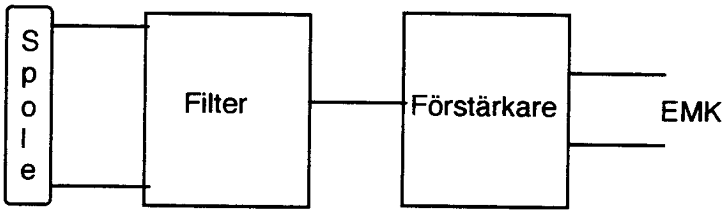
$$U = \varepsilon \cdot E \cdot \frac{A}{C},$$

där ε=kapaciviteten för vakuum
A=mätkroppens area
E=elektriska fältstyrkan
C=kapacitansen hos återkopplingen.



B. Magnetiska växelfält

Magnetfältet mäts med hjälp av spolar. Systemen innefattar tre mot varandra vinkelräta koncentriska cirkulära spolar. Spolarna är anslutna till förstärkare och integrerande nätverk så att utspänningen blir proportionell mot den magnetiska flödestätheten. Utsignalen passerar även högpass- och lågpassfilter för att bestämma frekvenskänsligheten, se principskissen nedan.



Den inducerade EMK:n i varje spole fås ur sambandet:

$EMK = N \cdot B \cdot A \cdot 2 \cdot \pi \cdot F$,

där N=antal varv i spolen
B=magnetiska flödet
A=spolens area
F=frekvensen.

Utsignalerna från spolarna används som ingångsvärde vid beräkning av effektivvärdet för amplituden på den magnetiska flödestätheten.

5. Uppskattning av magnetfältsexponering - hemlaboration

Bakgrunden till laborationsuppgiften är misstankarna om ett samband mellan magnetfältsexponering och cancer. Vi utsätts för lågfrekventa magnetfält från en mängd källor i det dagliga livet. Vilka av dessa källor skulle innebära störst risk? Det är inte möjligt med dagens kunskaper att ge ett klart svar på denna fråga. Det är dock rimligt att risken beror både på magnetfältets flödestäthet och exponeringstiden. Den australiensiske forskaren Vincent Delpizzo har i bifogade artikel beskrivit ett möjligt sätt att uppskatta årsexponeringen i μTh/år (medelvärdesbildat över människokroppen) från olika källor. Utgående från data från de cancerepidemiologiska studierna definierar Delpizzo källor som ger en exponering på 40 μTh/år som "Insignificant additional exposure" och källor som ger 200 μTh/år som "marginally significant additional exposure".

Läs igenom bifogad artikel och använd tekniken som beskrivs för att beräkna din årsexponering utgående från de mätningar av 50 Hz-magnetfält som du gör.

Beräkna årsexponeringen för dig själv eller en tänkt person genom att väga ihop exponering på arbetsplats, fritid och vid sovplatsen. Undersök några källor i arbets- eller hemmiljö och uppskatta, från magnetfält och typisk exponeringstid, om dessa innebär någon signifikant tillskottsexponering enligt ovan.

Skriv en rapport som dokumenterar dina mätningar och beräkningar.

I slutet av kursen redovisas en sammanställning av de olika laboranternas resultat.

En rapport kan förslagsvis se ut som följer:

1. Inledning: motivation, bakgrund
2. Skiss över bostaden
3. Beräkning av årsexponering (se nedan)
4. Jämförelse med Delpizzo's current configuration class (sid. 11 och 12 i artikeln)
5. Personlig kommentar:
    a) om laborationen har inneburit någon förändring i dina vanor
    b) om din upplevelse av risker i samband med elektriska och magnetiska växelfält har ändrats genom laborationen.

För att underlätta jämförelser med resultaten från era kamrater i andra labgrupper, förslår vi att alla följer denna procedur:

1. Kartlägg de allmäna nivåerna av 50 Hz magnetfält i rummet. Gör en skiss över rummet och skriv in mätvärdena på plats. Mät för enkelhets skull ca 1 meter över golvet. Försök finna källor till magnetfält.

2. Tänk över var du tillbringar din tid. Skriv upp en lista på de platser där du brukar vara. Skriv för varje plats upp hur mycket tid du tillbringar där under ett dygn. Mät det lågfrekventa magnetiska växelfältet vid dessa platser under dina vardagliga betingelser. Slå på de lampor du brukar ha på, osv. Om miljön utanför din bostad ger orsak till fält inuti bostaden (om du t.ex. bor i ett flervåningshus eller intill en kraftledning) är det en fördel om du gör mätningen vid den tid då du brukar vara hemma.

3. Räkna ut din årsexponering utgående från den information du nyss skrivit upp. Redovisa tillskottet till årsdosen från varje plats, dvs subtrahera inte bort någon bakgrundsnivå från mätvärdena. Se följande exempel:

Rum	Plats	Källa	B-fält	Timmar per dygn	Dygn/år	Exponering
Kök	spis	el-spis	2 µT	1 h/d	350 d/y	(2 µT * 1 h/d * 350 d/y =) 700 µTh/y
	matbord	lampa, brödrost	100 nT	2.5 h/d	350 d/y	(100 nT * 2.5 h/d * 350 d/y =) 87.5 µTh/y
Sovrum	säng	klockradio	...	...	...	...
etc.						
					Summa:	______________ µTh/y

Förslag på mätplatser: kök (spis/mikro), säng (väckarklocka), skrivbord (lampa), TV, stereo, hårtork, rakapparat, dammsugare, tvättstuga,...

Uppskatta bidraget till din årsexponering från dina resor, och från din tid på arbetet. Beräkna din totala årsexponering.

4. Ofta är det så att någon grupp får en högre årsexponering än de andra och de undrar varför. Då är det bra om det finns en lista över de källor till magnetfölt som de olika grupperna haft, och man kan jämföra och se om det är någon källa som bidrar ovanligt mycket till deras årsexponering. Gör därför en lista över de källor till magnetfält som ni haft omkring er, och deras magnetfält på en halvmeters avstånd.

5*. Överkurs: Elektriska växelfält. Studera det elektriska växelfältet runt några intressanta apparater. Pröva att mäta fältet med apparate avstängd. (Ibland är E-fältet då större än om apparaten är på). Prova att vända på stickproppen och mäta igen. (Det kan ge en kraftig reduktion eller ökning av fältet).

6**. Överkurs: Högfrekventa fält. En del apparater avger elektriska och/eller magnetiska växelfält i frekvensområdet 2 kHz - 400 kHz. Använd fältmätaren FD2 för att undersök om ni har några sådana. Mät på bruksavstånd och på 0.5 m som förut.

Appendix A

Mätobjekt eller rum:.. Datum:..................

Pos.	Magnetiska fält			Elektriska fält		Anm.
	5 Hz - 2 kHz	2 kHz - 400 kHz		5 Hz - 2 kHz	2 kHz - 400 kHz	

Det kan vara till hjälp att använda följande förkortningar:

G: vid golv
T: vid tak
Övriga värden: 1 m över golv
U: upp
N: ner

N: norr
V: väster
S: söder
Ö: öster

Hö: höger
Vä: vänster
Band I: 5 Hz - 2 kHz
Band II: 2 kHz - 400 kHz

Mätobjekt eller rum:.. Datum:...................

Pos.	Magnetiska fält			Elektriska fält		Anm.
	5 Hz - 2 kHz	2 kHz - 400 kHz		5 Hz - 2 kHz	2 kHz - 400 kHz	

Det kan vara till hjälp att använda följande förkortningar:

G: vid golv
T: vid tak
Övriga värden: 1 m över golv
U: upp
N: ner

N: norr
V: väster
S: söder
Ö: öster

Hö: höger
Vä: vänster
Band I: 5 Hz - 2 kHz
Band II: 2 kHz - 400 kHz

Bioelectromagnetics 11:139–147 (1990)

A Model to Assess Personal Exposure to ELF Magnetic Fields from Common Household Sources

Vincent Delpizzo

Australian Radiation Laboratory, Yallambie, Victoria, Australia

Emission data are inadequate to characterize the contribution of a source to the total personal extremely-low-frequency (ELF) magnetic field exposure. In this paper, a simple model is proposed that takes into consideration the position of the subject with respect to the source and the duration of exposure. The magnetic field is spatially averaged over the whole body of the exposed subject and integrated over time. Exposure is regarded as significant if it approaches or exceeds 400 μT-h/year. By use of this method, the ELF magnetic fields generated by several household sources were compared with the levels of residential external sources, to assess their relative significance. Some common domestic electrical appliances are found to be responsible for an exposure comparable to that from power lines. When the model is used to assess exposure to electric blankets, apparently conflicting findings may be reconciled.

Key words: power lines, cancer, electric blankets

INTRODUCTION

Wertheimer and Leeper [1979, 1982] introduced *wire coding* as a technique for estimating residential exposure to extremely-low-frequency (ELF) magnetic fields by classifying homes on the basis of the type, number, and proximity of electric transmission and distribution lines. This appears to be a powerful tool in epidemiological studies of residential exposure [Fulton et al., 1980; Savitz et al., 1988; Severson et al., 1988; Wertheimer and Leeper, 1979, 1982], given its simplicity and its relatively good reliability [Barnes et al., 1989; Kaune et al., 1987]. Using this technique, three studies [Savitz et al., 1988; Wertheimer and Leeper, 1979, 1982] have shown a statistically significant association between magnetic field exposure and the incidence of several types of cancers.

By definition, wire coding assumes that residential levels of magnetic fields are determined overhwelmingly by visible external electrical installations. Kaune and co-workers [1987] showed that in the case of the Washington State epidemiological study of adult cancer [Severson et al., 1988], this assumption was generally valid.

Received for review October 20, 1989; revision received March 19, 1990.

Address reprint requests to Dr. Vincent Delpizzo, Australian Radiation Laboratory, Yallambie, Victoria 3085, Australia.

However, in their supplementary analysis of the same study, Wertheimer and Leeper [1989] suggest that at least one internal source of exposure, that is, electrically heated beds, may be sufficiently significant to alter the result of a study whose statistical power is low. Wertheimer and Leeper [1989] pointed out that if the subjects of the Washington State study [Severson et al., 1988] are grouped into three classes (residents of low-exposure homes as determined by wire coding; residents of high exposure homes *or* user of electrically heated beds; residents of high-exposure homes *and* users of electrically heated beds) a trend of increasing cancer risk with increasing exposure emerges. A Mantel dose–response test shows this trend to be statistically significant ($\chi^2 = 6.9$, $P < .017$, two-sided).

Tomenius' results (1986) indicate that household sources may be very significant in Sweden. The great majority (77%) of the elevated magnetic fields (≥ 0.3 μT) measured by Tomenius at the entrance door of Stockholm residences were encountered in homes without visible electrical installations within a 150-m radius.

The magnetic fields of common household and industrial sources have been measured by several investigators [Boal and Joyner, 1988; Bowman et al., 1988; Gauger, 1984; Silva et al., 1989]. However, the exposure experienced by users of these sources is not simply related to the measured magnetic field but is a function of the position of the user relative to the source and of the pattern of use.

Awareness of the contribution of household sources to the total residential exposure is an important factor in the design and evaluation of epidemiological studies. Should a causal association between magnetic fields and cancer eventually be proved, the understanding of the significance of these sources will be useful in the formulation of safety guidelines.

In this paper we attempt to estimate the personal exposure due to some of the strongest domestic sources of ELF magnetic fields and to assess them against the exposure due to the magnetic fields associated with residences classified by the Wertheimer–Leeper wire code.

DEFINITION OF SIGNIFICANT DOSE

In the absence of a biological model to explain the observed association, any definition of dose must, to some extent, be arbitrary. For lack of a better alternative, we will assume that exposure is cumulative and averaged over the whole body. This decision is not based on firm evidence. However, the two methods used to assess residential exposure, wire coding and spot measurements, have been shown to be correlated to measurements averaged in time and space. We have as yet no data to indicate that they are correlated with other exposure parameters, such as peak values, or with any specific *window* of magnetic-field strengths. The decision to time-integrate the exposure is based on the observation that the sources surveyed are used on a daily basis, year-round or for extended periods (months) in the home. Averaging over the whole body is justified by the finding that different types of cancers have been found to be associated with ELF exposure, and that the mechanisms proposed to explain this association [Delpizzo, 1989a, and references cited therein] are not organ specific.

The three studies [Wertheimer and Leeper, 1982; Kaune et al., 1987; Barnes et al., 1989] that have compared magnetic fields measured in homes with the wire-code classification of those homes indicate rather consistently the median background level

TABLE 1. Magnetic Fields Associated with the Wire-Code Exposure Classes*

Study	VLCC[a]	OLCC	OHCC	VHCC
Wertheimer and Leeper [1982]	<.05	<.05	.12	.25
Barnes et al. [1989]	.03	.05	.09	.22
Standard Error of Median	.005	.006	.013	.043
Kaune et al. [1987]	.05	.05	.11	.2
25–75% limits	.025–.6	.03–.1	.07–.18	.17–.25
Average magnetic field strength	.04	.05	.11	.22

*Expressed in microtesla (μT).

[a] Includes "buried" and "end pole" classifications [Barnes et al., 1989].

associated with each class, making it possible to assign to each a typical magnetic field strength (Table 1). Thus, assuming that a subject is exposed to the residential background field for 15 h/day, 350 days/year,[1] we can estimate the typical doses received by residents in the four classes of homes:

$$E_{VLCC} = 0.04\ \mu T \times 15\ h/day \times 350\ day/y = 210 \sim 200\ \mu T\text{-}h/year$$
$$E_{OLCC} = 0.05\ \mu T \times 15\ h/day \times 350\ day/y = 263 \sim 250\ \mu T\text{-}h/year$$
$$E_{OHCC} = 0.11\ \mu T \times 15\ h/day \times 350\ day/y = 578 \sim 600\ \mu T\text{-}h/year$$
$$E_{VHCC} = 0.22\ \mu T \times 15\ h/day \times 350\ day/y = 1155 \sim 1100\ \mu T\text{-}h/year$$

where VLCC is very low current configuration; OLCC is ordinary low current configuration; OHCC is ordinary high current configuration; and VHCC is very high current configuration.

We then arbitrarily define significant additional exposure (E_s) as the exposure required to elevate the residential exposure of a subject living in a VLCC home to the level of that approximately received by an OHCC resident, that is, 400 μT-h/year. The results of Wertheimer and Leeper [1982] and of Savitz et al. [1988] indicate that elevated cancer odds ratios (OR) exist between these two residence classifications (Table 2). Similarly, on OHCC resident receiving one additional significant dose will receive a total dose approximately equivalent to that due to a VHCC home. A difference in the cancer incidence has also been observed between residents of these two classes of dwellings.

We further define two types of additional exposure:

Insignificant additional exposure is an exposure of

$$E_i = E_s/10 = 40\ \mu T\text{-}h/year$$

marginally significant additional exposure is an exposure of

$$E_m = E_s/2 = 200\ \mu T\text{-}h/year$$

---

[1] This assumes an absence from home of 2 weeks/year. During this time, the subject may still be exposed to magnetic fields, but this exposure is not characterized by his home's classification. Since there is no reason to believe that this exposure is correlated to the residential exposure, we must conclude that it contributes to the random misclassification of exposure.

TABLE 2. Reported Association Between Cancer Incidence and House Wire-Code Classification

Study	Cases	Controls	OR	95% CI
Wertheimer and Leeper [1982]				
VLCC	99	148	1.0	
OHCC	330	298	1.7	1.3–2.3
OHCC	330	298	1.0	
VHCC	108	74	1.3	.9–1.8
Savitz et al. [1988]				
Address at diagnosis:				
VLCC and buried	124	105	1.0	
OHCC	70	44	1.3	.8–2.1
OHCC	70	44	1.0	
VHCC	19	8	1.5	.6–3.7
Address 2 years before diagnosis:				
VLCC and buried	47	62	1.0	
OHCC	30	28	1.4	.7–2.7
OHCC	30	28	1.0	
VHCC	8	2	3.7	.7–19.0

METHOD

A number of domestic sources of ELF magnetic fields were measured by an omnidirectional magnetic field meter [Baylis, 1989]. This instrument, which may be operated in an automatic data-logging mode, also permitted the determination of the duty cycle of appliances operated by a thermostat. All measurements were carried out in Melbourne, Australia, on appliances designed for local use (240 V, 50 Hz). However, electric-blanket data were extrapolated to 110-V operation to permit comparison with results in the United States.

The readings were taken at 34 points on a 15-cm grid marked on a two-dimensional model of an adult human body. The model was located at a position corresponding to the mid-coronal plane of a person using or otherwise near the appliance (in bed, the user was assumed to lay supine, and the model was placed 12.5 cm from the blanket). Measurements were taken with the appliance on and off (to determine the background field). All readings were subsequently averaged and the background field was subtracted.

RESULTS

Most home appliances will not subject the user to any appreciable exposure to a magnetic field, because the field they produce is very localized [Gauger, 1984; Silva et al., 1989], and the periods of use are very short (hours or minutes). For example, although a kitchen range can generate a field density of tens of microteslas [Gauger, 1974], the contribution to the total exposure of the user is small. The whole-body-averaged exposure for a subject standing in front of a range with three elements and the oven on was measured to be 0.32 μT. The exposure of a person standing about one meter from the range was only 0.03 μT. Assuming that a subject

TABLE 3. Electric Blanket Use Patterns Required to Produce a Significant (E_s), Marginally Significant (E_m), and Insignificant (E_i) Additional Magnetic Field Exposure

Exposure			Use pattern[a]								
Blanket type	Voltage (V)	Field (μT)	E_s (400 μT-h/y)			E_m (200 μT-h/y)			E_i (40 μT-h/y)		
			A	B	C	A	B	C	A	B	C
Overb.	240	0.25	8	0.6	330	8	0.5	200	8	0.3	66
Underb.	240	0.20	8	1.0	250	8	0.75	165	8	0.25	100
Overb.	110	0.56	8	0.5	180	8	0.4	120	8	0.3	30
Underb.	110	0.45	8	0.75	150	8	0.25	230	8	0.25	45

[a] A, hours per day; B, magnetic field reduction factor, due to control setting and achieved through a reduction of the current intensity or of the duty cycle; C, days per year.

spent 1 h/day directly in front of the range and 3 h/day in its proximity, the time-integrated exposure would still be less than 150 μT-h/year. However, a few appliances may be responsible for a significant additional exposure.

Electric Blankets

Measurements were performed on three models of electric *under*blankets (called "mattress heating pads" in the United States) and one *over*blanket. All blankets were operated on the highest setting. The current flowing in the overblanket was calculated to be 0.4 A. Currents of the order of 1 A are common in the United States [Leeper E: personal communication] partly because of the lower operating voltage.

The average field density, calculated as described above, was 0.2 μT for the underblankets and 0.25 μT for the overblanket. These fields may be 2 to 2.5 times higher for appliances designed for 110-V operation. During normal use, exposure is regulated by the blankets temperature controls. For the underblankets, this is achieved by reducing the current flow by a factor of 0.25 for the "low" setting and 0.75 for the "intermediate" setting. Overblankets are normally equipped with a thermostat; therefore, the time-integrated magnetic field exposure is obtained by multiplying the measured average magnetic field by an appropriate duty cycle. Using the definitions given above, we may estimate the use patterns required to produce a significant, marginally significant, and insignificant additional exposure (Table 3).

Electric underblankets are more efficient than overblankets, because they do not replace conventional blankets. Therefore, repeated all-night use on other than low setting is extremely uncommon. (In a survey I conducted in Melbourne [Delpizzo, 1989b], less than 2 percent of electric underblanket users indicated that they keep the blanket on all night for more than 3 months a year with medium or high setting.) Overblankets, however, are designed for all-night use. Our model suggests that underblankets designed for 240-V operation may be regarded as insignificant sources of exposure under almost any realistic use pattern. However, 110-V *over*blankets, common in the United States, may certainly be responsible for a significant exposure.

Waterbed Heaters

Unlike electric blankets, waterbed heaters need to be on all-year round to maintain the water at a constant temperature (about 30 °C). The duty cycle varies between 0.2 and 0.4, depending on the room temperature and the degree of insulation of the mattress (i.e., the number and type of blankets used on the bed and the type of bed frame).

Exposure may vary greatly, depending on the position and on the type of the heating element. In early models of double waterbeds, the water-filled bladder is contained in a wooden frame. The base of this frame consists of two large boards that are simply juxtaposed. Manufacturers discourage placing the heating element on the joint, to avoid wear and tear. The position of the heater is further determined by the cable length and by the convenience of having the thermostat control near the head of the bed. As a result, in most cases, the heater is located directly under one of the users. In this case, the field strength averaged over the whole body is about 0.4 to 0.5 μT. Assuming an exposure of 8 h/day for 350 days/year, with a duty cycle of 0.35, the yearly exposure exceeds 400 μT-h/year. For the other user, the average field is 0.05 to 0.06 μT and therefore almost insignificant (~50 μT-h/year).

In a more recent design, the frame sides are made of thick, dense foam rubber. The water bladder is smaller and, in some models, partly filled with a fibrous material. Therefore a smaller, less powerful heater is required. This is often placed at the foot of the bed. Users of these models are subjected to an insignificant exposure (whole-body average exposure 0.02 μT; integrated exposure: 0.02 × 0.35 × 8 × 350 = 16.8 μT-h/year).

Concrete Slab Coil Heaters

Electric coils may be embedded in the concrete floor of a house and connected during off-peak demand periods, that is, in the early afternnon and at night. The operation of the coils during these periods is regulated by a thermostat. The typical duty cycle is 0.3. The whole-body-averaged exposures measured on a bed varied between 1 and 6 μT. Assuming operation for 8 h/day, 150 days/year with a duty cycle of 0.3, the annual exposure ranges from 360 to >2,000 μT-h/year. The exposure due to the brief afternoon operation may also be significant. An adult standing may receive up to about 6.5 μT, an adult sitting may receive up to 8 μT, while a small child playing on the floor may receive a whole-body average exposure of 15 μT or more. Assuming that the heater is operated for 1 h, the cumulative exposure may range between 900 and 2,200 μT-h/year. As for electric blankets, use pattern and therefore exposure may vary with climatic conditions.

House Wiring

Internal electrical wiring is unlikely to be a significant source of exposure, due to the cancellation of the fields generated by closely spaced wires. Fields recorded under high power conditions (i.e., when all lights and appliances were turned on in the house) have been found to be 40 to 100 percent higher than the fields recorded with all appliances off (i.e., when only external fields existed) [Boal and Joyner, 1988; Barnes et al., 1989]. However, the high-power condition is not only unrealistic but is impossible to be maintained for a prolonged period.

House wiring may be responsible for a non-neglibible exposure if field cancellation is imperfect (either because active and neutral wires are not close together or because of an unbalance between the forward and return currents), a person regularly spends a considerable amount of time in that area, and a large load is connected for long periods. In one instance, an elevated field (0.6 μT above background) was measured on a bed placed against a wall directly opposite the electric power meter box, where the active wire was connected to the consumption meter and the circuit breakers and therefore was separated from the neutral wire. A large load (the off-peak storage hot water system) was connected for 2 to 3 hours each night. Therefore, in this case, the cumulative exposure of the subject because of the house wires alone was >500 μT-h/year.

DISCUSSION

The model proposed in this paper is purely speculative and is not meant to be used for regulatory purposes. Although this paper has focused on domestic sources, the same approach may be used to determine the significance of sources outside the home.

The measurement results are mainly intended as examples. Emission data are likely to vary drastically with the locale, due, for example, to different distribution-line voltages. However this approach may be regarded as a working hypothesis for designing and assessing epidemiological studies. For example, use of this model may explain the conflicting opinions on the association between electric blanket use and cancer [Preston-Martin et al., 1988; Wertheimer and Leeper, 1989].

Preston-Martin and co-workers (1988) found no evidence of an elevated leukemia risk among electric blanket users in Los Angeles. They report a typical blanket use among their subjects of 8 h/day, 120 days/year, with a duty cycle of 0.4 to 0.6. Using electric-blanket-emission data, but no modeling, they estimate the exposure due to the blanket to be more than double the magnetic field exposure of a person living in a 0.1-μT background (typically on OHCC home). However, according to our model, those users received only little more than a "marginally significant additional exposure" (0.56 μT × 0.5 × 8 h/day × 120 day/y ~ 270 μT-h/year).

In the study by Preston-Martin et al. [1988], controls were matched to cancer cases for sex, race, birth year, and neighborhood (to match for socioeconomic status), but not for residential wire coding. If a small leukemia risk were associated with a marginally significant additional exposure, it could be overshadowed by the dilution and misclassification of exposure, resulting from the failure to note the residential and occupational exposure of the subjects. In addition, no correction was made for the use of electrically heated waterbeds, almost certainly more common among nonusers of electric blankets.

Wertheimer and Leeper [1989] found that data collected in Seattle, Washington, by Severson et al. [1988] indicated an association between "high" use of electric blanket and cancer. In Seattle there are approximately 8 months per year with an average temperature of 14 °C or less, compared with three in Los Angeles [*Times*, 1978]. Electric blankets are likely to be used for a much longer part of the year, even though the room temperature and therefore the duty cycle may not be significantly different. Under these conditions, our model indicates that a significant additional dose may be reached or exceeded in Seattle residents.

Even a marginally significant additional dose in subjects residing in HCCH is consistent with the marked elevation of the cancer risk observed by Wertheimer and Leeper [1982]. A marginally significant additional exposure in a subject residing in VLCC may result in a slightly elevated OR, in a way similar to that observed in residents of OLCC homes.

CONCLUSION

This paper proposes a model that could be used tentatively to assess the significance of individual sources in determining overall exposure to ELF magnetic fields. It is likely that this model may be applicable to some, but not all, exposure sources, because there are considerable differences between them.

The model should not be used with sources of intense but infrequent exposure. While in vitro studies have shown that ELF fields are capable of inducing various changes in the biochemistry at the cell membrane and in the hematopoietic and immune system [Joyner, 1988; WHO, 1984], these are reversible and often within normal physiological ranges. Therefore, only a prolonged exposure, resulting in a chronic imbalance, may be expected to have significant health effects.

The background residential magnetic field consists of numerous peaks and troughs reflecting the short-term and long-term variations in the current in the nearby electrical installations and appliances. This type of exposure is more similar to that from an electric blanket (because each part of the body is likely to be exposed to different field intensities as the subject moves in his sleep) than to those from floor-coil heaters, which are uniformly high. Incongruities in the validity of this model may indicate which exposure parameters are responsible for the suspected health effects of magnetic fields, should a causal link eventually be established.

ACKNOWLEDGMENT

I am grateful to E. Leeper and N. Werthcimer for useful discussions.

REFERENCES

Barnes F, Wachtel H, Savitz D, Fuller J (1989): Use of wiring configurations and wiring codes for estimating externally generated electric and magnetic fields. Bioelectromagnetics 10:13–21.

Baylis S (1989): Magnetic field recorder—Description and Instruction Manual. Version 1, ARL Technical Services Report. Yallambie, Australia: Australian Radiation Laboratory.

Boal TJ, Joyner KH (1988): "Levels of 50 Hz magnetic fields in the home and office environment in Australia." Radiation Protection Practice. Sydney: Pergamon Press, pp 485–488.

Bowman JD, Garabrant DH, Sobel E, Peters JM (1988): Exposure to Extremely low frequency (ELF) electromagnetic fields in occupations with elevated leukemia rates. Appl Ind Hyg 3:189–194.

Delpizzo V (1989a): An evaluation of the existing evidence on the carcinogenic potential of extremely low frequency magnetic fields. Australas Phys Eng Sci Med 12:55–68.

Delpizzo V (1989b): Use of electrical bed heating in Melbourne and implications for possible ELF magnetic field exposure. Radiat Protect Aust 7:67–69.

Fulton JP, Cobb S, Preble L, Leone L, Forman E (1980): Electrical wiring configurations and childhood cancer in Rhode Island. Am J Epidemiol 113:292–296.

Gauger JR (1984): "Household Appliance Magnetic Field Survey." Chicago: IIT Research Institute, IITRI E06549-2.

Joyner KH (1988): "Extremely low frequency electromagnetic radiation and interactions at the cell membrane. Radiat Protect Aust, 6:107–114.

Kaune WT, Stevens RG, Callahan NJ, Severson RK, Thomas DB (1987): Residential magnetic and electric fields. Bioelectromagnetics 8:315–335.

Preston-Martin S, Peters JM, Yu MC, Garabrant DH, Bowman JD (1988): Myelogenous leukemia and electric blanket use. Bioelectromagnetics 9:207–213.

Savitz DA, Wachtel H, Barnes FA, John EM, Tvrdik JG (1988): Case-control study of childhood cancer and exposure to 60 Hz magnetic fields. Am J Epidemiol 128:21–38.

Silva M, Hummon N, Rutter D, Hooper C (1989): Power frequency magnetic fields in the home. IEEE Trans Power Deliv 4:465–477.

Severson RK, Stevens RG, Kaune WT, Thomas DB, Heuser L, Davis S, Sever LE (1988): Acute non-lymphocytic leukemia and residential exposure to power frequency electromagnetic fields. Am J Epidemiol 128:10–20.

Times (1978): "The Times Atlas of the World." London: Times Books.

Tomenius L (1986): 50 Hz electromagnetic environment and the incidence of childhood tumors in Stockholm county. Bioelectromagnetics 7:191–207.

Wertheimer N, Leeper E (1979): Electrical wiring configurations and childhood cancer. Am J Epidemiol 109:272–284.

Wertheimer N, Leeper E (1982): Adult cancer related to electrical wires near the home. Int J Epidemiol 11:345–355.

Wertheimer N, Leeper E (1989): Re: Acute non-lymphocytic leukemia and residential exposure to power-frequency magnetic fields. Am J Epidemiol 130:423–425.

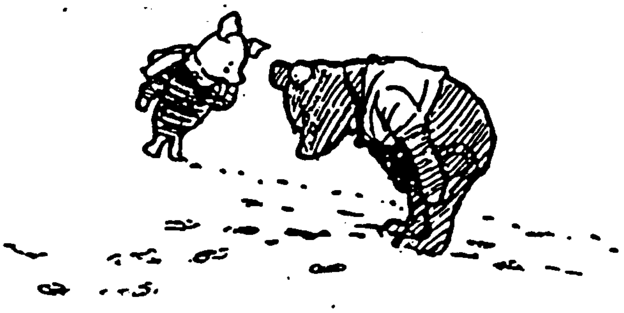
WHO (1984): "Environmental Health Criteria 35. Extremely Low Frequency (ELF) Fields." WHO-IRPA Publication. Geneva: World Health Organization.

TREDJE KAPITLET.

I vilket Puh och Nasse gå på jakt och nästan fånga en Tessla.

— Spår, sa Nasse. Märken efter tassar. Han pep till av förtjusning. O, Puh. Tror du, att det är en — en Tessla?

— Kanske det, sa Puh. Ibland ser det så ut och ibland inte. Man kan inte så noga veta med spår.



A.A. MILNE (1926)