Bioelectromagnetics 18:116–124 (1997)

# Effects Function Simulation of Residential Appliance Field Exposures

**Jun Zhang,[1] Indira Nair,[2]* and M. Granger Morgan[1]**

[1]*Oak Ridge National Laboratory, Oak Ridge, Tennessee*
[2]*Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, Pennsylvania*

This paper demonstrates the application of effects function analysis to residential magnetic field exposure, focusing on appliance sources and mitigation choices. Residential field exposure time series were synthesized by using a sample of background household field measurements, a model of average daily appliance use, and a small sample of EMDEX data of field exposure from 12 household appliances. Four alternative effects functions (average field strength with or without a threshold, field strength window, sudden field changes) were simulated by using the synthesized time series data for different exposure situations, such as high and low levels of appliance use, simple avoidance, and use of a set of hypothetical ''low field'' appliances (50% lower fields). In particular, field exposure from the use of bedside clocks and electric blankets was examined. Results demonstrate that the choice of effects function is critical for the ranks of field sources and exposure reduction choices. For the effects function of average field strength with or without a threshold, exposure from background fields dominated exposure from all appliances except for bedside clocks and electric blankets. In the case of the field strength window effects function, the dominant field sources changed with the width of the window. For the effects function based on rapid field changes, appliance use was the major source of exposure. Because of the small sample size of our data set and other simplifications, specific results should be viewed as illustrative. *Bioelectromagnetics 18:116–124, 1997.*


**Key words: magnetic fields; appliances; exposure; effects functions**

## INTRODUCTION

Recently, several epidemiological studies have suggested an association between cancer and the use of some appliances, such as hair dryers [Peters et al., 1991; London et al., 1991], black-and-white televisions [Peters et al., 1991], and electric razors [Lovely et al., 1994]. A comparison between field exposure from appliances and from other sources, such as distribution lines and house wiring, would be useful for epidemiological studies and for providing guidance on strategies for ''prudent avoidance'' [Morgan, 1992].

However, it is not clear what aspects of field exposures are relevant in defining exposure. A number of laboratory experiments have reported different characteristics of field exposure as important in a variety of biological effects. These characteristics include field strength, threshold, field strength window, field strength changes, frequency window, exposure duration, geomagnetic fields (DC fields), and other factors [Nair et al., 1989]. Given this state of scientific knowledge, we developed the concept of effects function to represent the important components of exposure that are biologically plausible [Morgan and Nair, 1992]. An effects function, as described below, is defined as a functional relationship between a hypothetical health effect level and certain characteristics of field exposure. Computer programs can be used to simulate different effects functions on field exposure time series to compare appliance fields and other sources. Our definition of effects functions and the simulation method are discussed in detail elsewhere [Morgan and Nair, 1992; Morgan et al., 1995].

The work reported here had two objectives: to determine the field exposure contribution of appliances compared with other ''background'' fields, which were measured in terms of several alternative effects functions; and to explore how different exposure management strategies affect field exposures in terms of effects

*Correspondence to: Indira Nair, Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213.

Received 14 November 1995; Final revision received 27 May 1996.

functions. To reduce residential field exposure, we may have many alternatives, such as changing house wiring, using ''low field'' appliances, or avoiding some appliances. In the absence of knowledge of the correct exposure metric, the effects functions simulation approach provides a method for incorporating different characteristics of field exposure to compare different alternatives. This paper explores two mitigation strategies related to appliances: using low-field appliances and avoiding appliances that have nonelectric substitutes, such as electric bedside clocks.

## EFFECTS FUNCTIONS

*Effects functions* are mathematical constructs that we designed in 1991 to represent the different possible exposure metrics and dose-response functions that may be implied by the current state of knowledge in bioelectromagnetics. Because both the exposure (dose) and response functions of the field were unknown, we collapsed these into a single ''effects function'' that maps field exposure pattern into resulting magnitude of a specific health effect [Morgan and Nair, 1992].

The details of the basis for choosing effects functions have been described by Morgan and Nair [1992]. Essentially, these are field dependencies that all have some plausibility, because the dependence was observed in laboratory experiments. For example, calcium efflux experiments show field strength and frequency windows. Studies on adenylate cyclase, protein kinase, and ODC activity show a bimodal response, that is, the presence or absence of a field is the relevant parameter. Thus, our effects function to represent intensity windows as a dose measure is the number of times a presumed window (with position and width chosen by us as ''reasonable'' values) is evidenced in the field time series represented by the exposure data. To demonstrate the use of effects functions in this paper, we chose five of the seven effects functions proposed in our previous work. These are described in Table 1. The effects functions chosen are based on a review of biological effects as of 1989, and the details are provided elsewhere [Morgan and Nair, 1992; Zhang, 1993]. A more recent paper also describes the various possible exposure metrics as deduced from experimental evidence to date [Valberg, 1995].

## MATERIALS AND METHODS

### Data Sets and Data Collection

Three data sets were used in this work. Data set A consisted of average field values measured in 704 homes across the United States from the 1,000-home study by the Electric Power Research Institute [Zaffanella, 1993]. Additional data are now available, but, at

**TABLE 1. Effects Functions Used in this Work and the Relevant Metric for Each. The Parameter Used for Each Effects Functions is our Estimate of Reasonable Values Based on Biological Evidence and the Ranges of Fields Encountered in Residential Environments. [Morgan and Nair, 92; Zhang 93]**

| Effects function description | Relevant metric used | Notation |
|---|---|---|
| 1. Effects proportional to: average field strength B | Time average of B | $E_1$ |
| 2. Effect proportional to: average field strength above a threshold (chosen here as 0.3 μT) | Time average of all B greater than threshold, chosen here as 0.3 μT | $E_2(3)$ |
| 3. Effect binary in field strength, i.e., effect occurs as long as field is above a particular value (regardless of field strength magnitude) and no effect when field is below threshold | Percent time when field is above specified threshold value, chosen as 0.3 μT | $E_3(3)$ |
| 4. Effect occurs when field strength is in a particular range (intensity window) | Percent time when field strength is in specified range (window). Two such functions tested: 0.15 $\mu T \leq B < 0.25$ μT and 0.25 $\mu T \leq B < 0.35$ μT | $E_4(1.5, 1)$<br>$E_4(2.5, 1)$ |
| 5. Effects proportional to field *changes* above specifc values | Counts of no. of times per hour successive values differ by more than a specified amount $\Delta B$. Three values for $\Delta B$ tested: 0.1 μT, 0.3 μT, 0.5 μT | $E_5(1)$<br>$E_5(3)$<br>$E_5(5)$ |

**TABLE 2. Type and Number of Records Containing Appliance Field Exposure**

| Appliance | Number | Note |
|---|---|---|
| Hairdryer | 7 | |
| Curling iron | 5 | |
| Electric razor | 10 | include two razors of plug-in type |
| Microwave oven | 8 | |
| Electric range | 6 | |
| Blender | 6 | include two food processors |
| Garbage disposal | 5 | |
| Vacuum cleaner | 10 | |
| Sewing machine | 4 | |
| Electric drill | 5 | include one sander |
| Clockradio | 9 | include two radioclocks of rotary type |

the time this work was being done, only average values were available.

Data set B consisted of EMDEX (Enertech, Inc., Campbell, CA) records of field exposure subjects using a variety of appliances. We collected these data using a small opportunity sample of Pittsburgh residents. The specific details are reported in Table 2. The appliance field exposure data were extracted from continuous 24 h EMDEX records of volunteers as they went about their regular activities. The data were recorded by using an EMDEX II meter with a sampling interval of 1.5 s. Depending on the appliance, volunteers were instructed either to put the EMDEX meter at spots near their heads or to wear it at their waists while using the appliances. They pushed the EVENT button when the appliances were turned on and off and recorded their activities on log sheets. In this way, the EMDEX data collected includes appliance fields with background fields as well as background fields alone. Subtracting the latter from the former yields appliance fields. However, because the field exposure is from 60 Hz AC magnetic fields, the precise field subtraction involves two aspects of the field vector: space angle and temporal phase angle. In reality, it is very difficult to define the space angles and temporal phase angles. Furthermore, the EMDEX meter records the rms value of a resultant field vector, which depends on the position of the meter when the field is measured. Consequently, to subtract a background field $B_0$ from a total field $B_t$ to get the appliance field $B_a$, we use a simple square root method, i.e., $B_a^2 = B_t^2 - B_0^2$. This approximation sometimes overestimates and sometimes underestimates the appliance field value, and we assume here that it therefore represents a reasonable midrange value for the calculated appliance fields. Table 2 shows all categories of appliances and the number of data sets collected in each category. We excluded some anomalous data that showed appliance fields beyond the typical ranges reported by EPA [1992] and by Silva et al. [1989]. These high readings usually resulted from problems with the background fields.

Data set C consisted of EMDEX records of field exposure with no appliance use. These were obtained from a set of 24 h residential field exposures that were collected from an opportunity sample of 47 Pittsburgh residents in an earlier study [Morgan et al., 1995]. Exposure records collected during sleeping hours for subjects who did not use electrical bedding were used for the purpose of background field synthesis, which is described in the next section (referred to as the sleeping data).

## Synthesis of Field Exposure

Field exposures were synthesized through a two-step process that first created a sample of background field and then combined it with a sample of appliance field. The EPRI home data, as mentioned above, consisted of 704 average values, not a time series. To obtain realistic background data, these averages had to be synthesized into a continuous time series. We could do this by using simple moving average models, such as the autoregressive moving average (ARMA) model, which adds a random-noise time series to the averages. However, analysis of our sleeping data showed that the background field is not truly random, but shows autocorrelations at long lags. This is presumably because there are diurnal use patterns that are reflected in the load and periodic variations in the power generation system. Therefore, we obtained the noise series from the sleeping data by subtracting the average from the time series. We used this as the sample of noise fields to add to the randomly selected average field strength values from data set A (the EPRI 704 home data). This constituted our synthesized ''background'' exposure.

To add appropriate appliance field exposure to the background exposure records, we constructed a model of average daily appliance usage. By average daily usage, we mean the average usage across appliance owners and nonowners and across weekdays and weekends. The probability of average daily usage of an appliance is the product of the probability of possession of the appliance and the probability of daily usage by the owners. Because of limited information on people's appliance usage, we generated both a high and a low value for subjective estimates of the probability of usage based on a combination of our subjects' responses and a number of estimates available in the literature (see Table 3, footnotes). Mean values of use duration were estimated by referring both to our subjects' responses and to a report about regular individual time-use patterns [SRC, 1982].

Table 3 gives our estimates of probabilities of

**TABLE 3. Model of Average Appliance Usage**

| | Women | | | Men | | |
|---|---|---|---|---|---|---|
| Appliance | Probability of high usage | Probability of low usage | Mean use time (min.) | Probability of high usage | Probability of low usage | Mean use time (min.) |
| Hairdryer | 0.95 | 0.5 | 8 | 0.5 | 0.2 | 2 |
| Curling iron | 0.8 | 0.5 | 5 | 0 | 0 | 0 |
| Electric razor | 0.05 | 0 | 1 | 0.33** | 0.2 | 1 |
| Microwave oven | 0.9* | 0.4 | 3 | 0.9* | 0.4 | 3 |
| Electric range | 0.5* | 0.3 | 15 | 0.2* | 0.1 | 10 |
| Blender | 0.2 | 0.05 | 1 | 0.1 | 0 | 1 |
| Garbage disposal | 0.5 | 0.2 | 1 | 0.5 | 0.2 | 1 |
| Vacuum cleaner | 0.2 | 0.05 | 10 | 0.2 | 0.05 | 10 |
| Sewing machine | 0.2 | 0.05 | 10 | 0 | 0 | 0 |
| Electric drill | 0.01 | 0 | 1 | 0.2 | 0.1 | 1 |
| Clockradio | 0.8 | | 468 | 0.8 | | 468 |
| Elec. blanket | 0.0625 | | 468 | 0.0625 | | 468 |

*Estimates in [Biracree and Biracree, 1988], electric range counts 53.3%; microwave oven was predicted to reach 80% of families by 1990.

**One third of American men are estimated to use electric razor, and the plug-in type is about one third. [Gauger, 1985]

appliance usage and mean durations of use for women and men. The actual use times of appliances for each synthesized data set were generated by drawing samples from the log-normal distribution with mean shown in Table 2. An appropriate standard deviation, which was subjectively chosen not to exceed reasonable times for an activity, was determined to ensure a reasonable range for the distribution, e.g., a distribution for hair dryer use time should not exceed 30 min. Electric blanket exposure was implemented deterministically with a single measured time series. According to several epidemiological studies, the usage prevalence of electric blanket ranges from 15 to 65% [Wertheimer and Leeper, 1982; Florig and Hoburg, 1991]. We assume, as a conservative estimate, that 25% of people use electric blankets for 3 months per year. Therefore, the average per capita probability of daily usage of electric blankets is of the order of 1/16 for the whole year.

Subjective probabilities of high and low usage and estimated mean time are based on the parameters in Table 3. Records of appliance field exposure were superimposed on 50 exposure records of background fields to yield exposure records of combined background and appliance fields. These 50 samples consisted of 25 men and 25 women. We simulated nine situations as follows: 1) base situation (background field exposure alone), 2) low usage of appliances, 3) low usage of appliances with avoidance, 4) low usage of appliances with low field (50% of current) designs, 5) high usage of appliances, 6) high usage of appliances with avoidance, 7) high usage of appliances with low field (50% of current) design, 8) high usage of appliances with bed-side clock, and 9) high usage of appliances with bed-side clock and electric blanket. Here, avoidance means that people avoided the use of some appliances. Table 4 shows the appliance usage assumed for the avoidance condition. Appliances were taken to be avoidable or not avoidable according to this scheme. The scheme is admittedly arbitrary, and it is used solely for demonstration of this method.

In the avoidance scenario, fields from the appliances listed as avoidable were excluded when calculating effects function values. The simulations for low-field appliances arbitrarily assumes a low-field design that lowers the magnetic fields by 50%. In fact, in our data set appliance fields have a large range in each category. In our simulation, we did not classify them as high-field appliances or low-field appliances, but we decreased all appliance fields by 50%.

## Simulation of Effects Functions

Elsewhere, we have described how one can write a computer program to apply a number of different effects functions to personal-monitor time series data [Morgan et al., 1995]. For example, suppose one wants to implement an effects function based on an intensity window. A sampled personal-monitor time series is obtained, and a computer program then searches the time series for those instances when the field strength lies inside the range of the window. The final result of this search composes an effects function value. The effects functions used for this simulation are listed below. All of the parameter values were selected for the purpose of illustration: 1) effects function based on average field strength [$E_1$ (average B)]; 2) effects function based on average field strength above a threshold of 0.3 μT [$E_2(3)$]; 3) effects function based on percentage of time when field strength is above a threshold of

**TABLE 4. Avoidance of Appliance Usage Assumed in this Work**

| Appliance | Avoidable | Appliance | Avoidable | Appliance | Avoidable |
|---|---|---|---|---|---|
| Hairdryer | Yes | Electric range | Yes | Sewing machine | No |
| Curling iron | Yes | Blender | Yes | Electric dril | No |
| Elecric razor | Yes | Garbage disposal | Yes | Clockradio | Yes |
| Microwave oven | No | Vacuum cleaner | No | | |

0.3 μT [$E_3(3)$]; 4) effects function based on field strength window [$E_4(1.5, 1)$, % B when 0.15 μT ≤ B < 0.25 μT; $E_4(2.5, 1)$, % B when 0.25 μT ≤ B < 0.35 μT]; and 5) effects function based on field strength changes [$E_5(1)$, counts of $\Delta B \geq 0.1$ μT per h; $E_5(3)$, counts of $\Delta B \geq 3$ μT per h; $E_5(5)$, counts of $\Delta B \geq 0.5$ μT per h]. Note that, because of the 1.5 s sample rate, EMDEX data do not allow the exploration of rapid transients. After we obtained the effects function values from the simulation, we calculated the sample means for the data set of 50 synthesized samples for comparisons under different situations.

## RESULTS

### Comparison of Field Sources

To compare the contributions of appliance and background field sources to exposure, we obtained the value of each effects function for appliance fields (effects function value of AF) by subtracting the effects function value for background fields (effects function value of BF) from the effects function value for exposure records of background and appliance fields (effects function value of BAF). Then, the fractional contribution of appliance field exposure was obtained by dividing effects function value of AF by effects function value of BAF. The same procedure also determined the fractional contribution of background fields.

Thus, the relative exposure contribution of appliances shown in Figures 1–4 was obtained by the procedure represented in the following equation over the distribution of field values for the ''average'' record.

$$\left.\begin{array}{r}\text{Fractional contribution of}\\ \text{appliance fields for a given}\\ \text{effects function k, EFCNk}\end{array}\right\} = \frac{E_k(\mathrm{BAF}) - E_k(\mathrm{BF})}{E_k(\mathrm{BAF})}$$

Depending on the effects function simulated, different sources of residential fields contribute different fractions of the daily field exposure. For the effects function of average field strength $E_1$ (Ave B) shown in Figure 1, the background fields contribute a much larger portion (87%) than the appliance fields (13%). Including the use of a bed-side clock (22% motor driven, 78% digital) used for about 8 h/day lowers this fractional contribution of the background fields, as shown in Figure 1b, to 63.4% for background fields, 9.6% for appliance fields, and 27.0% for clock fields.

Background fields also contribute the most to the effects function $E_2$, which considers the percentage of time spent above a threshold of 0.3 μT, $E_3$ (% B > 0.3 μT). The background fields constitute 90% of exposure, and appliance fields constitute only 10% of exposure. For this effects function, adding a clock to the sources results in the clock contributing the largest portion, 57%, compared with 40% from background fields and 4% from appliance fields.

Field exposure from appliances becomes the major fraction for $E_5$, the effects functions of field changes. Figure 2 shows the two situations, low and high usage of appliances, for the effects function $E_5(1)$ of counts of $\Delta B \geq 0.1$ μT per h. For this effects function, appliance fields contribute 28% under low usage (Fig. 2a) and 40% under high usage (Fig. 2b).

Figure 3 shows that the appliance fields become dominant for the effects function $E_5(3)$ of counts of $\Delta B \geq 0.3$ μT per h, as 90% for the low usage and 94% for the high usage. This situation is also true for the effects function of counts of $\Delta B \geq 0.5$ μT per h. This is consistent with the fact that there are usually not many field changes higher than 0.3 μT in a normal residential background.

Figure 4 shows the relative contribution of background and high appliance usage for two effects functions—$E_1$ (average B) and $E_3$ (percentage of time when B > 0.3 μT). For the effects function of average field strength shown in Figure 4a, the background field contributes 44%, the blanket contributes 31%, and the clock contributes 19%. All other appliances together contribute 6.63%. For the ''binary'' effects function $E_4$, which is measured as the percentage of time when B ≥ 0.3 μT (shown in Fig. 4b), the clock contributes the largest fraction (39%), the background contributes a slightly smaller fraction (36%), the blanket contributes 21%, and other appliances contribute only 3%. Com-

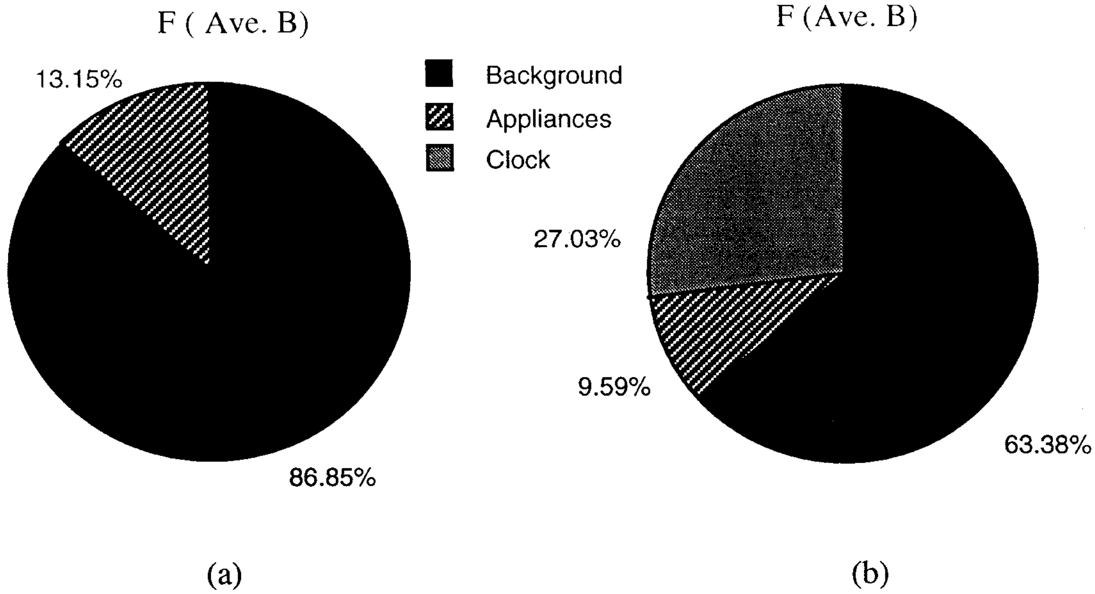


Fig. 1. **a:** Contributions of different sources for $E_1$ [average (Ave) B]. **b:** Illustration of the dominant contribution of the bedside clock, which is assumed to be used continuously for 7.8 h a day, compared with much smaller periods of use for other appliances.

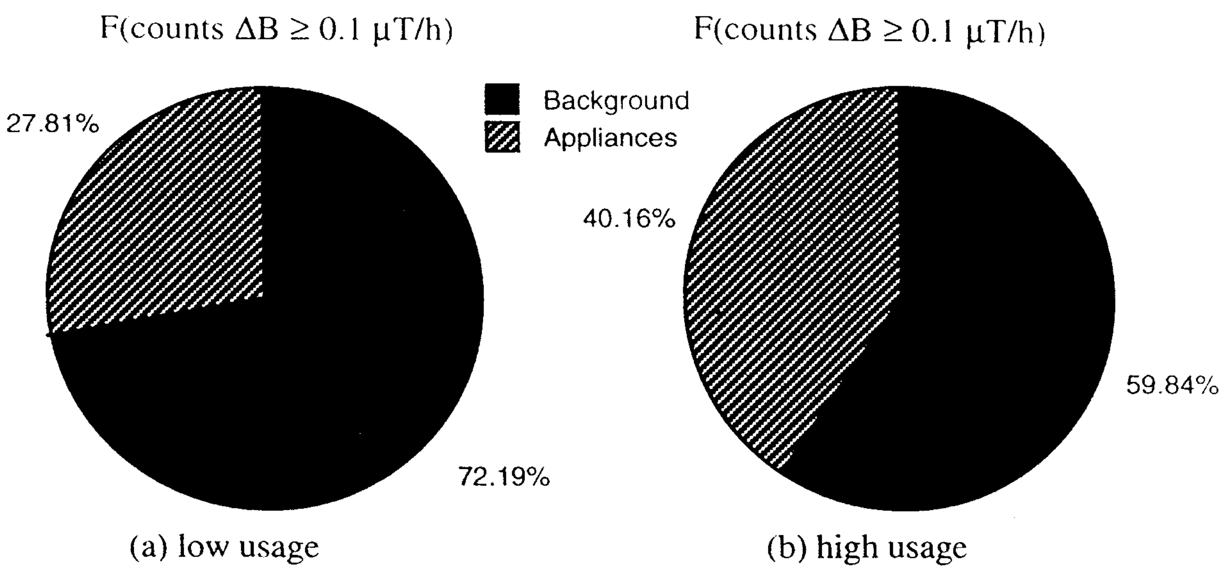


Fig. 2. Fractional contributions of appliances for $F_5(1)$ (counts $\Delta B \geq 0.1$ μT/h) for low (**a**) and high (**b**) usage.

parison with the effects function $E_1$ (average B) in Figure 1a shows that, if this metric is operative, then average B would not be an appropriate measure of exposure, especially for ranking sources.

### Comparison of Field Exposure Reductions

Table 5 lists the ranges of calculated fractional exposure reductions for five avoidance situations for each effects functions. These are 1) avoidance compared with base case of low appliance usage (Table 5, second column); 2) avoidance compared with base case of high appliance usage (Table 5, third column); 3) avoidance with base case of high appliance use, including bedside clock (Table 5, fourth column); 4) avoidance with base case of low appliance usage with low (50%) field appliances (Table 5, fifth column); and 5) avoidance with base case of high appli-

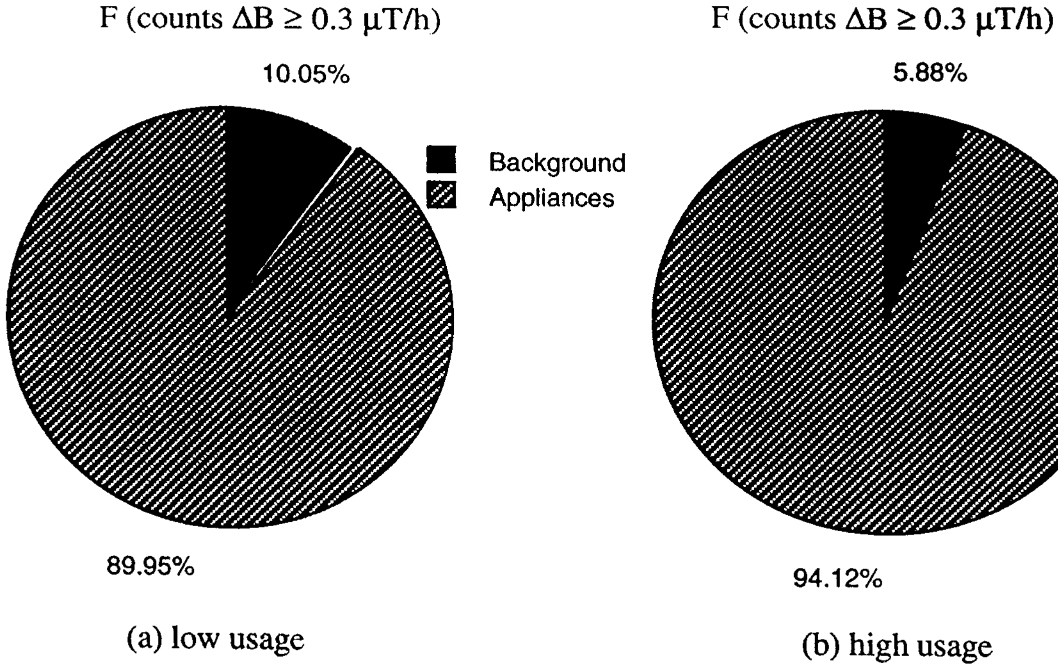


Fig. 3. Fractional contributions of appliances for $E_5(3)$ (counts $\Delta B > 0.3\ \mu T/h$). Appliances provide the dominant contribution, 90% for the low-usage scenario (**a**) and 94% for the high-usage scenario (**b**).

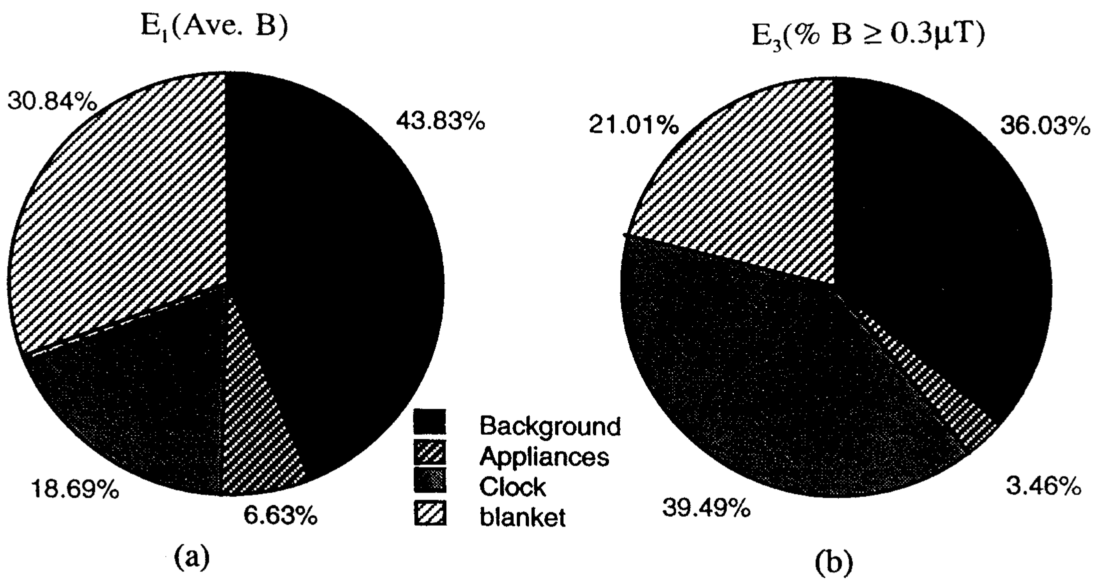


Fig. 4. Contributions of different sources for $E_1$ (Ave B; **a**) and $E_3$ [percentage of time when B (% B) $> 0.3\ \mu T$; **b**]. This demonstrates that, depending on the combined appliance usage, the average field may not be an appropriate exposure metric if the relevant metric depends only on excursions above a certain value.

ance usage with low (50%) field appliances (Table 5, sixth column).

The percentages shown are fractional reductions obtained for the two strategies of avoidance and 50% lowering of field values for appliances relative to different base cases. It is apparent that we do not see

**TABLE 5. Percentage Reduction of Exposure (as measured by effects function) for Different Strategies of Avoidance and Lowering Field by 50% Compared to Various Base Use Scenarios**

| | Percent exposure reduction for strategy: avoidance compared to base case of: | | | Percent exposure reduction for strategy: low field appliance design compared to base case of: | |
|---|---|---|---|---|---|
| Effects function (F) | Low usage of appliance | High usage of appliance | High usage of appliance including clock | Low usage of appliance | High usage of appliance |
| $F_1$ (Ave. B) | 3 | 5 | 29.6 | 4 | 9 |
| $F_3$ (Ave. B $\geq$ 0.3 μT) | 10 | 13 | 54 | 11 | 25 |
| $F_2$ (% B $\geq$ 0.3 μT) | 3 | 5 | 58 | 2 | 3 |
| $F_4$ (1.5, 1) (1.5 $\leq$ B $>$ 0.25 μT) | 0.7 | 1 | 21 | −0.13 | 0.2 |
| $F_4$ (2.5, 1) (2.5 $\leq$ B $<$ 0.35 μT) | 0.07 | 0.8 | 38 | −0.09 | 0.1 |
| $F_5$(1) ($\Delta$B $\geq$ 0.01μT/h) | 21 | 27 | 26 | 11 | 13 |
| $F_5$(3) ($\Delta$B $\geq$ 0.3 μT/h) | 62 | 71 | 62 | 40 | 44 |
| $F_5$(5) ($\Delta$B $\geq$ 0.5 μT/h) | 62 | 76 | 62 | 43 | 44 |

big reductions for those effects functions for which appliance fields do not make large contributions (e.g., $E_1$, the effects function $E_2(3)$ of average field strength, and, with the exception of the clock, the effects function of percentage of time when B $\geq$ 0.3 μT). For the effects function of average field strength above 0.3 μT, the usage of low-field appliance may result in an 11–25% reduction (compared with a 10–13% reduction from avoidance). It is interesting, but expected, that, for the case of a field strength window, the use of low-field appliances with fields in the window can result in an *increase* in effects function.

## DISCUSSION

The specific numerical results reported in this paper should be viewed as only illustrative, given the limited data and assumptions on which they are based. However, the work illustrates a method to analyze the sources of residential field exposure and exposure reduction choices. It demonstrates that the ranking of the sources of residential field exposure and comparison of exposure reduction choices depend critically on the effects function employed. Therefore, the selection of mitigation strategies will target different field sources, depending on what kind of effects function, if any, proves to be valid. If an effects function based on field strength is valid, then it is important to implement mitigation strategies for the background fields, electric bedding, and some bed-side clocks. If an effects function that involves field changes, such as $E_5$, is found to be valid, then it would be important to avoid appliances, especially electric blankets, and to encourage appliance design changes.

Although our EMDEX data have a 1.5 s sampling interval and do not really reflect dB/dt, they still capture some rough or ‘‘global’’ field changes that may embody many transients. Appliances generate switching transients when they are turned on or off, as indicated by Guttman et al. [1992]. In addition, some appliances, such as hair dryers and heating pads, also generate ‘‘randomly occurring transients during normal operation due to motor brush sparking and heater switching’’ [Guttman et al., 1992]. Our EMDEX data do show some fluctuations in the hair dryer field series. In fact, other appliances, such as electric ranges and vacuum cleaners, also show a type of load-unload field change.

This simulation has several limitations that restrict the generality of the conclusions that can be reached from the numerical results obtained. These limitations include the small size of the samples of appliance field exposure data for each category, the use of only very approximate estimates of average appliance usage, and several simplifications and assumptions in the synthesis process of field exposure time series. This method could become increasingly useful in exposure management for residential field exposure as more data become available and as more scientific evidence supports plausible effects functions.

## ACKNOWLEDGMENTS

This work was supported by Southern California Edison. We thank Luciano Zaffanella for the EPRI data and Victoria Massimino for assistance with the paper.

## REFERENCES

Biracree T, Biracree N (1988): ‘‘Almanac of the American People.’’ New York: Facts on File, pp 258–259.

EPA (1992): EMF in your environment: Magnetic field measurement of everyday electrical devices. Washington, DC: US EPA Office of Radiation and Indoor Air, 402-R-92-008.

Florig HK, Hoburg JF (1991): Electric and magnetic field exposure associated with electric blankets, EPRI TR-100180.

Gauger J (1985): Household appliance magnetic field survey. IEEE Trans Power Appar Syst 15:439–446.

Guttman JL, Niple JC, Silva JM (1992): High-bandwidth measurements of transient magnetic fields in residential environments. In: Abstracts, Bioelectromagnetics Society ''The First World Congress for Electricity and Magnetism in Biology and Medicine, Orlando, FL, June 14–19, 1992. P-192.''

London JL, Thomas DC, Bowman JD, Sobel E, Cheng T-C, Peters JM (1991): Exposure to residential electric and magnetic fields and risk of childhood leukemia. Am J Epidemiol 134:923–927.

Lovely RH, Buschbom RL, Slavich AL, Anderson LE, Hansen NH, Wilson BW (1994): Adult leukemia risk and personal appliance use: A preliminary study. Am J Epidemiol 140:510–517.

Morgan MG (1992): Prudent Avoidance. Public Utilities Fortnightly March 15, 1992: 26–29.

Morgan MG, Nair I (1992): Alternative functional relationships between ELF field exposure and possible health effects: Report of an expert workshop. Bioelectromagnetics 13:335–350.

Morgan MG, Nair I, Zhang J (1995): A method for assessing alternative effects functions that uses simulation with EMDEX data. Bioelectromagnetics 16:172–177

Nair I, Morgan MG, Florig HK (1989): Biological effects of power frequency electric and magnetic fields. Washington, DC: OTA Background Report.

Peters JM, Thomas DC, Bowman JD, Sobel E, London SJ, Cheng TC (1991): Exposure to residential electric and magnetic fields and risk of childhood leukemia. Interim Report, EPRI EN-7464 Project 2964.

Silva M, Hummon, NP, Rutter D, Hooper C (1989): Power frequency magnetic fields in the home. IEEE Trans Power Deliv 4:465–478.

SRC (1982): ''1975–1981 Time Use Panel Synthetic Week Respondents.'' Ann Arbor, MI: Survey Research Center, Institute for Social Research, University of Michigan.

Valberg PA (1995): Designing EMF experiments: What is required to characterize ''exposure''?. Bioelectromagnetics 16:396–401.

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

Zaffanela LE (1993): Survey of residential magnetic field sources. EPRI TR-102759.

Zhang J (1993): ''Parametric Approach to Quantitative Assessment of EMF Risks.'' Pittsburgh, PA; Carnegie Mellon University, Ph.D. Thesis.