TOPIC #9: MODELING EMF PERSONAL EXPOSURE

SYNOPSIS

Prepared by
T. Dan Bracken
T. Dan Bracken, Inc.
Portland, OR

Purpose

To summarize the state-of-knowledge of methods for modeling personal exposure to magnetic fields.

Introduction

Exposures to environmental agents can be determined directly through PE measurements or indirectly through models based on time/activity information and exposure levels. Often it is not possible to obtain direct measures of exposure. In such cases, models are a tool to provide estimates of past or present exposures. For example, retrospective epidemiological studies require estimates of past exposures that can be obtained only through modeling. Similarly, for contemporaneous assessments it may not be practical to obtain PE measurements because of logistics and/or cost.

The time/activity information in a model describes where, when, and for how long individuals are in a location and in what activity they are engaged. For EMF exposure models, a magnetic field is associated with each time/activity category of interest. Exposure is then estimated from an aggregation of time in each category and field level. The field levels may be based on PE measurements during similar activities, on survey measurements in specific locations, or on calculated field levels. For a general time/activity category, exposure is often based on the field levels presumed for or assigned to a broad surrogate such as wire-code category for residential exposure or job category for occupational exposure.

Ideally, data from large-scale population-based time/activity surveys could provide the necessary time/activity information for EMF exposure assessment models. Unfortunately, time/activity diary categories in such surveys are not specific to EMF exposures: for example, it is difficult to link EMF exposures to diary categories that were selected for estimating exposures to air- or water-borne pollutants.

Modeling EMF exposures is difficult because field levels are dependent on proximity to area (background) and local sources, and are also highly variable within the categories usually associated with time/activity data (e.g., inside residence, inside kitchen, inside vehicle, and outside). Furthermore, most subjects can not readily identify specific sources, other than familiar appliances and tools, nor can they recognize and remember specific conditions associated with exposures in an environment.

The lack of an exposure parameter that is linked through dose to health outcome also complicates the development of EMF exposure models. The data base for TWA average exposures in particular environments or from sources is fairly extensive. However, data on exposure levels for other exposure parameters in these same locations are sparse. Consequently, EMF exposure models have concentrated on estimating TWA for specific time periods.

Estimates may be required for contemporaneous or historical EMF exposures. PE measurements or exposure models can estimate exposures of the former type, but only models are possible for historical exposures.

RAPID Program

Many of the projects sponsored by the RAPID Engineering Program are directly related to modeling EMF PE. RAPID Projects #3 and #7 (Zaffanella, 1996; Rankin and Bracken, 1997) and Kaune et al. (1996) developed explicit exposure models. RAPID Projects #1 and #3 collected data to characterize field levels for appliances and other sources (Electric Research and Management, Inc., 1997; Zaffanella, 1996). RAPID Project #6 (Zaffanella and Kalton, 1998a; 1998b) collected contemporaneous time/activity and PE measurement data to characterize exposures of the general public. These data can be used directly as inputs to models for exposure assessment.

RAPID Engineering Project #2 (Bittner, 1997) developed a methodology for classifying micro-environments within a complex facility to permit targeting of measurements at locations where exposures occur. RAPID Project #4 (Bracken et al., 1997) evaluated methodologies for incorporating time/activity record-keeping into EMF PE measurement studies. They also found that time/activity data collected for use in modeling exposure to air pollution was not useful in modeling EMF exposures.

Residential Exposure

Models of residential exposure have been based on contemporaneous survey and PE measurements, on field levels assigned to surrogates such as wire-code category, and on computed fields from nearby power lines. Sources of residential exposure include external power lines, internal wiring, ground currents, and appliances (cf., Kaune, 1993). Exposure models have been developed to address one or more of the three source types. Models based on PE measurements account for all sources. Reliance on survey measurements, typically conducted at the center of rooms, or computed fields from nearby power lines to establish exposure levels may neglect contributions to exposure from internal wiring and appliances.

PE measurements have been used to build models for current and recent exposures. Extrapolation of contemporaneous field measurements to model past exposure is more problematic. However, there seems to be a reasonable degree of stability in measured residential fields over periods of months to several years that support their use in historical exposure models. Dovan et al. (1993) found that average spot measurements, repeated five years apart in houses in Denver, were rather well correlated. PE, spot, and long-term measurements were also relatively stable over up to six visits made over a two-year period to 396 houses in a nationwide survey (Bracken et al., 1994a). The stability of measured fields depends on the constancy of the external electrical system and the internal wiring of a residence. Significant changes in either of these can affect magnetic-field levels. However, electrical facilities are commonly designed with a long lifetime, making modifications, such as changes in line configuration, infrequent.

External Power Lines

Historical exposure models have often relied on field estimates related to the proximity of local power lines. Exposure levels have been assigned to homes based on the wire-code category of a home and on field calculations. Both approaches tend to ignore the contributions to exposure of local sources experienced when a person moves from place to place in the home.

Categorical wire-code classification schemes for magnetic-field exposure are predicated on the relationship between field level and the distance from the power line and on the assumption that larger conductors are carrying larger currents (cf., Kaune, 1993). The schemes assign higher exposures to higher categories based on these factors. Investigations of the relationship between residential field levels (PE and survey measurements) and wire-code categories indicate that field levels generally increase in the hierarchical scheme, but that there is considerable overlap of the field levels found in different categories. Assignment of quantitative exposures based on wire-code category is therefore uncertain. However, wire-code categories have been somewhat successful in categorizing exposures as high or low.

Computational models provide another non-invasive method to model residential magnetic-field exposures. In an epidemiology study in the United Kingdom, Myers et al. (1985) used calculated fields to estimate the contribution to exposure of nearby power lines. To account for historical exposure they used the maximum current condition (load) during the period of interest for their calculations. Feychting and Ahlbom (1993) modeled residential exposures in Sweden back as far as 40 years, using fields calculated from topographical and historical load data for nearby transmission lines. In this case, historical calculations were more strongly associated with disease than contemporary spot measurements, even though the two surrogate measures had relatively high correlation (Feychting et al., 1996).

Internal Wiring and Ground Currents

Residential factors that appear to be related to fields from internal wiring and grounding are: residence size, presence of two-prong receptacles, incorrectly wired 3-way switches, the presence of more than one electric service panel, and connection to a water system with conductive or non-conductive pipes. The influence of these factors on average field levels has been quantified in both the 1000-home (Zaffanella, 1993) and 1000-person (Zaffanella and Kalton, 1998a) surveys. However, assigning a quantitative field value to these factors for modeling purposes is difficult.

Mader et al. (1990) developed a computational model to account for household wiring and grounding as well as external power lines. It relies on the geometry and measured current of the grounding circuit and a measurement of the external power-line field. The level of access and sophistication required to collect the input data may limit widespread implementation.

Appliances

Many models for EMF exposure from appliances have been based on measured and calculated appliance fields, the relative location of the user, and the frequency and patterns of use (Delpizzo, 1990; Florig and Hoberg, 1990; Mader and Peralta, 1992; Wilson et al., 1996). Results indicate that most household appliances are not a significant source of TWA whole-body exposures, but can be a dominant source of TWA and peak exposures for extremities. Specific sources with elevated fields that are used for long periods of time, such as older electric blankets, other bed heating devices, and electric heating coils in the floor can affect TWA exposure.

Kaune et al. (1996) investigated exposure produced by domestic appliances in a group of 50 women in the United Kingdom. They compared questionnaire data with PE measurements, and found appliance use to be unrelated to measured TWA exposures. However, a measure of peak exposures was found to be related to appliance use. These results are consistent with those from previous models that relied on estimated appliance fields and did not have confirming PE measurements.

Occupational Exposure

Occupational exposures have been modeled at two levels: 1) using time/activity/task information plus PE or survey measurements to estimate exposures for specific activities and job categories; and 2) aggregating across job categories to produce exposures over an occupational history for individuals.

Time/activity/task Models

PE measurements within tasks and estimated time in tasks were the bases for an EMF exposure model for workers in electrical and non-electrical job categories (Bowman et al., 1992). Average exposures were estimated for tasks and job categories for both current and historical (20 years ago) conditions. Time-in-task and historical variations were based on interviews with experienced supervisors.

TWA and peak exposures have been modeled for transmission- and distribution-line workers performing live-line maintenance tasks (Bracken, et al., 1994b). PE measurements established exposure levels for particular tasks, current levels, worker locations, and facility types. Incremental annual exposures attributable to new live-line work practices were computed based on the reported frequency of task performance and the assigned exposure for each task. PE measurements were adjusted to coincide with the annual average current estimated during maintenance activities. Annual exposures during live-line maintenance tasks have also been modeled for French workers from calculated fields and estimated times performing tasks (Hutzler et al., 1994).

RAPID Project #3 (Zaffanella, 1996) relied on survey measurements of area (background) fields and sources to provide the field input to an exposure model. Information on the number and type of persons and the time they spent in different areas was obtained through a questionnaire. The field and time/activity information was combined to estimate exposures by person type in grocery stores, machine shops, hospitals, schools, and office buildings.

Job-exposure Matrix

Magnetic-field exposure models based on a job-exposure matrix (JEM) developed from PE measurements have been employed in numerous epidemiology studies (Bowman et al., 1992; Sahl et al., 1993; Kromhout et al, 1994; Thériault et al., 1996). Common to all these is the assignment of an exposure to each job category based on PE measurements or other data and the computation of exposure for individuals based on their job histories.

Comprehensive JEMs that include occupations outside the electric utility industry are less developed; however, they are needed if exposure models and assessments are to include more industries and workers. Floderus et al. (1996) presented a JEM for mean and maximum magnetic-field exposures of the 100 most common occupations in Sweden. The exposures were based on PE measurements for a population-based random sample of 1098 men. Yost et al. (1997) have constructed a JEM for 46 two-digit Standard Occupational Classification (SOC80, 1980) based on PE measurements from five studies. However, the number of workers contributing measurements in many codes is limited, and the individual codes at the two-digit level can encompass many occupations with a broad range of EMF exposures.

Total Exposure

RAPID Project #6 (Zaffanella and Kalton, 1998a; 1998b) provides the first set of comprehensive data for total exposure. RAPID Project #7 (Rankin and Bracken, 1997) developed a questionnaire-based model for exposure to three magnetic-field parameters: TWA, peak, and harmonics. Time/activity and source-use information is collected using a questionnaire. Field values based on reported measurements are assigned to various locations and sources (appliance, tools, etc.) at home, at school and in other environments. Work exposure is estimated from a JEM based on SOCs (Yost et al., 1997). Both point-estimates and statistical distributions can be accommodated for the time/activity and field inputs to the model.

Implications for Risk Assessment

Modeling of EMF exposures is still in at a formative and exploratory stage. It has not been the subject of scientific review to the extent that other engineering aspects of EMF have been.

Considerable uncertainty exists in the assignment of exposures to specific exposure categories within both residential and occupational models. This uncertainty is compounded as exposures are combined to model long-term or total exposures. Therefore, it is important to include collection of location/time/activity data in future studies.

Except for a few extended-use appliances (e.g., electric blankets), appliances do not appear to contribute to residential TWA exposures. However, appliances do contribute to peak exposures and to extremity exposures.

Changing technologies must be considered in modeling exposures. This applies to changing work practices and especially to appliances, where batteries have replaced AC power and new low-field designs have been introduced. Historical changes in average residential exposures and within homes are expected to be less dramatic because of the long-term stability of the external power system and wiring within houses.

Remaining Questions

1. What exposure parameter is relevant to health outcomes and risk assessment?
2. What is the most effective methodology for modeling historical residential exposures: contemporary measurements, calculated fields, wire-code categories, or a combination of methods?
3. Are there practical time/activity categories for questionnaires and diaries that can be linked specifically to EMF exposures?

References

Bittner, P (1997): Development of recommendations for guidelines for environment-specific magnetic-field measurement. RAPID Engineering Project #2. Magnetic Measurements for Oak Ridge National Laboratory EMF Research Program. U.S. Department of Energy.

Bowman,JD; Sobel,E; London,SJ; Thomas,DC; Garabrant,DH; Pearce,N; Peters,JM (1992): Electric and magnetic field exposure, chemical exposure, and leukemia risk in "electrical" occupations. Final Report TR-101723. (EPRI TR-101723, Project 799-27, Final Report, December 1992) Prepared by USC School of Medicine, Department of Preventive Medicine for Electric Power Research Institute, Palo Alto, CA. 100 pages.

Bracken,TD; Rankin,RF; Senior,RS; Alldredge,JR (1994a): The EMDEX Project: Residential Study, Volumes 1-3. (EPRI TR-104325) Electric Power Research Institute, Palo Alto, CA.

Bracken,TD; Rankin,RF; Long,PJ; Senior,RS; Keller,M; Gray,WS (1994b): PG&E lineworker EMF monitoring study: Personal exposure measurements. *In*: W/L Associates Ltd. (Ed.) (1997) Project abstracts: The annual review of research on biological effects of electric and magnetic fields from the generation, delivery & use of electricity. W/L Associates, Ltd., Frederick, MD, 34-35.

Bracken,TD; Rankin,RF; Wiley,JF; Bittner,P (1997): Recommendations for guidelines for EMF personal exposure measurements. RAPID Engineering Project #4, T. Dan Bracken, Inc., Portland, OR, for Oak Ridge National Laboratory EMF Research Program, U.S. Department of Energy.

Delpizzo,V (1990): A model to assess personal exposure to ELF magnetic fields from common household sources. Bioelectromagnetics 11, 139-147.

Dovan,T; Kaune,WT; Savitz,DA (1993): Repeatability of measurements of residential magnetic fields and wire codes. Bioelectromagnetics 14(2), 145-159.

Electric Research and Management, Inc. (1997): Development of recommendations for guidelines for field source measurement. RAPID Engineering Project #1. For Oak Ridge National Laboratory EMF Research Program, U.S. Department of Energy.

Feychting,M; Ahlbom,A (1993): Magnetic fields and cancer in children residing near Swedish high-voltage power lines. Am. J. Epidem. 138(7, 1 October), 467-481.

Feychting,M; Kaune,WT; Savitz,DA; Ahlbom,A (1996): Estimating exposure in studies of residential magnetic fields and cancer: Importance of short-term variability, time interval between diagnosis and measurement, and distance to power line. Epidemiology 7(3, May), 220-224.

Floderus,B; Persson,T; Stenlund,C (1996): Magnetic-field exposures in the workplace: Reference distribution and exposures in occupational groups. Int. J. Occup. Environ. Health 2(3, July-September), 226-238.

Florig,HK; Hoburg,JF (1990): Power-frequency magnetic fields from electric blankets. Health Phys. 58(4, April), 493-502.

Hutzler,B; Baraton,P; Vicente,JL; Antoine,JC; Roux,M; Urbain,JP (1994): Exposure to 50 Hz Magnetic Fields During Live Work. CIGRE International Conference on Large High Voltage Electric Systems, Paris, France. 9 pages.

Kaune,WT (1993): Assessing human exposure to power-frequency electric and magnetic fields. Env. Health Persp. 101(Suppl. 4), 121-133.

Kaune,WT; Preece,AW; Grainger,P; Golding,J (1996): Assessment of human exposure to magnetic fields produced by domestic appliances. Lockheed Martin Energy Systems, Inc., Oak Ridge, TN. 130 pages.

Kromhout,H; Loomis,DP; Mihlan,GJ; Peipins,LA; Kleckner,RC; Iriye,R; Savitz,DA (1995): Assessment and grouping of occupational magnetic field exposure in five electric utility companies. Scand. J. Work Environ. Health 21(1, January), 43-50.

Mader,DL; Barrow,DA; Donnelly,KE; Scheer,RR; Sherar,MD (1990): A simple model for calculating residential 60-hz magnetic fields. Bioelectromagnetics 11(4), 283-296.

Mader,DL; Peralta,SB (1992): Residential exposure to 60-Hz magnetic fields from appliances. Bioelectromagnetics 13, 287-301.

Myers,A; Cartwright,RA; Bonnell,JA; Male,JC; Cartwright,SC (1985): Overhead power lines and childhood cancer. (Proceedings of IEE International Conference on Electric and Magnetic Fields in Medicine and Biology.) IEE, London. pp. 125-130.

Rankin,RF; Bracken,TD (1997): Development of a magnetic field exposure model. In: W/L Associates Ltd. (Ed.) (1997): Project abstracts: The annual review of research on biological effects of electric and magnetic fields from the generation, delivery & use of electricity, San Diego, California, USA, November 9-13, 1997. W/L Associates, Ltd., Frederick, MD. 148 pages.

Sahl,JD; Kelsh,MA; Greenland,S (1993): Cohort and nested case-control studies of hematopoietic cancers and brain cancer among electric utility workers. Epidemiology 4(2, March), 104-114.

SOC80 (U.S. Department of Commerce - Office of Federal Statistical Policy and Standards) (1990): Standard occupational classification manual. U.S. Government Printing Office. Washington, DC.

Thériault,G; Goldberg,M; Miller,AB; Armstrong,B; Guénel,P; Deadman,J; Imbernon,E; To,T; Chevalier,A; Cyr,D; Wall,C (1994): Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada, and France: 1970-1989. Am. J. Epidem. 139(6, 15 March), 550-572.

Wilson,BW; Lee,GM; Yost,MG; Davis,KC; Heimbigner,T; Buschbom,RL (1996): Magnetic field characteristics of electric bed-heating devices. Bioelectromagnetics 17, 174-179.

Yost, MG; Touchstone, JA; Wrensch, M; Miike, R; Carozza, SE; Bowman, JD (1997): Development of a population based job-exposure matrix for 60 Hz magnetic fields. Poster presented at the biological effects meeting in San Diego, November, 1997.

Zaffanella,LE (1993): Survey of residential magnetic field sources. Vol. 1: Goals, results, and conclusions. (EPRI TR-102759-V1, Project 3335-02) Electric Power Research Institute, Palo Alto, CA.

Zafanella, LE (1996): Environmental Field Surveys: EMF RAPID Program engineering project #3. Enertech Consultants, Lee, MA.

Zaffanella,LE; Kalton,GW (1998a): Survey of personal magnetic field exposure. Phase I: Pilot study and design of Phase II. EMF RAPID Program Engineering Project #6. Vol. 1. 2 vols. Enertech Consultants, Lee, MA for Oak Ridge National Laboratory EMF Research Program, U.S. Department of Energy.

Zaffanella,LE; Kalton,GW (1998b): Survey of personal magnetic field exposure. Phase II: 1000-person survey. Interim Report. EMF RAPID Program Engineering Project #6. Vol. 2. 2 vols. Enertech Consultants, Lee, MA, for Oak Ridge National Laboratory EMF Research Program, U.S. Department of Energy.