# TOPIC #8: PERSONAL EXPOSURE CHARACTERISTICS

## SYNOPSIS

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### Purpose

To summarize present knowledge regarding the characterization of EMF PE, the implications of this knowledge with regard to risk assessment, and important questions that remain to be answered.

### Introduction

The characterization of contemporaneous exposure of groups and individuals to EMF is best achieved through PE measurements. The purpose of the individual study determines the optimal approach for acquiring and analyzing PE measurement data.

RAPID Engineering Project #4 (Bracken et al., 1997a) summarized past efforts and developed guidelines for contemporaneous PE monitoring. Guidelines for PE study design provide recommendations for selecting the field characteristics to be measured; selecting appropriate instrumentation; developing a sampling strategy; establishing time-activity record-keeping protocols; and developing plans for data management, data analysis, and documentation of the study's methods and results. Additional discussion and references for topics discussed in this synopsis are available in the RAPID #4 report.

RAPID Engineering Project #6 (Zaffanella and Kalton, 1998a; 1998b) developed and implemented a protocol for randomly sampling and measuring PE exposures of the general population. Other RAPID-sponsored studies developed and implemented PE measurements for office workers (Hogue, 1995) and for residential exposure to appliances (Kaune et al., 1996).

### Previous Measurements

Substantial effort has been made to characterize PE for selected groups, notably that of electric-utility employees and adults and children in residential settings. The first occupational studies involved electric-field PE measurements for electric-utility workers. Subsequent studies have emphasized magnetic fields, but have occasionally included electric-field measurements as well. Electric-field PE measurements have rarely been made in non-utility environments. Later, more extensive studies have focused largely on exposures of utility workers to magnetic fields (cf., Deadman et al., 1988; Sahl et al., 1994; Thériault et al., 1994; Bracken et al., 1995; Kromhout et al., 1995). PE measurements have also been made in other industries/occupational settings, such as for telephone and telecommunications workers, automobile workers in a transmission assembly plant, office workers, refinery workers, and staff in health-care facilities.

Residential exposure has been characterized in the United States, the United Kingdom, and other countries using PE measurements (Bracken et al., 1994; Kaune et al., 1996; Zaffanella and Kalton, 1998a; 1998b). PE measurements have also been performed to characterize exposures of individuals in other environments, such at school and while traveling.

**Nature of Exposures**

***Electric Fields***

Principal sources of electric-field exposures (above levels commonly found in residential and most occupational environments) are air-insulated high-voltage equipment such as transmission lines and energized equipment in substations. Fields under transmission lines and in substations can range up to 12 kV/m and above for very high voltage systems. Thus, only electric-utility personnel in some work environments are exposed consistently to high electric fields, and those who work near such sources (line workers and substation workers) have the highest PE. However, even these highly exposed groups spend only minutes per day in fields above a few kV/m.

Typical levels in homes and offices are less than 10 V/m. Public exposures to electric fields above 100 V/m are generally incidental exposures near high-voltage transmission facilities. Persons with homes abutting transmission line rights-of-way could experience higher fields in their yards, depending on distance from the line and shielding provided by vegetation and other objects. PE measurements of electric-field exposure at typical environmental levels are extremely difficult to perform accurately and to interpret.

***Magnetic Fields***

PE measurements show considerable variability within a day and between averages for different days. RAPID Project #6 found that the geometric mean of TWA 24-hour exposures for adults was 0.9 mG; the arithmetic mean was 1.24 mG. This and other studies have demonstrated that exposures for individuals during the day can be highly variable, depending on intended and incidental proximity to sources. For example, during the approximately 1000 days of measurements from RAPID Project #6, 30% of subjects had exposures greater than 100 mG; 2% had exposures above about 1 G during a 24-hour period.

It is often difficult to identify specific sources of high fields from PE measurements without careful observation or intimate knowledge of a task. TWA can be strongly influenced by high field measurements of very short duration, especially in occupational environments. This can contribute to apparent differences in TWA exposure for individuals with similar medians and/or geometric means. The nature of sources also contributes to the overlap in PE exposures for traditional location/activity/status categories, such as environments and job categories.

The distribution for daily TWA 24-hour exposures in RAPID Project #6 was approximately log-normal, with a considerable range of exposures (geometric mean, 0.9 mG; geometric standard deviation, 2.17). However, the vast majority (85%) of daily exposures was below 2 mG. Similar variability—a wide range of exposures, with most at low field levels—has been observed in other PE studies with both occupational and residential groups.

RAPID Project #6 also examined PE in various environments and for different age groups, where PE measurements had been performed previously. They found that PE was generally lower in schools than at home or at work; and that, based on a limited sample, exposures of infants and toddlers were lower than those of their mothers. They observed exposures lower for school-age children that can be attributed to where they spend a significant portion of their time: in bed and at school, the two lowest field locations observed in RAPID Project #6.

PE measurements indicate that certain electric-utility occupations and a few others in other industries have relatively high magnetic-field exposures. These exposures are generally associated with both task-oriented and incidental proximity to power generation, transmission, and distribution equipment. However, even in these highly exposed groups, the time spent in fields above 1 G is very small (Bracken et al., 1997).

## Study Design Issues

### *Exposure Parameters*

With few exceptions, the exposure parameter used to characterize EMF PE has been the magnitude of the electric or magnetic field. Depending on the PE meter used, the magnetic-field magnitude refers to the 50/60 Hz resultant field or the broad-band resultant field for the range of about 40 to 1000 Hz. Recorded field parameters in PE studies should include at least the capability to produce a TWA for the time period of interest for comparison with other studies.

Other possible magnetic-field exposure parameters are: frequency content, field polarization, DC field, spatial orientation of the AC field relative to the body or relative to the DC field, and transient fields. However, the instruments required for these more complex measurements are generally too bulky for easy adaptation as PE meters.

### *Instruments*

It is now possible to perform magnetic-field PE measurements over several days with a small, easy-to-wear meter that records fields at frequent intervals. RAPID Project #6 used a new, small, user-friendly PE meter that samples at 0.5-second intervals and stores summary measures for 10-minute periods over a 29-hour data-collection period. There is no consistent method available for collecting accurate electric-field PE data.

For PE characterization, time-series data for individual measurements or short time periods are preferred to permit construction of exposure distributions by activity or location. Time-series data also permit computation of summary measures of field temporal variability.

Placement of magnetic-field PE meters is less critical than that for electric-field meters, because the body does not perturb the magnetic field. Location has been driven by subject preferences and capabilities. PE magnetic-field meters have generally been worn in a belt pouch. RAPID Project #6 placed meters in stuffed animals/backpacks for measuring PE of infants and small children. No guidance has been developed for meter placement in comparing PE measurements with exposure levels established by guideline-setting organizations.

### *Sampling*

The variability of EMF exposure and the relative lack of high-level exposures often argue for as large a sample size as practical to fully characterize PE. There is now sufficient data from existing studies to make reasonable estimates of the required sample size to achieve a specified level of precision in PE estimates (e. g., power computations).

Exposures can have a high variability within and among occupational groups, or among houses with similar wire codes. It therefore can be difficult to identify homogeneous exposure groups for EMF (Kromhout et al., 1995).

Subjects for PE measurement studies have been selected using convenience, random, and targeted sampling. Kromhout et al. (1995) employed a random sample of utility workers in five companies for PE monitoring. RAPID Project #6 distributed PE meters by mail to over 1000 randomly selected subjects from the public.

The right-hand skewed distributions for EMF exposures among groups supports the use of targeted sampling to capture high, but infrequent, exposures. For example, residential studies involving PE measurements have used a targeted approach to over-sample PE in houses with high wire-code categories (Rankin and Bracken, 1994). Using a targeted sample affects the representativeness of the sample and prompts the use of appropriate weighting of samples.

### *Time-activity Record-keeping*

Several methodologies have been used to record time-activity information concurrently with EMF PE measurements. Simple record-keeping methods (entries in a diary) have been used. However, in some cases, the localized nature of EMF sources makes it desirable to record the subject's proximity to specific sources with some precision.

RAPID Project #4 discusses extensively various approaches to time-activity data collection specific to magnetic-field exposure. A decision tree illustrates considerations that apply to collecting time-activity data, and provides guidance to researchers in selecting the optimal protocol. However, selecting the right diary categories remains problematic, because the categories must recognize EMF-related activities and sources and still be familiar to a subject.

### *Data-collection Protocols*

A range of proven protocols is available for EMF PE measurement studies. Complete descriptions of data forms, time-activity diaries, and data-collection procedures are available for both occupational and residential settings (Loomis et al., 1994; Kaune and Zaffanella, 1994; Rankin and Bracken, 1994; Zaffanella and Kalton, 1998a).

Unsupervised data collection without observers is practical, but care must be taken to develop and communicate protocols to subjects, in order to minimize protocol violations that jeopardize data quality. Pilot studies have proven to be an essential part of the design of PE characterization protocols.

Research to date has usually employed a small data-logger, with either a contemporary diary maintained by the subject or observer-recorded task and location information. These design elements have typically restricted the subject population to adults. However, RAPID Project #6 successfully collected limited data for infants, toddlers, and children.

PE measurements among children have been hampered by overly large PE meters and difficulty in obtaining permission for measurements in schools. The instrument and protocols used in RAPID Project #6 demonstrated that the former impediments can be overcome in large. In addition, protocols for PE measurements with children were developed and tested in two pilot studies (Kaune and Zaffanella, 1994; Koontz and Dietrich, 1994).

***Analysis Strategies***

The individual study determines the data-analysis strategy that is employed. For example, exposure assessments for epidemiologic studies have generally relied on the TWA computed over days or weeks. In occupational studies, TWA for specific job categories or tasks has been integrated into a job-exposure matrix. In exposure assessment studies, time-series measurements of magnetic fields have been able to describe many indices of exposure for electric and/or magnetic fields for multiple time periods.

Summary measures for EMF exposure can be characterized as measures of central tendency, maximum level, exceedence level, and variability. Most studies used more than one measure to indicate central tendency; some have provided multiple measures within each category.

Biological or mechanistic research provides no guidance on which parameter and summary measure of EMF exposure are appropriate to characterize exposure relative to effects. The selection of the exposure parameter thus is somewhat arbitrary and tends to be driven by analogy with other environmental agents and available instrumentation, rather than by science: hence the choice of magnetic-field TWA as a common measure of exposure. Fortunately, the TWA of magnetic-field PE measurements is closely related to other possible metrics, including peak exposure and time above specific thresholds. However, it appears that more than one exposure parameter or set of related parameters is required to account for exposure variability (Armstrong et al., 1990; Sahl et al., 1994; Savitz et al., 1994; Villeneuve et al., 1998).

## Implications for Risk Assessment

Methodologies exist today to measure magnetic-field PE reliably. Early shortcomings of instrumentation and protocols have been overcome. However, the individualized and highly variable nature of exposures still contribute to uncertainty in PE characterization.

Certain occupational groups—primarily occupations in the electric utility industry—have consistently exhibited high EMF PE measurements. However, PE measurements are unable to distinguish exposures among the majority of occupational categories.

There is considerable variability within seemingly homogeneous exposure groups. This leads to overlap in the exposures from different groups and to possible mis-classification of exposure for individuals within groups.

PE measurements indicate that individual TWA exposures are almost anecdotally dependent on specific activities and locations. Determining and recording the circumstances that contribute to these exposures are difficult. This complicates the definition of a typical day for the purposes of data collection and exposure assignment.

## Remaining Questions

1. What is the biologically relevant field parameter that should be recorded by PE measurements?
2. What level of precision is desired in a PE characterization? *If the researcher desires to determine only how many subjects are in certain predetermined categories of exposure, then the necessary level of precision may be quite crude. However, if the focus is on the exposure of a specific person, then the level of precision may be much more demanding.*
3. How detailed must information be about the activities and locations contributing to exposure in order to accurately characterize exposure? To delineate homogeneous exposure groups? *Modeling requires detailed information about the time, place and activities of a subject. Drawing these data from the subject can be quite demanding. What techniques are best for obtaining the information needed as inputs to models—including activity/location, task-specific sources and indirect or incidental exposure sources?*
4. How best should the data collection be designed to maximize the value of the data (and minimize the collection effort)?
5. Are PE measurements appropriate for comparing exposures with magnetic-field guideline levels?

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