EMFRPEP-4

RECOMMENDATIONS FOR GUIDELINES FOR EMF PERSONAL EXPOSURE MEASUREMENTS

RAPID PROJECT #4

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EXECUTIVE SUMMARY

This project developed recommended guidelines for electric and magnetic field (EMF) personal exposure measurement (PEM) studies. The recommendations are flexible and intend to provide guidance for investigators with varied research objectives, rather than dictate specific methodologies. The guidelines fall into two categories: general guidelines for planning a study, and specific guidelines for developing a detailed study design and protocols. Supporting discussions, and suggested implementation procedures are also included.

General Guidelines
The purpose of establishing general guidelines for exposure studies is to ensure that valid data are collected and that the data meet the study objectives including, if appropriate, any risk assessment requirements. To accomplish these goals, investigators should employ the following steps when planning an EMF PEM study :

1. **Develop a clearly stated purpose for the EMF PEM study;** and

2. **Complete a written study plan before developing specific protocols or beginning measurements.**

By succinctly stating the purpose of the study at the outset, and referring to it frequently, questions regarding the overall study design and the written study plan can be addressed without ambiguity. The purpose statement may evolve as the study design develops and resource constraints are addressed but any changes or compromises in the purpose will be clearly known. Before beginning measurements there must be a purpose statement that is understood and accepted by the investigators, their managers, and all sponsors of the study.

The written study plan is a general descriptive document and should address the following elements of the EMF PEM study:

- **Resource Assessment.** Are there sufficient personnel, instrumentation, financial support and organizational support to adequately address the purpose of the study?
- **Exposure Model.** How are the physical exposure measurements related to a hypothetical biological endpoint?

- **Study Design.** What general study design is likely, including proposed exposure measurements, instrumentation, sampling strategies, data collection protocols, data management plan, and documentation?

- **Subject Issues.** What requirements are there for consent, confidentiality, level of effort by subjects, communication with subjects and dissemination of a subject's PE data?
- **Quality Assurance.** What steps will be taken to ensure adherence to protocols, instrument accuracy, and data integrity?
- **Uncertainty Evaluation.** What are the anticipated sources of error and what limits do they impose on the study's ability to achieve its purpose?
- **Archival Plan.** How will the study data and documentation be archived?

Specific Guidelines

The recommended specific guidelines for developing detailed plans and protocols for a PEM study apply to six elements of a study: study design, subject issues, quality assurance, uncertainty evaluation, archival plans and pilot studies. The topics and issues addressed in the specific guidelines are:

Study Design. Specific recommendations are provided for: selecting the field characteristics to be measured, selecting appropriate PEM 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. It is recommended that, at a minimum, a time-weighted average exposure of the resultant magnetic field should be measured and reported. Sample size, sampling parameters, and resource considerations are discussed along with a presentation of the sampling strategies: simple random sample, systematic sample, stratified sample, cluster sample and multistage sample. The following methodologies for time-activity record-keeping are presented: diary, self-administered or interview questionnaire employing retrospective, prospective or concurrent record-keeping.

Subject Issues. Guidance is provided for managing subject-related issues such as: obtaining organizational approvals for the participation of subjects; developing the forms to obtain a subjects informed consent; developing the procedures to maintain the confidentiality of subjects; developing clear, unambiguous PEM protocol instructions for the subjects; developing a plan to provide subjects with their PEM data; and developing PEM procedures that minimize the possibility of protocol violations.

Quality Assurance. Recommendations to ensure the quality and integrity of the data from a PEM study include: the implementation of appropriate and generally accepted procedures for the sampling process, data collection, data management, and data analysis; the implementation of a plan for verifying the calibration and confirming the functionality of PEM meters on a regular basis; the development of methods for assessing the consistency of the PEM and its associated data and the completeness of all data soon after each observation; and the introduction of automated and/or manual procedures for verifying the accuracy of the data entered into data bases.

Uncertainty Evaluation. An uncertainty evaluation of a PEM EMF study should be performed to determine the magnitude and acceptability of factors likely to contribute to uncertainty; and to plan for an estimate of both the observed uncertainty introduced by various factors and overall observed uncertainty. The evaluation will assist in planning and implementing data validation procedures.

Archival Plan. Guidance is provided to develop specific plans for the archiving of raw data, processed data, study documents, and other study materials such as forms; written protocols; instructions to subjects and data collectors; and software tools.

Pilot Studies. The specific recommendations include pilot studies of all aspects of the study design. This includes testing protocols for: sampling, instrumentation, PEM, time-activity record-keeping, subject participation, and quality assurance.

Background Materials

The document contains a literature review of PEM studies that provides background information and reference to works presenting PEM protocols and related issues. Selected references have been summarized in a standard format and included as an appendix.

To illustrate the effects of subject characteristics on activities possibly related to EMF exposure, existing time-activity survey data for children and adults in California were examined. The largest and most consistent differences in locations and activities observed in these data were related to age and gender. The differences suggest that these should be important subject attributes in an EMF PEM study.

The guidelines were tested in two pilot studies by an independent investigator. One pilot study measured EMF PE for 50 high school students who kept concurrent time-activity diaries and completed questionnaires regarding their activities. The subjects for the second pilot study were employees at an electronics manufacturing plant. They either kept a time-activity diary or their activities were recorded by an observer during work hours. PEM results from both pilot studies are presented in an appendix. Modifications and enhancements were made to the guidelines in response to feedback from the pilot studies investigator.

Summary

The combination of the general guidelines, specific guidelines, and background materials provides a prospective investigator of electric and magnetic field personal exposure with a foundation for developing, implementing and reporting a scientifically sound, valid PEM study.

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1

INTRODUCTION

The purpose of developing guidelines for electric and magnetic field (EMF) personal exposure measurements (PEM) is to ensure reliable and comparable data across PEM studies. Study techniques may vary due to different populations or objectives, but the resulting data should be consistently reported and comparable, to the extent possible. Any guideline must allow creativity by the research-oriented investigator and provide specific guidance to industrial hygienists or other results-oriented investigators, requiring a standard protocol. Recognizing measurement studies with different purposes is an important aspect of these recommendations. The guidelines presented here intend to produce comparable data across studies while remaining flexible.

The recommendations for designing and implementing an EMF PEM program describe a three-stage process. The first step is to clearly state the purpose of the PEM program. The next stage addresses the fundamental elements of an EMF PEM study, including an assessment of the scientific and organizational resources that will be required. This process is codified in a written study plan. These stages are described in Section 5 of this report.

The third stage of a PEM study involves the design, implementation and documentation of specific procedures and protocols for: sampling strategies, selection of measurement parameters; instrumentation, measurement and data collection, data management, data analysis, quality assurance, uncertainty evaluation, and archiving the study methods and results. The methods for designing these elements of an EMF PEM study are described in Section 6: Specific Guidelines for EMF PEM Study Design.

Methodologies to address specific issues of PEM studies include:

- How should subjects be selected?
- What is the appropriate sample size?
- Are PEM the appropriate means of characterizing exposure?
- Should area monitoring and/or modeling exposure be used with PEM?
- What characterization of exposure should be used?
- What detail is required for time/environment and time/activity?
- What detail is required for characterizing exposure from specific sources?
- What exposure characteristics should be addressed?
- What summary measures should be used?
- What instrumentation is required: meter type, sampling interval, frequency response, etc.?
- What measurement protocols are appropriate?

These guidelines will not provide answers to these questions for every exposure assessment scenario. Rather, these general recommendations and specific guidelines provide tools for systematically addressing these questions.

Applying these tools in implementing an EMF PEM study is often an iterative process, requiring tradeoffs between goals, resources and practical matters. Issues raised during preparation of a written study plan can illuminate limitations of the study design. This process compels one to address the choice of exposure characteristics, instruments, and protocols. The specific guidelines present considerations related to these decisions.

The following background materials are included: a review of previous PEM studies (Section 2); a methodology for characterizing subjects and identifying exposure components (Section 3); a discussion of EMF exposure variability and its implications for study design (Section 4); summaries of selected EMF PEM studies (Appendix A), and a description of time-activity data from a previous study (Appendix B). The design, implementation and results of two pilot studies performed utilizing these guidelines are summarized in Section 7 and detailed in Appendix C. Section 8 contains a summary of the recommendations and guidelines developed during this project.

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EMF PEM LITERATURE AND RESEARCH SUMMARY

2.1 Inclusion Criteria

To provide background on protocols used for EMF PEM in the past, a literature search was conducted. The results of this search as they apply to study design parameters and techniques relevant to EMF PEM are presented below. 'Certain of the references were selected for summarization and are included in Appendix A as a resource for future study designs. To be included in the summaries in Appendix A an article or report in the summarization process had to meet the following criteria.

> The journal article or report had to be a published paper or accessible final report. No abstracts or preliminary results were included. Only reports that could be readily obtained from the author or sponsor were considered.
>
> For use in developing recommended guidelines, it was necessary that the measurements protocol used in the published study be described in some detail.
>
> The number of sampled days was greater than 20 to provide an extensive demonstration of the protocols. This criterion was relaxed in cases where a study addressed methodological issues with fewer samples.
>
> The results of the measurements were described in terms of exposure indices comparable with other studies and measures of variability were included.

For each summarized study, parameters important for developing exposure guidelines were recorded in the standard format shown in Table 2.1. Examples of entries for some

Table 2.1
Format for Describing EMF PEM Studies

Citation:	Author, Title
Setting:	residential, occupational
Purpose of study:	epidemiology, exposure characterization, methodological
Measured parameter:	electric field, magnetic field or both
Sample:	number and description of subjects
Subject sampling:	random, convenience, targeted
Instruments:	Model and manufacturer
	Type: accumulating, continuous,
	Characteristics: field metric, range, frequency response
	Sampling interval
Meter placement:	worn/not worn location; type of meter holder
Time-activity record-keeping:	self reported; observed, list of activities/environments
Protocol summary:	data collection protocols, quality assurance in data collection and data management, distribution of data to subjects
Analysis strategy:	full shift, by task, by environment, within worker, between workers
Exposure indices:	measures of central tendency, measures of peak or maximums, measures of variability, indices specific to the study
Other recorded parameters:	wire code category, current, task, location/environment, job title or category
Related citations:	other references to the data or study

of the parameters are given in Table 2.1. Where more than one citation was available for a study, the reference with the most detail about the PEM and exposure characterization was selected for summarization. Related citations for each study are listed to facilitate accessing information about the study, if the primary reference is not available. The following discussions highlight results from the summarized studies and other sources.

2.2 Purpose of Study

EMF PEM studies have been implemented to achieve many objectives: to characterize exposures of subjects in epidemiologic studies, to characterize exposures of specific groups or components of exposure, or to investigate methodologic issues of EMF exposure assessment. PEM can also be used as part of a response to questions from employees or the public about EMF exposures.

The incorporation of EMF PEM into an epidemiologic study is a complex undertaking. The component(s) of exposure that is (are) to be included must be determined. Studies of risks associated with occupational exposures have generally included only the component of EMF exposure received at work: [Bowman et al., 1992; Floderus et al., 1992; Wenzl, 1992; Sahl et al., 1994; Thériault et al., 1994b; Kromhout et al., 1995]. However, Breysse et al. [1994b] included non-work PE measurements to establish a reference level in their characterization of telephone workers exposure. In the occupational epidemiologic studies, job exposure matrices with adjustments for historical exposures have been employed to account for the diverse occupational histories of subjects.

Epidemiologic studies that include residential EMF exposure have generally relied on surrogates other than PEM for characterizing past or present EMF exposures. However, in an epidemiologic study of pregnancy outcome, Bracken MB et al. [1995]

employed several measures of EMF exposure including PEM to capture both residential and occupational exposures of subjects.

PEM studies have been performed to characterize exposures of specific groups, especially in occupational settings. Exposures of utility workers to electric and/or magnetic fields have been studied extensively [Bracken, T. D., 1986; Male et al., 1987; Deadman et al., 1988; Wong, 1992; Merchant et al., 1994; Sahl et al., 1994; Thériault et al., 1994b; Bracken, T. D. et al., 1995; Kromhout et al., 1995]. Specific occupations among utility workers have also been targeted for PEM because of their exposure to high fields. Guénel et al. [1993] examined exposures of workers in thermoelectric generating plants. The exposures of transmission and distribution live line workers have also been investigated with PEM for various purposes [Gamberale et al., 1989; Pretorius, 1993; Bracken, T. D. et al., 1994a].

Exposures for workers in other industries have also been characterized by PEM. In addition to the aforementioned study by Breysse et al. [1994b], exposures of telephone and telecommunications workers were characterized in a large monitoring effort conducted by Rainer et al. [1992]. Other industries and occupational settings where EMF PEM have been employed include: automobile workers in a transmission assembly plant [Wenzl, 1992]; office workers [Breysse et al., 1994a]; refinery workers [Cartwright et al., 1993]; and health care facilities [Philips et al., 1995].

Residential exposure has been characterized in several countries using PEM. These include the United States [Bracken, T. D. et al., 1994b]; the United Kingdom [Renew et al., 1990]; Denmark [Skotte, 1993]; and South Africa [Vogt, 1992]. Residential exposures for persons living near transmission lines have been characterized with PEM by Kavet et al. [1992] and Levallois [1995].

Numerous studies incorporated PEM to explore methodological issues in EMF exposure assessment. Silva [1985] collected electric field PEM to characterize exposure in specific occupational and recreational activities. Several studies have examined the feasibility of assessing childhood exposure with PE measurements [Kaune and Zaffanella, 1992; Koontz et al., 1992; Kaune et al., 1994]. Delpizzo [1993] examined the effect of meter location on PEM by placing six meters at various locations on the body.

PE measurements have also been used to demonstrate to employees and the public the nature and magnitudes of their exposures. Such efforts are generally informal and do not follow the strict protocols inherent in other types of PEM studies. In fact, PEM are not necessarily the best vehicle to respond to questions. They require considerable time and require more interpretation of the results than do point-in-time measurements. Often the preferred method for responding to questions is with point-in-time survey measurements in various areas and near specific sources [Misakian et al., 1993; NEMPG (National EMF Measurement Protocol Group), 1993].

2.3 Environments and Measured Parameters

PE measurements have been performed in both occupational and residential environments. The initial occupational studies involved electric field PEM of utility workers. Subsequent studies have included both electric and magnetic field measurements or just magnetic field measurements. Electric field PEM have rarely been made in non-utility environments: the absence of high voltage sources except in or near electric power facilities results in most occupational and residential areas having low electric fields. The difficulties in performing and interpreting electric field PE measurements in low field areas limit the value of such measurements [Bracken, T. D., 1993].

PE measurements in residential settings have emphasized magnetic fields. Survey measurements have demonstrated that residential electric fields are low and apparently not associated with health outcomes [Barnes et al., 1989; London et al., 1991]. The few studies that have included PE measurements of residential electric fields have confirmed the low levels observed with survey measurements [Deadman et al., 1988; Bracken, T. D., 1990].

In addition to occupational and residential environments, PE measurements have been performed in other environments as well. For a study that included both electric and magnetic field exposure at work and at home, measurements were also reported for the general environments of travel and "other" [Bracken, T. D., 1990]. Kaune and Zaffanella [1994] captured magnetic field TWA exposure at home and at school for a group of children. Silva [1985] examined electric field exposure during agricultural and recreational activities near transmission lines.

2.4 Sampling Considerations

Subjects for PE measurement studies have been selected using several methods. Perhaps the most frequent is the convenience sample, where an investigator visits a site and selects volunteers from those present and willing. This approach was used by Breysse et al. [1994b] for telephone workers and by Sahl et al. [1994] for utility workers.

Because of the logistics of distributing and collecting EMF PE meters, random sampling for PEM subjects has not been used frequently. Kromhout et al. [1995] employed a random sample of utility workers in five companies for PE monitoring. They distributed simple on-off meters by mail to the selected employees.

Residential studies involving PE measurements have tended to use a targeted approach to sampling in order to capture and examine purported and known contributors to exposure. Bracken et al. [1994b] targeted residences with specific nearby electrical facilities. As intended, this technique produced an excess of houses in the relatively infrequent high wire-code category. (Wire-code category refers to a schema for classifying residences by the nature of and distance from nearby power lines. High wire-code categories purportedly reflect higher magnetic field exposures for the residents.) Kaune and Zaffanella [1992] selected subjects for PEM based on wire code categories and also the magnitude of ground currents at the house. Koontz et al. [1992] targeted a range of exposures by using neighborhood wiring characteristics and the averages of drive-through measurements to characterize census tracts in four exposure categories.

Targeted sampling has also been used in occupational studies. The large number of studies of utility workers reflects the identification of this particular group as one with expected high exposures. Within the utility worker group there are specific job titles that have been targeted because of their high exposures. In a study of line workers performing live-line tasks on transmission and distribution lines, Bracken et al. [1994a] targeted workers performing specific tasks using specific work methods.

The right-hand skewed distributions for EMF exposures among groups drives the use of targeted sampling. Subjects with specific exposure circumstances that purportedly result in high, but infrequent, exposures are sought out in the sampling process. The use of a targeted sample obviously affects the representativeness of the sample. In the study where wire code category was used to drive selection, a more representative sample of residents was constructed based on the distribution of randomly selected houses at each measurement site [Bracken, T. D. et al., 1994b].

The variability of EMF exposure and the paucity of high exposures often argue for as large a sample size as practically possible for PEM studies.

2.5 EMF PEM Instruments

Several different PEM instruments have been used for EMF exposure assessment. These can be characterized as accumulating and continuous recording meters. The accumulating meter integrates field readings in a single or multiple data registers over the course of the measurement period. The result is a single value representing the integrated exposure over a known time. Sophisticated versions of this type of meter accumulate exposures in several different field intervals or bins. A continuous recording PE meter uses a data logger to record and store each field measurement at fixed intervals. Thus, each measurement made with this type of meter can be assigned a time and field value(s).

EMF instrumentation can be described in terms of the sensor, the signal processing electronics and the data storage method. EMF meters have been evaluated and their desirable characteristics identified [IEEE AC Fields Working Group, 1991; IEEE, 1995]. All components of the EMF measurement process have evolved as interest in EMF exposure assessment has increased. It is now possible to perform EMF PE measurements over several days with a small comfortably worn meter that records fields at frequent intervals. Specifications and sources of EMF PE meters that are available commercially are given in Section 6.

PE measurements have been performed for both power frequency electric fields and magnetic fields. After the initial interest in electric field exposure characterization waned, most effort has been placed in the development of instruments for magnetic field PEM.

<u>Electric field</u> A summary and discussion of early electric field exposure meters is contained in Bracken [1985]. The first EMF PE measurements were to characterize utility worker exposure to electric fields [Deno, 1979]. A small conducting plate mounted at the surface of the body served as an electric field sensor. The induced current from the plate is proportional to its area and the incident electric field. Because the electric field is always normal to the surface of a conducting object, one plate is sufficient to measure the field at such a location. In the first PE meters the induced current was integrated over the time the meter was worn either in a single accumulator or in a set of accumulators for different field levels [Deno, 1979]. The accumulators

provided integrated exposures in (volt/meter)-hours, allowing a time-weighted average (TWA) field to be computed if the duration of measurements was known. The meter could be placed on a hard hat, in an arm band or in a shirt pocket. An empirically determined conversion factor can be used to convert the field at the surface of the body to the unperturbed field without the body present.

A simple system that accumulated time spent in eight field levels or bins was described by Chartier and Bracken, [1987] and used to characterize electric field exposures of utility workers [Wong, 1992; Henshaw et al., 1996]. This meter which averaged fields over four second intervals could be placed in an arm band or worn in a shirt pocket. Male et al. [1987] reported on a similar approach to characterizing utility worker exposure using a meter with four bins.

A more sophisticated 16-bin logarithmic system was used in a PE meter that records exposures to electric fields, magnetic fields, and high frequency transients (HFT) [Heroux, 1991]. This meter maintains the recorded data in a time series format so analyses during different periods can be performed on the data. This meter, worn on the belt or in a shirt pocket and sampling at one minute intervals, was used in a large epidemiologic study of utility workers [Thériault et al., 1994b].

Although designed primarily for recording magnetic field exposures, EMDEX technology meters have also been used for monitoring electric fields with an external sensor [Enertech Consultants, 1989a, b; Bracken, T. D., 1990]. These data loggers measure the field at fixed intervals and record the level in a time series format.

There are several difficulties associated with electric field PEM [Bracken, T. D., 1993]. The response of a small electric field meter is very dependent on the location of the meter on the body and the position of the body relative to sources. Both of these factors make interpretation of electric field PE measurements difficult. The small size of PEM devices dictates a small area for the electric field sensor and thereby reduces the sensitivity of electric field meters. Deno and Silva [1984] used a conducting vest as a sensor for electric field PEM to overcome both these difficulties. The induced current from the vest was recorded in one of five accumulators.

Magnetic field The same progression in monitoring devices can be seen in magnetic field PE instrumentation where a coil or set of coils is most often used as the sensor. A simple single-axis coil system worn on the wrist was linked to an accumulator to measure integrated exposure [Bracken, M. B. et al., 1995]. However, a single coil only captures one component of the vector field and extrapolation to the magnitude of the vector field requires several assumptions about the nature of the fields and the orientation of the coil. In fact, Bracken MB et al. [1995] used the single coil as a relative measure of exposure and did not try and convert it to an absolute measure of field exposure.

A device that combines the signals from three orthogonal sensors is the preferred method of measurement for the magnitude of the vector magnetic field. A three coil version of the accumulating wrist-worn exposure meter, the 3-D AMEX (Enertech Consultants, Campbell, CA), was developed by Kaune et al. [1992]. The incorporation of three coils makes this meter too large to be worn on the wrist. This meter has an on-off switch that allows accumulation of exposures only during specified times. Kaune and Zaffanella [1994] report on using two such meters for accumulating TWA exposure at home and school for children. In another study, the simplicity of operation of this meter allowed it to be distributed by mail to randomly selected subjects [Kromhout et al., 1995].

The combination electric field, magnetic field, and (HFT) monitor described by Heroux [1991], records at a predetermined interval the readings from each of five sensors. This EMF PE meter was developed under the auspices of Institut de Recherche d' Hydro-Québec (IREQ) and was manufactured by Positron, Inc., Montreal, Quebec, but is no longer commercially available. It is commonly referred to as the IREQ or Positron dosimeter.

Measurements from the electric field sensor, three orthogonal coils and the HFT monitor are recorded in one of 16 logarithmically scaled levels. The electric field sensor has a sensitivity of 0.6 V/m. The upper bin captures fields above 10,000 V/m. The three orthogonal coils measure magnetic field components in the range of 0 to >50 µT. The frequency response of EMF sensors is narrow band centered at 50/60 Hz. The high field transient monitor records the presence of transients in the 5 - 20 MHz frequency band as the fraction of time they occur from 0 to >0.2237.

Sampling can be done at one minute or five second intervals. The data logger can collect data for over two weeks with the one-minute sampling interval. After data collection is complete the data are retrieved via a communication link with a personal computer. The integration of the three magnetic field vectorial components into a single level is performed by custom software. The IREQ meter has been employed in numerous epidemiologic and exposure assessment studies [Deadman et al., 1988; Renew et al., 1990; Guénel et al., 1993; Skotte, 1993; Merchant et al., 1994; Thériault et al., 1994b; Levallois et al., 1995].

The EMDEX (Electric and Magnetic Field Digital EXposure System) data logger was developed under the sponsorship of the Electric Power Research Institute (EPRI) and has evolved into a group of commercially available products (Enertech Consultants, Campbell, CA) that can be used for PEM.

The EMDEX II data logger records the analog output from three orthogonal coils in a digital time series format. An auxiliary input is available for recording input from an electric field or current sensor. The EMDEX II is available in a normal (0.1 mG to 3 G) or high field version (4 mG to 120 G). It also has the capability to record the broadband resultant field in two frequency ranges (40 to 800 Hz and 100 to 800 Hz) allowing determination of the field magnitude at the power frequency fundamental of 60 Hz and at higher harmonics.

The time of each measurement is determined from the start time of the data collection period and the sampling interval. Sampling interval can be preprogrammed from 1.5 seconds to 5 minutes or longer with special programming. The recording period is determined by memory capacity and battery life, which are influenced by sampling interval, recording mode, and ambient temperature.

An event mark can be placed in the data stream by pressing a button on the front of the unit. The data logger can be preprogrammed to record either the component fields or the resultant field. After data collection is complete, the stored data is retrieved via a communication link with a personal computer. The measured field can be displayed directly, facilitating the use of the meter for survey purposes as well as PEM.

The EMDEX Lite is a smaller version of the EMDEX II with reduced capabilities. It still produces a time-series record of the resultant field, but lacks, among other features, a resident program for data collection and event marking capability.

The EMDEX Mate is also smaller than the EMDEX II. It is a more sophisticated accumulating meter than a simple integrator. It records the mean, standard deviation, minimum, maximum and accumulated time above specific thresholds for field measurements during operation.

Various versions of the EMDEX technology have been used for EMF PE exposure measurements in epidemiologic and exposure assessment studies [Bracken, T. D., 1990; Bowman et al., 1992; Floderus et al., 1992; Kavet et al., 1992; Rainer et al., 1992; Wenzl, 1992; Cartwright et al., 1993; Bracken, T. D. et al., 1994a, b; Breysse et al., 1994a; Sahl et al., 1994].

All of the above PEM meters record properties of the field magnitude, usually expressed as the resultant. The SPECLITE (Innovatum, Inc., Houston, TX) is a small data logger that records the magnetic field in 30 frequency bands between 40 and 1000 Hz at one minute intervals [Philips et al., 1995]. This permits an estimate of the frequency spectrum of magnetic field exposure.

The responses of PEM meters to magnetic fields and, to a lesser degree, electric fields are designed to exhibit a sharp low frequency cutoff to filter out spurious signals caused by movement in the static fields of the earth.

2.6 Meter placement

The placement of the PE meter on the body is much more crucial for electric field measurements than for magnetic field measurements. The location of the sensor strongly affects the magnitude of the electric field that is measured. For example, the electric field at the surface of the head for a subject standing in a vertical electric field of 10 kV/m is 180 kV/m compared to about 80 kV/m at the arm [Deno, 1977]. The actual field measured at these two locations depends on the size, shape, and exact placement of the meter. In addition, a meter located on the hard hat (head) will be less affected by body and arm position than will a sensor located on the arm or chest.

Several locations were investigated during initial electric field exposure measurements [Deno, 1977]. These included placement of sensors on the hard hat, in an arm-band pouch and in the shirt pocket. For the convenience of wearers, most large data collection efforts settled with an arm band or shirt pocket location [Bracken, T. D., 1986; Male et al., 1987; Wong, 1992]. One large study collecting both electric and magnetic field exposure data allowed subjects to wear the PEM meter in either a shirt pocket or in a belt pouch [Guénel et al., 1993; Thériault et al., 1994a]. Some studies have measured exposures with a meter worn on a belt [Bracken, T. D., 1990; Skotte, 1993]. Obviously, electric fields measured at the waist or hip are going to be strongly affected by body position and orientation.

Placement of magnetic field PE meters is not as critical as for electric field meters, because the body does not perturb the magnetic field. Location of the meter therefore has been driven by convenience and comfort of the wearer. PEM meters for magnetic field have generally been worn in a belt pouch.

Delpizzo [1993] investigated the impact of meter location on the characterization of whole body average exposure among office and shop workers. Six integrating meters were placed at various locations on the body of subjects who wore them for two hours while performing normal work activities. Meters at the hip location were found to underestimate whole-body average and head exposures. Chest-worn meters were found to be superior for assessing the occupational exposures considered.
As part of the exposure assessment for a brain cancer study at an automobile plant, Wenzl [1992] compared exposures at the head location of workers with those at the waist location. The TWA exposures were estimated from observations of time spent at different work stations and from survey measurements at those locations. He found that for individual workers exposures varied both ways, with the head exposure sometimes higher and sometimes lower. There were no jobs or departments with consistent differences between the two locations, thus justifying the use of unadjusted PEM from a waist-worn meter to characterize exposure in this case.

In a study of the magnetic field exposures of live-line workers, a special harness for holding the meter at the chest was designed with the assistance of the line workers [Bracken, T. D. et al., 1994a]. This placement ensured that wearing the meter did not interfere with performing tasks in an environment where safety is of paramount importance.

The smaller integrating PE devices offer more flexibility in placement. The single coil device was small enough to be worn on the wrist by women in a study of pregnancy outcome [Bracken, M. B. et al., 1995]. The 3D-AMEX integrating meter has been worn in a pouch at the waist by adults [Kromhout et al., 1995], carried in a pouch sewn to suspenders or belts by children [Kaune et al., 1994], and placed in a fabric cube next to infants [Kaune et al., 1994].

In all cases, protocols have called for the removal of the PEM monitor when wearing it might pose a safety risk to the wearer or when the functionality or integrity of the meter would be jeopardized. Thus, belt-worn meters would generally not be worn during live-line work. Subjects are instructed to remove the meter when bathing, swimming, engaged in contact sports, or performing activities such as working from a ladder where interference from the meter could pose an inconvenience or safety hazard.

Protocols for placement of the PE meter when it is not worn have called for: placing it nearby to the subject when it is not worn [Bracken, T. D., 1990; Bracken, T. D. et al., 1994b; Breysse et al., 1994a; Kaune et al., 1994]; placing it at a pre-selected location near the bed and generally away from appliances when sleeping [Kavet et al., 1992; Rainer et al., 1992; Merchant et al., 1994; Rankin and Bracken, 1994; Levallois et al., 1995]; placing it in a pre-selected location to characterize long-term field levels in the house [Renew et al., 1990; Bracken, T. D. et al., 1994b]; and turning the meter off when not worn [Kaune and Zaffanella, 1992].

2.7 Exposure Parameters

2.7.1 Field Magnitude

The most common exposure parameter for EMF PE measurements has been the magnitude of the electric or magnetic field. Depending on the PEM meter that is used, the magnitude refers to the 50/60 Hz resultant field or the broadband resultant field embracing all field components in the range of about 40 to 1000 Hz. For both electric and magnetic fields, the field of interest has generally been the unperturbed field, that is the field when no subject is present. The small size of PEM meters means that PEM measurements characterize the field at essentially a point in space, although a larger volume may be of more interest for characterizing exposures.

When variability of the field magnitude has been used as an exposure parameter, it has been considered over different time scales: e. g., over the course of a day or other measurement period, between measurements (seconds), or at times shorter than the measurement duration (less than a cycle). In the latter case, the fields may be characterized as transients. Variability between successive measurements has been characterized using the difference between successive measurements and by the first-lag auto-correlation coefficient [Bracken, T. D., 1990; Breysse et al., 1994b]. A measure of exposure "jaggedness" was computed from the percentage of adjacent minutes with mean exposures differing by greater than 0.5 µT [Wenzl, 1992].

Electric Field. Electric fields are characterized by a single measurement of induced current. The magnitude of the field is measured directly at the point of measurement averaged over the area of the sensor. To extrapolate the measured electric field at a point to an unperturbed electric field value over the volume of interest requires several assumptions. For a constant unperturbed field, the field measured with a PEM meter will depend on the location of the meter on the body, the posture of the subject and the orientation of the subject with respect to electric field sources. Since posture and body orientation are constantly changing, assigning values to account for them is ambiguous and introduces uncertainty in the estimate of unperturbed field.

One approach for quantifying electric field exposures has been to convert the measured electric field exposure into an equivalent exposure in a uniform vertical electric field [Silva, 1985; Chartier and Bracken, 1987]. This approach allows comparison between different subjects and different studies. However, there is considerable uncertainty in such a conversion and a common caveat for electric field exposure measurements is to interpret them with caution and compare them in a relative, rather than absolute, sense [Bracken, T. D., 1990]. Thus, measurements of the electric field magnitude are affected by the measurement process as well as by temporal and spatial variation inherent in environmental fields.

Magnetic Field. The magnitude of the magnetic field is best captured with a set of three orthogonal coils. A single coil device requires that it be oriented along the direction of the field (impossible for a PE meter) or that assumptions be made about the orientation of the coil relative to the field. Measurements with a single coil can also be used as a relative measure of magnetic field exposure [Bracken, M. B. et al., 1995].

With a three coil sensor system the magnitudes of the field from each coil are combined to produce the resultant field (the square root of the sum of the squares of the field components). Depending on the polarization of the field the resultant can range from being equal to the maximum field (linearly polarized) to $\sqrt{2}$ times the maximum field (circularly polarized) [IEEE, 1995]. PE meters generally measure the resultant field and use it as a metric for the magnetic field magnitude.

2.7.2 Frequency

Information about the frequency content of EMF PEM has generally been characterized as either narrow band (e.g., 50/60 Hz) or broadband (e.g., 40-1000 Hz) magnitude. However, one study was able to provide frequency spectra in this range for magnetic field exposures [Philips et al., 1995].

2.7.3 Other Field Attributes

Other characteristics of the magnetic field that could be used as exposure parameters include: field polarization, dc field, spatial orientation of the ac field relative to the body or relative to the dc field, and transient fields. These other attributes of magnetic field exposure have been characterized using survey meters and long term fixed-location data logging, and in some instances, with PEM. However, the instruments required for these more complex measurements are generally too bulky for easy adaptation as PE meters.

There are portable survey meters that record both the field magnitude and phase of the magnetic field components allowing polarization to be determined [Dietrich et al., 1992; Rankin and Bracken, 1994; Rauch et al., 1994]. However, the physical size of these instruments makes them unsuitable for PEM and at present there is no meter for assessing this parameter via PEM.

The magnitude of the static field and its orientation relative to the ac field is also of possible interest as an exposure metric. A small dc field meter that provides instantaneous and integrated measurements of dc field magnitude is available and could be used for PEM (Model HI-3550, Holaday Instruments, Eden Prairie, MN). The relative orientation of the ac and dc fields could not be determined with this meter.

Another field characteristic that can be, and has been, recorded in EMF PEM studies is the presence of high frequency transients (HFT) in the range of 5 to 20 MHz [Heroux, 1991]. Although not strictly an EMF attribute, transients have been hypothesized as a possible agent for biological effects and therefore may be of interest in exposure assessments of electrical environments. One study that used the Positron (IREQ) meter evaluated exposures to transients present during PEM [Armstrong et al., 1994]. However, interpretation of the source(s) and frequency of transients recorded by this meter is not clear when assessing exposure [Guttman et al., 1994; Peralta et al., 1994].

2.7.4 Time

When using a data logger for PEM, the time in fields or activities can be determined and time can be used as another metric for exposure. In one study the time in task was estimated by expert panels and then integrated with field measurements to produce exposure and time in field estimates [Bowman et al., 1992]. Breysse et al. [1994b] estimated time performing work tasks from observations of subjects. In another study the time in task, as determined by observers' bar code scans, was integrated with estimates of task frequency and field measurements to produce annual exposure and time-in-field estimates [Bracken, T. D. et al., 1994a].

2.8 Exposure Summary Measures

PEM have generally recorded magnitude as the parameter for magnetic field exposure. Summary measures that have been used for the magnetic field magnitude can be characterized as measures of central tendency, maximum level, exceedence level, and variability. Specific summary measures reported within each category are listed in Table 2.2. Obviously, not all studies used all measures. However, most studies used more than one measure to indicate central tendency and some provided multiple measures within each category (Cf., Breysse et al., [1984, 1987]; Sahl et al. [1994]; Wenzl et al. [1992].

Table 2.2
Exposure Indices Reported for EMF PEM Studies

Metric	Category	Index
Field magnitude	Central tendency	Arithmetic mean of day, of days Median of day, of days Geometric mean of day, of daily means Time-integrated exposure for task, for day, for week Mode Geometric mean of one minute averages
	Maximum	Absolute maximum for task, for day, for week Average of maximums for task 75th percentile 90th percentile 95th percentile 95% confidence interval
	Exceedence	Fraction exceeding: 0.5, 1, 5, 10, and 100 μT Percent above: 0.2 μT Percent above: 0.2, 0.78 μT Number of exceedences per hour above 1.0, 2.0 μT Fraction exceeding: 0.3 and 1 μT
	Variability	Standard deviation Geometric standard deviation Standard error of daily means Range 10th to 90th percentiles Difference between successive measurements First lag auto-correlation coefficient Within-subject variance Between-subject variance Ratio of 97.5th and 2.5th percentiles Ratio of 95th to 5th percentiles Percentage of adjacent measurements differing by at least one bin Percentage of adjacent minutes with means differing by 0.5 μT
Frequency of field		Magnetic field frequency spectra (40 - 1000 Hz)

Metric	Category	Index
Time	Central tendency	Arithmetic mean time in task, in day Time in field intervals
	Exceedence	Percent of time above: 0.25, 2.5, and 25 µT Time above 20µT Time per day above 0.4 kV/m
	Maximum	Time spent in peak field

2.9 Time-activity Record-keeping

Several methodologies have been used to record time-activity information concurrently with EMF PEM. These have ranged from simply turning a data collection meter on and off to demarcate the periods of interest to generating a stored record of activities with a bar code scanner. It is possible to use simple record-keeping methods with a few entries for EMF studies. However, because of the localized nature of EMF sources, it is, in some cases, of interest to record the subject's proximity to specific sources with some precision. To accomplish this, traditional time-activity logs and/or observers have been used. In addition, time-stamped bar code scans have been used to delineate specific tasks or locations in some EMF exposure assessments [Sahl et al., 1993; Bracken, T. D. et al., 1994a].

In several studies, the PEM meter simply recorded data during the period of interest and all collected data was assigned to that activity or environment. Typically, this approach has been used to record data for a work day or shift [Floderus et al., 1992; Wenzl, 1992; Sahl et al., 1994; Kromhout et al., 1995]. In recording children's exposure in this manner, two meters were used: one to accumulate exposure during children's time at home and the other for time at school [Kaune and Zaffanella, 1992; Kaune et al., 1994]. The appropriate meter was simply turned off or on when leaving or entering either of these activities.

Contemporaneous diaries have also been used to record time/activity information while performing EMF PEM. Simple diaries maintained by the subjects have been used in both occupational and residential studies [Deadman et al., 1988; Bracken, T. D., 1990; Renew et al., 1990; Kavet et al., 1992; Koontz et al., 1992; Skotte, 1993; Bracken, T. D. et al., 1994b; Merchant et al., 1994; Levallois et al., 1995]. When accumulating meters were used, the nature of the activities during the day was recorded without reference to time [Bracken, T. D., 1986; Wong, 1992] or with specific times to facilitate the comparison of modeled exposures with measured exposures [Kaune et al., 1994].

When a data logger is used, the time when environments or activities occur can be linked to the EMF measurements. In these cases, it is advantageous to note the exact time of an activity or entry into an environment in the diary and if possible, place an event mark in the data. The level of detail in self-reported time/activity diaries has ranged from a few general categories [Deadman et al., 1988; Renew et al., 1990; Kavet et al., 1992; Merchant et al., 1994; Levallois et al., 1995] to entries for up to 20 specific work environments [Skotte, 1993].

When specific times are recorded in the diary for merging with EMF measurement data, the diary time must be synchronized with the data logger time. This has been done by physically confirming that all the clocks were synchronized before data collection or by having the data logger display the time of day [Bracken, T. D., 1990]. Not only did the latter method ensure a common time for the diary and measurements, but it also provided an indication that the data logger was functioning. In addition, the time display replaced the field reading on the meter and discouraged subjects from using the meter to measure fields.

Use of a data logger capable of inserting an event mark in the EMF data stream has facilitated the identification of changes in status and the assignment of data to specific environments during data management [Bracken, T. D., 1990; Bracken, T. D. et al., 1994b]. This capability has been particularly advantageous in occupational environments where field levels can change quickly and a written time to the nearest minute may not be sufficiently accurate to delimit periods of interest. The use of event marks and diary entries for time also provided useful redundancy in the data management process.

In circumstances where it was not convenient or possible for a subject to record their activities in a diary, observers have recorded subject location and/or activity in a diary or log sheet. This methodology has been used for many occupations during EMF exposure measurements: office workers [Breysse et al., 1994a], telephone workers

[Rainer et al., 1992; Breysse et al., 1994b], utility line workers [Gamberale et al., 1989] and health care workers [Philips et al., 1995]. Rainer [1992] developed machine readable log sheets for telephone worker tasks. The log sheet was divided into 15 minute intervals where an observer could record one of 10 work environments.

Alternatives to a written diary have been employed to facilitate the recording of location or task by utility workers. An electronic recording device (CATLOG) was used by utility line workers to self-report their location as on the ground, on the tower, on the conductor, or elsewhere [Pretorius, 1993]. This device periodically recorded a dc voltage determined by a switch setting that was selected to correspond to the worker location.

A small bar code reader that time-stamps each scan was used in place of diaries or logs in two EMF PEM studies. In one case, subjects carried the credit card sized bar code reader and scanned entries for tasks from a set of bar codes that was developed exclusively for each occupation [Sahl et al., 1993]. In a study that quantified EMF exposure during live-line work, an observer used a bar code reader to record (with the time) the locations of up to six crew members [Bracken, T. D. et al., 1994a]. Times in the bar code data were based on the same computer clock as times in the EMF data. The two types of data were linked to allow analysis of exposures by location, as well as by task and work method.

In any time/activity record-keeping system, unambiguous definitions of activities and environments and specifications for entering data are required. Examples of instructions for completing activity diaries and logs are contained in Rainer [1992]; Bracken [1990]; Bracken et al. [1994b]; and Bracken et al. [1994a].

2.10 Other Exposure-related Parameters

Many parameters besides EMF levels have been recorded during PEM studies: some to characterize the work location or subjects, and others to examine their relationship with EMF PEM. During occupational studies parameters that have been recorded to describe the location of measurements include: Standard Industrial Classification (SIC) code; general work location (type of facility); specific work location (specific facility); general work environment; specific work location or environment at a facility; and general or specific tasks. Parameters used to describe subjects have included: standardized occupational job categories; company job title; age. The currents and voltage present on nearby sources can affect exposures and have been recorded in some instances.

Residential exposure studies with PEM have included "other parameters" associated with: external electric facilities at a residence; internal wiring characteristics; ground currents at house; appliance use by subjects; electrical consumption during PEM; house characteristics; neighborhood characteristics; and socio-economic indicators. Perhaps, the most commonly included other parameter in residential studies is the assignment of a house to a wire code category based on the proximity and characteristics of external electrical wiring. The wire code category was originally proposed as a surrogate for EMF exposure by Wertheimer and Leeper [1979, 1982]. Wire code classification schemes have been included in almost all residential exposure studies since then. Internal wiring characteristics that have proven to be sources of elevated fields include: old "knob and tube" wiring, mis-wired three-way switches, and faulty grounds on electrical sub-panels. The protocols for a study investigating the long-term relationship between TWA PE and wire code category incorporate measures from all the "other parameter" categories mentioned above [Rankin et al., 1996].

2.11 Data Collection Protocols

A range of protocol descriptions is available for EMF PEM studies. Of particular interest are those references that go beyond the level of detail required in journal publications and that contain complete PEM protocols, including data forms, time-activity diaries, and data collection procedures. Data collection protocols for occupational electric field PEM studies are described in detail by Bracken [1986] and Wong [1992]. However, these studies used instrumentation that is no longer available.

Methodologies for magnetic field PEM data collection and concurrent time-activity recording have been detailed by: Bracken [1990]; Bowman et al. [1992]; Matanoski et al. [1992]; and Rainer et al. [1992]. Loomis et al. [1994] described the procedures for distributing PE meters by mail to randomly selected utility employees. Bracken et al. [1994a] presented a complete protocol for integrating PE measurements with observations of worker location using a bar code scanner.

Residential PE protocols have been described in detail by Kaune and Zaffanella [1992]; Koontz et al. [1992]; Bracken et al. [1994b]; and Rankin and Bracken [1994]. Kaune and Zaffanella and Koontz both describe protocols for PEM of children. Bracken et al. describe the methodology for distributing PE meters through trained local data collection managers at numerous geographic locations.

2.12 Analysis Strategies

Data analysis strategies employed in EMF PEM studies have been dependent on the purpose of the study. For example, exposure assessment for the purpose of epidemiologic studies have generally relied on the time-weighted average (TWA). TWA has been computed over days [Floderus et al., 1992; Kromhout et al., 1995] or weeks [Thériault et al., 1994b]. Bowman et al. [1992] used TWA constructed for tasks to develop exposure models for electrical and non-electrical workers.

To estimate past exposures, PEM measurements made on current workers are entered into an exposure assessment matrix with or without adjustment for changing work practices. Wenzl [1992] accounted for past exposures by selecting locations with older machinery present for exposure measurements. Exposures in the past are constructed from a combination of time spent in different job categories and estimated exposures for that job category.

In studies that have emphasized exposure characterization, analyses have been performed to describe exposures in terms of different PE indices, to investigate relationships between different exposure indices, to examine the variability of exposures, and to compare PE indices with other magnetic field metrics.

Studies with time-series measurements of magnetic fields have been able to describe many indices of exposure for electric and/or magnetic fields. For example, in epidemiologic exposure assessments, Breysse et al. [1994b] and Wenzl [1992] both described occupational PE exposures in terms of indices of central tendency, maximum level and variability. Bracken TD et al. [1994b, 1995] employed a large number of PEM indices to describe both residential and occupational exposures to electric and magnetic fields.

Guidance from biological or mechanistic research as to which attribute and index of EMF exposure is appropriate to characterize exposure relative to effects is lacking. Therefore the selection of an exposure index is somewhat arbitrary and tends to be driven by analogy with other environmental agents and available instrumentation, rather than by science. In order to investigate the relationships between indices and perhaps select preferred indices, Savitz et al. [1994] examined correlations between different indices of exposure. With a similar purpose, Sahl et al. [1994] performed principal components analyses to identify groups of indices that characterized exposure.

Examples of the analysis of the variability of exposures within and across subjects can be found for occupational exposures in Kromhout et al. [1994, 1995] and for residential PEM in Bracken et al. [1994b].

Comparisons between different methods of characterizing exposure have been a common component of EMF PEM studies. PEM can be a time-consuming and expensive undertaking requiring considerable effort, especially in an epidemiologic study where there may be many subjects. Therefore identification of a reliable surrogate for occupational or residential PEM has been a goal of many analyses. The analyses of PEM by Bowman et al. [1992] indicated that jobs that were in an "electrical occupation" category generally had higher exposures than those in a "non-electrical occupation" category. Examinations of exposures by job categories within the electric utility industry have identified specific occupations, such as electricians, substation operators and line workers, with high exposures [Bracken, T. D., 1990; Sahl et al., 1994; Thériault et al., 1994b]. However, there remains considerable variability within categories making quantification of exposures by this surrogate difficult.

In residential studies, PEM have been examined for a relationship with external electric facilities, electrical consumption, appliance use, housing characteristics, neighborhood characteristics, and other parameters that might predict exposure Cf., Kaune and Zaffanella [1992]; Bracken et al. [1994b].

3

EMF SUBJECTS AND EXPOSURE COMPONENTS

EMF are physical agents whose only pathway for exposure is the simultaneous presence of the subject and EMF. EMF are essentially ubiquitous in developed countries. Therefore the details of EMF exposure are controlled by three aspects: the levels of EMF in various environments, the movement of the subject through locations in the environments, and the activities of a subject in those environments. The purpose of this section is to provide a process for identifying and including exposure components – environments, locations, and activities – in an EMF PEM study.

The principal steps in the process are:

1) identify the groups of subjects for PEM based on attributes that may affect EMF exposure;
2) identify the components – environments, locations and activities – that may contribute to EMF exposures for these subjects; and
3) select the appropriate methodology for capturing exposure component (time-activity) information.

These steps are an essential portion of developing a sampling strategy as described in Section 6.3

3.1 Subject Attributes

The environments, locations and activities that contribute to exposure are dependent on specific attributes of the subject. Subject attributes should be identified that may distinguish the EMF exposure of one subject from another: for example, job category.

The subjects can then be grouped for purposes of sampling into apparent homogeneous exposure groups. Several subject attributes that may be relevant to EMF exposures are identified in Table 3.1. The subject attributes include: age, gender, geographical area type, type of residence and status (student, employed, etc.). Possible characteristics or groupings for these attributes are also given in Table 3.1. These particular attributes and characteristics were identified from existing time-activity survey data as possibly affecting EMF exposure. They are not meant to be exhaustive. During the process of determining exposure components, additional subject attributes and groupings may be identified for a specific study.

3.2 Exposure Components

A day is comprised of a series of exposure components for a subject. It is important to first account for all components and then identify those components which can affect EMF exposure in the context of the objectives of a study. To ensure consideration of all components, initially the day can be segmented into three general environments: Home, Work (School for children and some adults) and Other. These environments can be subdivided by location or activity, to produce a second tier of exposure components. The second tier locations/activities are distinguished by their (hypothesized) contribution to overall EMF exposure for a subject. In the case of some studies, it may not be necessary to go to this second tier of components. For example, if only residential exposure is being investigated, it would not be necessary to consider locations in the Work or Other environments. However, the process should always ensure that 100 percent of a prospective subject's time is initially accounted for and that components are mutually exclusive.

Table 3.1
Possible EMF Subject Attributes*: a) Children; b) Adults

a) Children

Attribute	Characteristics
Age:	0-2, 3-4, 5-7, 8-11
Gender:	Male, female
Area type:	Rural, suburban, city
Type of residence:	House, apartment, other
Enrolled in school:	Yes, no

b) Adults

Attribute	Characteristics
Age:	12-14, 15-17, 18-24, 25-34, 35-44, 45-54, 55+
Gender:	Male, female
Area type:	Rural, suburban, city
Employment status:	Employed, not employed, retired
Occupation:	Job category
Type of residence:	House, apartment, other
Enrolled in school:	Yes, no

* Based on existing time-activity data [1991a]; and [1991b]. See Appendix B.

Depending on the nature of the study and the subjects, each second tier location/activity can be further segmented into locations/activities to produce another level of exposure components. The decision to segment a location or activity into additional components will depend on an evaluation of the nature and extent of likely exposure within that "parent" location or activity.

Examples of exposure components derived from existing time-activity data categories for children and adults are given in Tables 3.2 and 3.3. The 24-hour day for children and adults can be divided into location components, as shown in Table 3.2. The components were produced by aggregating existing time-activity survey data that contain detailed location and activity information about how individuals spent a 24-hour day [Wiley et al., 1991a, b]. The location components were selected as being possibly related to EMF exposure or as representing natural divisions of activities where EMF exposures might differ between subjects. The specific locations that were aggregated to produce the exposure components in Table 3.2 are discussed in Appendix B.

Activities can be similarly organized in a hierarchical exposure component structure. In this case, the highest level would still be the general environments of Home, Work, and Other. The general environments can then be subdivided into their associated specific activities: preparing food, cleaning house, traveling by automobile, etc. Examples of hierarchies of activities developed from the existing data for children and adults are shown in Table 3.3 [Wiley et al., 1991a, b]. The specific activities that were aggregated to produce the components in Table 3.3 are discussed in Appendix B.

The activities in Table 3.3 are quite general and would seem to provide little guidance in selecting exposure components for measurement. For the purposes of some EMF studies, it may be more appropriate to identify and capture exposure measurements during specific activities that are clearly related to EMF exposure. Elevated EMF exposures are often associated with specific short term activities, such as using an

Table 3.2
Possible EMF-related Exposure Components by Location*: a) Children; b) Adults

a) Children

Environment	Location†	
Home	Kitchen Bedroom	Inside home Outside home
School		
Other	Inside away from home Outside away from home	Day-care home Day-care commercial Travel

b) Adults

Environment	Location†	
Home	Kitchen Bedroom	Inside home Outside home
Work	Work place	
Other	Inside away from home Outside away from home School	Travel Train/rapid transit

* Based on existing time-activity data [1991a] and [1991b]. See Appendix B.

† Survey responses of "unknown" are omitted.

Table 3.3
Possible EMF-related Exposure Components by Activity*: a) Children; b) Adults

a) Children

Environment	Activity†
Home	Sleeping Home, low EMF Home, possible EMF
School	School
Other	Outdoor Away from home Travel

b) Adults and teenagers

Environment	Activity†
Home	Sleeping Home, low EMF Home, possible EMF
Work	Work
Other	Outdoor Services (errands) Non-home events Travel

* Based on existing time-activity data [1991a] and [1991b]. See Appendix B.

† Survey responses of "unknown" have been omitted.

electric hair dryer or using a power tool. In some studies, it may be advantageous to enumerate these individual activities and treat them as events rather than as part of a continuum of activities.

Thus, location and activity information may be recorded best with a log or time-activity diary, while very specific and discrete EMF-related activities may be better suited to recording with a survey or by counting occurrences.

3.3 Exposure Component Stratification Tables

A possible tool for developing an exposure component hierarchy is a set of exposure component stratification tables.[1] The component stratification table, as shown in Table 3.4, can be used to assess the disposition (inclusion, repetition, etc.) of each possible exposure component.

The hierarchy of exposure components appropriate for subjects in a study will be dependent on the purpose of the study, the scope of the study, the diversity of the subjects and other factors. For each subject group it may be necessary to develop a separate set of component stratification tables.

The construction of component stratification tables is intended to produce estimates of the duration, magnitude, variability, and importance of exposure experienced by individuals or groups of individuals in both general and specific locations or activities. This information can assist in the selection of exposure characterization methods for each component. The emphasis here is on PEM. However, for a given component, the preferred characterization method may be PEM, modeling using survey or source measurements, or no estimate of exposure. By systematically proceeding through a hierarchy of exposure components for each type of subject, it is possible to identify the

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[1] *component, here and in the remainder of this discussion, is used as a generic term to include environments, locations, and activities at any level in the hierarchy.*

Table 3.4
Generalized Exposure Component Stratification Table

Subject type:							
	Component characteristic*				**Evaluation***		
Component	**% Time**	**Ave. Mag. Fld.**	**Var. of Mag. Fld.**	**Sources/ special**	**Include?**	**Separate?**	**Divide?**
1. *Home*							
1.1 *Component 1*							
1.2 *Component 2*							
1.3 *Component 3*							
.....							
2. *Work*							
2.1 *Component 1*							
.....							
.....							
3. *Other*							
.....							

* See Table 3.5 for key to characteristic and evaluation entries.

components of importance for a particular EMF study, to establish a priority for PEM, and to identify, and possibly account for, exposures during periods without measurements. Besides identifying the exposure components suitable for PEM, this process provides guidance on the appropriate level of time-activity monitoring and the importance of including EMF sources in PEM characterizations.

The generalized exposure component stratification table shown in Table 3.4 offers a standard format for evaluating exposure components in each level of the hierarchy. The set of parameters and questions required for each component in the hierarchy are listed in Table 3.5 as well as below. The standard elements for a component are specific to a given type of subject and consist of:

- Estimate of the percentage of time spent in the component;
- Estimate of the average field in the component;
- Estimate of field variability in the component; and
- Presence of predominant and/or unusual sources.

These elements permit an evaluation of the exposure contribution of each component for that subject type.

The standard questions that are asked about each component are:

- Should the component be included in PE measurements?
- Should the measurements taken in the component be separated from those in other components?
- Should the measurements in the component be further divided within the component?

Table 3.5
Key to Exposure Component Stratification Tables

Table entry	**Description**
% Time	What percentage of time does this type of subject spend in this component?
Ave. Mag. Fld.	Estimate the daily average magnetic field (µT) for this type of subject in this component.
Var. of Mag. Fld.	Estimate the range (or other parameter) of magnetic fields expected for this type of subject in this component.
Sources/ special	Are there sources or special field conditions in this component that warrant inclusion in PE characterization?
Include?	Should PE in this component be measured in the exposure characterization?
Separate?	Should PE in this component be recorded separately from PE in other components on the same tier?
Divide?	Should PE in this component be subdivided further?

The answers to these questions determine whether the level of record-keeping necessary for each component and whether another tier in the exposure component hierarchy is required.

An example of an exposure component stratification table is shown for a study of exposures among utility line workers in Table 3.6 [Bracken, T. D. et al., 1994a]. In this case, the objective of the study was to characterize the differences between the use of hot-stick (HS) and bare-hand (BH) techniques for live-line transmission-line work. To achieve this, PEM were required only when tasks were being performed (Component 2.2). In order to characterize exposures, it was necessary to: separate the types of tasks (2.2.1 & 2.2.2), record locations while performing the live-line tasks (2.2.2.1 - 2.2.2.4); and to record task, current, voltage, and work method. It was also necessary to measure exposures during non live-line tasks to account for changing work practices. The field levels in each component were estimated from previous measurements and experience. The shaded cells in Table 3.6 reflect the exposure components when PEM are required.

3.4 Selecting Exposure Groups

Information about prospective subjects and their expected exposures is used to stratify the subjects into exposure groups with presumably homogeneous exposures. Identifying homogeneous EMF exposure groups may not be an easy task. EMF exposures can be highly variable within traditional exposure groups, such as job categories, and EMF exposures can vary greatly among subjects who, otherwise, are similar in many ways. Therefore the assignment of subjects to groups by anticipated exposures will often have to be tempered by natural groupings, such as place, gender, age, occupational status, etc. and by their accessability for measurement.

The purpose of the study will determine which of the groups are to be sampled and what priority to place on sampling each group. Factors that affect the selection and

Table 3.6
Example of Exposure Component Stratification Table: Live-line Transmission Line Workers The shaded area describes the exposure components to be measured.

Subject type: Live-line transmission line workers							
	Characteristics				Questions		
Component	% Time	Ave. Mag. Fld, μT	Var. of Mag Fld, μT	Sources/ special	Include?	Separate?	Divide?
1. Home	50	-	-	-	No	-	-
2. Work	25	-	-	-	Yes	No	Yes
2.1 Non-task time	20	<1	>1	-	No	-	-
2.2 Task time	~5	-	-	Voltage, current, task	Yes	No	Yes
2.2.1 Non Live-line	~2	>1	>1	Other lines	Yes	Yes	Yes
2.2.2 Live-line	~3	-	-	HS or BH*	Yes	Yes	Yes
2.2.2.1 On ground †	~2	<10	<10	-	Yes	Yes	No
2.2.2.2 Climbing tower †	«1	<10	>10	-	Yes	Yes	No
2.2.2.3 Working in tower †	~1	>10	>10	-	Yes	Yes	No
2.2.2.4 On conductors†	«1	>10	>100	-	Yes	Yes	No
3. Other	25	-	-	-	No	-	-

* HS = Hot-Stick, BH = Bare Hand

† Applies to both 2.2.1 Non Live-line tasks and 2.2.2 Live-line tasks

priority of groups for PEM in an EMF study are no different than those for studies monitoring other parameters. For example, a study to develop baseline information about EMF exposures will require many subjects. In a diagnostic study that is responding to questions or complaints about EMF, the exposures of specific individuals will be emphasized. For a study monitoring compliance with occupational exposure limits, workers in high exposure job categories or performing high exposure tasks will be singled out. In an epidemiologic study, the subjects will be selected according to standard sampling procedures for the type of study, case-control, cohort, or cross-sectional.

The subject attribute and exposure component stratification tables provide a convenient methodology for selecting exposure groups for a PEM study. The steps in this process are:

1) Construct subject attribute tables and identify each type or group of subject to be included;

2) Construct the component stratification tables for the home, work/school, and other environments for each type of subject;

3) Determine the components where PE measurements are needed for the subjects;

4) Determine whether PEM in the selected component(s) are to be separated from PEM in other component(s)

5) Determine whether PEM in the selected components are to be divided into more than one location and/or activity (subcomponent);

6) If a component is to be divided, identify the locations and activities (lower tier components) within the component where PEM are needed;

7) Construct lower tier exposure component tables and determine whether the lower tier components need to be separated and divided;

8) If a lower tier component needs to be divided, repeat the process of identifying locations and activities to produce another level of exposure components;

9) Continue the process of identifying and dividing until components no longer need to be divided;

10) Select a sampling plan, PEM protocols, and a time-activity record-keeping system commensurate with each subject type and component stratum developed in this process.

This may be an iterative process. The identification of exposure components may suggest additional subject attributes, subject groups, or component aggregations.

3.5 Time-activity analyses

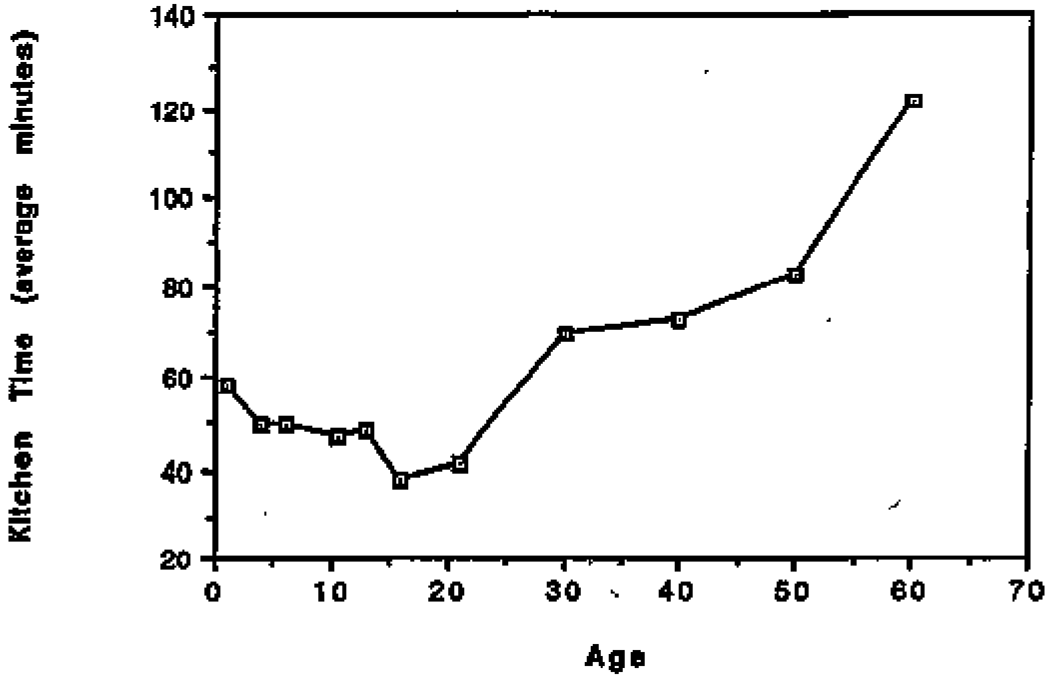
The identification and selection of subject groupings and exposure components may require time-activity information for prospective subjects. To illustrate the effects of subject characteristics on activities that are possibly related to EMF exposures, we examined time-activity data for adults and children from two surveys performed in California in 1987-1991 [Wiley et al., 1991a, b]. There are also time-activity surveys that cover the entire U.S. population [Silvers et al., 1994]; [Nelson et al., 1994]. The methodology and results of these examinations of the California data are described in detail in Appendix B. For our purposes, the large number of activities reported by telephone survey, respondents were aggregated into the locations and activities shown in Tables 3.2 and 3.3, respectively. The distribution of time spent in these locations and activities were then examined by the subject characteristics shown in Table 3.1.

The largest and most consistent differences in locations and activities observed among the population subgroups were related to age and gender. These differences are discussed in more detail in Appendix B and may prove helpful in selecting the subject attributes and exposure components for a proposed study. Specific locations of interest for EMF exposure in the home were the kitchen and bedroom. As an example of the analyses that were performed on these data, the average minutes spent in the kitchen during the day as a function of age are shown in Figure 3.1.

For general activities, a measure of possible EMF exposure was constructed from the time reported for use of appliances in non-work settings, most often in the home. This measure was calculated as the sum of minutes during the day engaged in the following activities, possible appliances are in parentheses: food preparation (electric stove), cleaning house (vacuum cleaner), washing clothes (washer), dressing and grooming (hair dryer), doing homework (computer) and use of radio. This measure, though undoubtedly speculative and unreliable, provides an example of what could be done with survey data. If the survey data had been targeted toward likely EMF sources the accuracy and reliability of the measure would improve substantially. In general, this measure of possible EMF exposure was higher for women than men and increased with age. Figure 3.2 shows the minutes spent during the day in possible notable EMF exposure activities as a function of age.

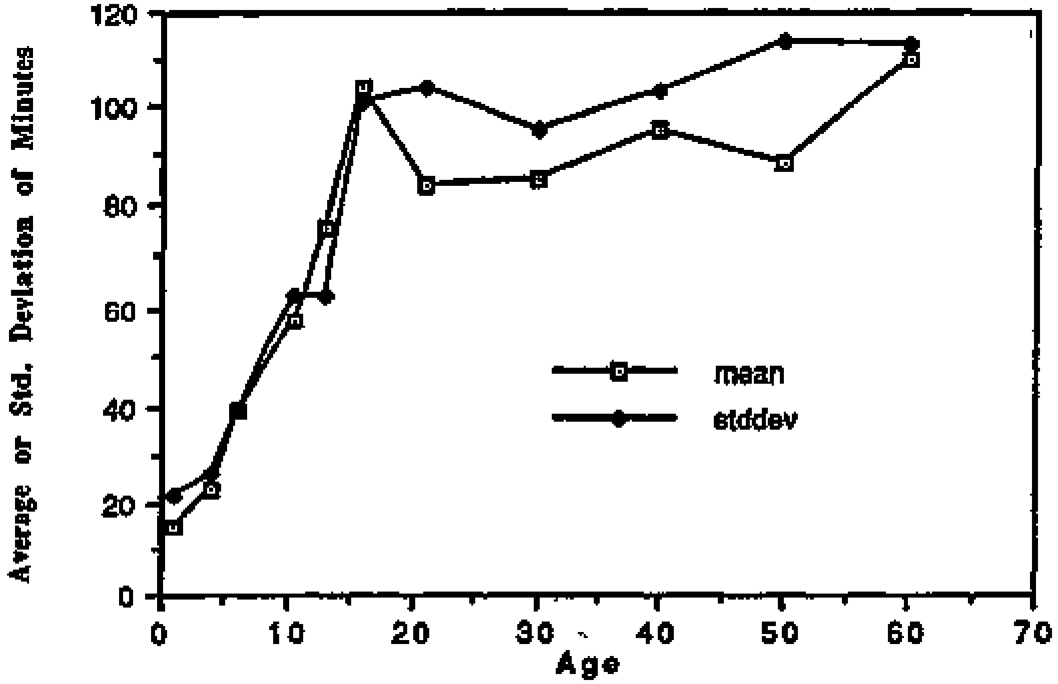
This is an example of how existing activity pattern surveys can provide a foundation for the evaluation of potential EMF exposure in general population samples. Though designed for another purpose, this surely illustrates the kinds of variation in activity patterns that are likely to be observed in any survey that includes subjects with a broad range of demographic characteristics. To the extent that peoples' activities and locations can be linked to potential EMF exposures using information from available databases, even data intended to address the other issues may be a useful tool for planning EMF studies.

Figure 3.1
Average Time in the Kitchen Versus Age



Based on data from [Wiley et al., 1991a]; and [1991b].

Figure 3.2
Minutes of Possible EMF Exposure Versus Age



Based on data from [Wiley et al., 1991a]; and [Wiley et al., 1991b].

The surveys examined and reported here include a substantial number of questions (see the list in Appendix B) dealing with possible exposure to air pollutants during the 24-hour reference period. Though not placed in the chronology of activities and locations, these questions provide valuable information about the possible extent of exposure to specific pollutants. Analogous questions about specific appliance and equipment use and proximity to other known sources, should be considered for use in surveys dealing with possible EMF exposures.

4

PEM VARIABILITY

Whenever a study attempts to characterize an attribute of a subject, the more variable the attribute, the more data are necessary to estimate the attribute with a given level of confidence. Therefore variability in PEM affects the many elements of the study plan including the exposure model, study design, and quality assurance. Variability issues influence so many aspects of the study design and measurement protocols of a PEM project that variability warrants this general discussion. No presentation of this subject can be exhaustive and responsive to the needs of all investigators and all study scenarios. Because of the complexity of PEM variability issues, resultant magnetic field, which is the best understood and most widely reported field characteristic, will be the principal subject of this discussion.

4.1 Variability Factors

EMF PE is determined by the nature of EMF sources which impact a subject and aspects of the subject's activities. The fields from a source will vary over space. Some sources produce fields over a relatively broad area, with fields that fall-off slowly with increased distance from the source (for example, the fields from a transmission line). Other sources produce more localized fields, which fall-off rapidly with distance (most house-hold appliances). Sources may also move through space, altering the fields present in an area (an arc welder on a robot arm).

The fields from sources also vary over time. The fields produced by some EMF sources rise and fall over time, consider the gradual rising and falling of field levels due to changing load on residential power lines during a day. Other fields change rapidly when sources turn on or off (for example, an electric drill). The variation over time in field level due to a source may be a consequence of some systemic patterns (as in the seasonal variation of load on a transmission line), it may be due to some automated process (an induction furnace at a foundry cycling on and off) or because of some activity by the subject (using a hair dryer) or someone nearby (a coworker using an electric tool). In addition, the fields produced by an EMF source have multiple characteristics, including magnitude, direction, frequency content, and polarization. These field characteristics may also differ over time. For example, while an industrial facility is operating during the day, but not at night, capacitors on the power lines may act to maintain a satisfactory voltage. Hence, the operation of these capacitors may introduce transients on the lines only during the day.

Subjects also move through space over time, resulting in a wide range of sources influencing their PE. The nature of the sources (including their field magnitude and the degree to which their fields are localized), the status of the sources during the time the subject is exposed (on/off, high/low, etc.), and the subject's proximity to the sources affect the subject's PE. All these factors can result in an extremely complex pattern of PEM over time.

4.2 Characterization of Variability

PEM vary for a given subject (within-subject variability). This variability is a consequence of the subject's locations and the subject's activities. Subjects in a PEM study may also be grouped, whether by convenience (for example, all workers in a manufacturing plant) or because of presumed homogeneity of exposure (transmission line workers at a utility). PEM also varies between the subjects in a group (between-subject variability, also called within-group variability). The variability in PEM between groups of subjects may also be of interest (between-group variability). Examples of the analysis of the variability of exposures within and across subjects can be found for occupational exposures in Kromhout et al. [1994, 1995] and for residential PEM in Bracken et al. [1994b].

Various summary statistics are available to characterize the variability of PEM including: standard deviation, range, intra-quartile range, etc. One or more of these summary measures can be calculated for a subject. Within-subject variability can be assessed based on its summary measure(s). Between-subject variability can be examined based on comparisons between the summary measures of two or more subjects.

In order to assess between-group variability, one or more summary measures must be computed for the variability of each group. The measurements for all subjects in a group can be pooled and variability summary measures computed in a traditional manner. Summary measures for variability can be computed by pooling all the measurements for a group. This results in the summaries being weighted by the number of measurements contributed by a subject. Alternatively, the variability of summary measures of the subjects can be examined.

The purpose statement of the PEM study provides guidance regarding the variability issues which are of greatest importance. PEM studies that intend to monitor compliance, may seek to determine whether any subject exceeds some guideline. Here, within-subject variability is most important because each subject's PEM will be compared to an objective standard and precision in determining exposure for that subject is likely to be critical.

In an epidemiologic study, the goal is the correct assignment of subjects to groups which are based solely on the degree of exposure. The variability of PEM for any given subject directly effects the ability of the study to accurately make this assignment. (Misclassification can attenuate a study's ability to identify an association.) If the assignment to groups is based on objective exposure values, then within-subject variability is important, just as it was with compliance monitoring. However, if the assignment is based on relative exposure among the subjects then between-subject variability is also an important consideration.

Some PEM studies seek to identify the relative exposure of groups of subjects. For example, the objective of a study may be to determine if subjects in certain types of homes have residential exposures which are larger, or smaller, than subjects in other types of homes. In this instance, between-group variability becomes an important factor as well.

Several formal statistical procedures are available for decomposing and analyzing the variance in a body of PEM.

4.3 Implications for Study Design

PEM Variability must be considered in many aspects of a study plan and specific protocols. During development of the study plan, the investigator should review the existing literature, looking for published works which help to estimate the likely variability in PEM in their study population. Section 2 of this document provides a starting point for that exercise.

In developing the exposure model, the investigator may wish to employ a mean value to estimate exposure from PEM. The variability of PEM has a direct bearing on the precision with which the true mean can be estimated.

Estimates of variability profoundly affect sampling strategies. The desired precision in exposure estimates in combination with the expected exposure variability in the population will suggest the necessary sample size. For example, the within-subject variability of PE for outdoor activities in remote areas is considerably less than that for the work place. Consequently, estimating the mean exposure of a subject hiking in the wilderness to within 0.1 mG with a confidence of 95%, requires fewer PEM than estimating the mean exposure of a subject in an automobile manufacturing plant with the same degree of precision and confidence.

Anticipating the likely contribution of each type of variability in PEM allows the investigator to develop a sampling strategy which seeks to maximize the utility of the resources available to the study. For example, in a residential PEM study, the investigator must decide: if residences should be grouped (or stratified) and what strata dimensions to use; how many residences to sample generally and how many to sample within each stratum; how long a measurement period should last; if repeat measurement periods are warranted; and if the number of measurement periods should vary by stratum and/or by other important sampling elements. Variability considerations specific to each of these decisions are important for developing a study plan, as illustrated by an example from a large residential PEM study.

In the EMDEX Project Residential Study, PEM measurements were collected during up to six visits at 396 houses in the United States and Canada [Bracken, T. D. et al., 1994b].

The reported results of a variance component analysis of these data can provide guidance in addressing sampling questions. For houses with overhead wiring, the differences in PEM between houses (between-subject) were much greater than the differences between visits to a house (within-subject). This argues for fewer measurements at more houses if the aim is to accurately characterize residential PE for these houses. In fact, this analysis allowed the researchers to estimate the number of visits to each type of house that would be required if the investigator wanted to estimate mean PE for that type of house within a specified tolerance. (Only single-unit residences were included in the study and a convenience sample of sites and houses was employed, therefore the results may not be representative of all residences.) Thus, the analysis of the variability in these data provided insight into the nature of residential EMF exposures and offered a foundation for sampling strategy decisions in subsequent residential studies.

The variability of PEM also impacts the quality assurance practices which will be employed by a study. Validation procedures are frequently employed at several points in data collection, transfer, management and analysis. Knowledge regarding the expected variability of the data can contribute to the establishment of control limits to identify data which deserve review.

4.4 Uncertainty and Variability

Uncertainty should not be confused with variability. Together they determine our confidence in the PE estimates produced by a study, however, uncertainty results from limitations in the study design and shortcomings in its implementation. All PEM studies are designed in the context of certain constraints, from finite funding to existing instrumentation. These practical constraints result in design compromises, producing a design which is less than ideal. The result is increased uncertainty in study findings due, for example, to sampling fewer subjects than desired.

Rarely is a PEM study implemented exactly as it was designed. Shortcomings in implementation result in additional uncertainty. For example, non-participation by certain types of subjects or a failure to comply with measurement protocols by other types of subjects can produce biased results.

Some uncertainties are known or can be estimated (e.g., those resulting from design decisions), others are likely to be unknown (e.g., when implementation produces biases). Uncertainty is often difficult to quantify with any precision, but the types of uncertainties present in a study should, to the extent practical, be identified, assessed, and documented.

5

GENERAL EMF EXPOSURE ASSESSMENT GUIDELINES

The general approach described here draws heavily on the proposed Good Exposure Assessment Practices (GEAP) proposed by Hawkins et al. [1992]. These practices identify basic scientific principles that should be followed in exposure assessment projects. The U.S. Environmental Protection Agency (EPA) has also published general guidelines for exposure assessment [EPA, 1992].

The purpose of establishing general guidelines for exposure studies is to ensure that valid data are collected and that the data meet the study objectives including, if appropriate, any risk assessment requirements. A generally accepted approach to exposure assessment applies to studies that include EMF PEM as well as to studies that are investigating other environmental agents or employing other types of EMF measurements. No amount of specific guidance on measurement protocols can overcome a poorly conceived general study design. The procedures outlined in the general guidelines seek to minimize shortcomings in the overall study design.

There are several characteristics of EMF exposures that strongly support the adherence to GEAP. The many sources of variability in EMF PEM measurements make interpretation of measurements difficult without appropriate sampling strategies and detailed protocols. The specific EMF exposure parameter or summary measure, if any, associated with health-related outcomes is not known. Thus, the evaluation of field characteristics and measures for inclusion may be ambiguous and more than one EMF parameter may be selected for measurement. These factors contribute to the need for a well-planned study design which is the outcome of following general exposure assessment guidelines.

The emphasis of the general guidelines is on identifying and stating the purpose of the study and on creating a written study plan that outlines a study design. These two steps should occur prior to developing specific protocols and making measurements. It is particularly important to establish a clear statement of the purpose of the study and measurements. By first focusing on what question or questions the data will be called upon to answer, it is possible to develop a strategy that is effective in combining a sampling scheme and measurement method [Lynch, 1979]. This is especially true for EMF PEM where variability is large and the factors contributing to PE and its variability can be numerous and complex.

5.1 General Recommendations

The recommended general approach to EMF PEM studies is outlined in Table 5.1 and discussed below. The first recommended general guideline is:

To develop a clearly stated purpose for the EMF PEM study.

By succinctly stating the purpose of the study at the outset, and referring to it frequently, questions regarding the overall study design and the written study plan can be addressed without ambiguity. The purpose statement may evolve as the study design develops and resource constraints are resolved but any changes or compromises in the purpose will be clearly known. Before beginning measurements there must be a purpose statement that is understood by, and acceptable to, the investigators, managers, and sponsors of a study.

EMF measurement studies can encompass a variety of purposes, including:

- exposure characterization, either for individuals or groups;
- ascertainment of exposure status for epidemiologic studies;

Table 5.1
General EMF Exposure Assessment Recommendations and Study Elements

No.	Description
Recommendations	
1	Develop and state the purpose of the study.
2	Complete a written study plan that documents the purpose of the study and addresses the study elements described below.
Elements in the Study Plan	
1	Assess the available organizational, personnel and financial resources.
2	Present an exposure model that transforms measurements to personal exposure.
3	Present a study design that describes the sampling strategy, data collection protocols and data management procedures in general terms.
4	Plan for subject issues including human subjects committee approval, distribution of data to subjects, and anonymity.
5	Present a quality assurance plan covering all aspects of the project.
6	Discuss the uncertainty of measurements, models and study design assumptions.
7	Present a plan for archiving data produced by the study.

- exposure monitoring to assess compliance; and
- responses to employee or public requests for information on EMF exposure.

Establishing the purpose of an EMF study at the outset helps determine whether the inclusion of PEM is appropriate. Before embarking on data collection, the ability of PEM to respond to the needs of the study must to be evaluated. For example, characterization of the field levels in an environment may be better accomplished by survey measurements than by PEM.

The second recommended general guideline is:

> **To complete a written study plan prior to developing specific protocols or beginning measurements.**

Production of written documents describing a study encourages a complete and structured consideration of the elements of an EMF PEM effort. Two levels of written study documentation are recommended: a general study plan and detailed protocols. The study plan should include a general description of the following study elements: 1) Resources; 2) Exposure model; 3) Study design; 4) Subject issues; 5) Quality assurance; 6) Uncertainty; and 7) Archival plan.

A written study plan forces the investigator to codify the purpose of the measurements and document the consideration of all the elements described below. A study plan provides a context for the evaluation of project feasibility technical approach, and resource requirements by investigators and their organizations.

The extent of and level of detail in a study plan will depend on the complexity of the measurements study and the number of design issues requiring evaluation. For example, measurements to determine compliance with occupational exposure guidelines may follow a standardized protocol developed by a professional organization and require little planning. However, an exposure characterization for an epidemiologic study may entail research and the development of many aspects of the study design, requiring considerable planning and project resources. Study design options and their impacts on satisfying study objects and resource allocation can be examined in the study plan. The study plan may change during the development of detailed project protocols due to practical matters, resource limitations and the like. However, the presence of a written study plan addressing general study elements provides the context for developing and evaluating specific protocols.

The written protocols will elaborate on elements of the study plan, including detailed procedures for sample selection, data collection, data management, quality assurance, data analysis and archiving data. The protocols also include specific measurement procedures, data collection forms and check lists. The production of the detailed protocols for an EMF PEM study will utilize the specific guidelines described in Section 6. The remainder of this section describes the elements that should be considered in preparing a study plan.

5.2 Study Elements

5.2.1 Resource Assessment

Successful completion of a project requires having commitments for adequate organizational support, personnel, and financial resources. Inclusion of this element in the study plan highlights the need to assess the availability of these resources. The sponsoring or responsible organization should understand the purpose of the study and commit sufficient resources to complete the study. A plan should be developed to communicate, on an on-going basis, the status of project resources to the responsible organization.

The purpose and scope of the study will determine the level of expertise required to design and implement the PEM study. Because of the potential for large variability in EMF exposures leading to questions of data validity and interpretation, studies involving PEM should include or have access to personnel familiar with EMF sources and exposures. In the case of exposure characterization for epidemiological studies, such personnel should be directly involved in the development of measurement protocols. However, in other situations, data collection can be performed by trained individuals without technical or EMF backgrounds. Monitoring the work place for compliance with exposure guidelines could utilize industrial hygienists familiar with work practices and trained in EMF measurements.

The number of individuals expected to be involved in conducting the PEM and their level of effort must be assessed, documented, and a commitment for these resources must be obtained from appropriate parties in the organization(s) sponsoring and conducting the study. Estimation of these resources is based on the proposed study design including: sampling strategy, sample size, subject solicitation procedures, geographic diversity of measurement sites and subjects, length of time required to perform the measurement protocols, and other factors which are specific to the purpose of the PEM study.

All phases of the study must be considered when estimating the financial resources which will be required, from protocol development through reporting of results. Hard costs related to instrumentation, equipment, supplies, and other study expenses, possibly including contracted work, must be estimated. Soft costs, especially personnel costs incurred by the organizations conducting the study, must also be estimated. These costs are used to determine both an estimated total cost for the study and a cost per exposure unit (subject, workday, residence, etc.).

The number of subjects to be sampled depends on practical and statistical considerations. (See Section 6.3) The availability of subjects depends largely on the setting of the PEM study. Studies monitoring compliance in settings where organizational support for the research effort has been obtained should have minimal difficulty securing the desired number of available subjects. However, studies requiring volunteers from the general public must assess the resources required to perform proper, successful solicitation and selection procedures. A PEM study must determine the personnel and financial resources required for obtaining the desired sample of subjects. This assessment process may require the assistance of parties familiar with the types of solicitation procedures proposed for the study, for example telephone solicitation experts.

Identifying the instrumentation required for a PEM study involves properly determining the characteristics of the instrument(s) to be used and then selecting the type of instrument(s), including make and model. (Section 6.2 discusses this matter in more detail.) This resource assessment addresses the availability of satisfactory instruments, within the organization plus loaned instruments, and the costs associated with possible leases or purchases.

Inclusion of a resource assessment in the written study plan facilitates an estimate of the financial support that is required to complete the study and allows alternative approaches to be explored.

5.2.2 Exposure Model

The exposure model describes what EMF characteristics will be measured, generally how they will be measured and how the measured characteristics will be evaluated and used to characterize personal exposure. Developing an exposure model consists of: 1) identifying one or more field characteristics to be measured, 2) selecting appropriate meters, 3) determining placement of the meter on the subject and, 4) if more than one measurement is collected per subject for a given field characteristic, selecting appropriate summary measures.

EMF have many physical characteristics which can be measured, for example the magnitude of the fundamental frequency. (A detailed discussion of field characteristics is contained in Section 6.1) Currently, magnetic and/or electric fields are measured at a single point on the body. (Future technologies may permit measurements at several locations to better characterize whole-body exposure.) Some instruments measure more than one characteristic of the field, and some also collect multiple measurements of a given characteristic over time. (See Section 6.2 for a discussion of instrumentation.) Hence one or more PEM are often obtained for each subject.

When a subject has multiple measurements for a field characteristic, appropriate statistical descriptors (summary measures) are selected by the investigator to characterize that subject's exposure. The most commonly used summary measure is time-weighted-average (TWA). Summary measures are founded on the purpose of the study. They may be selected for a variety of reasons including their specification in an exposure guideline or because they are based on biological or health-related outcome hypotheses.

The exposure model may incorporate assumptions which must be documented in the study plan. For example, when the meter is placed on the subject's chest in hopes of characterizing whole body exposure or when the selected summary measures are based on biological hypotheses.

The study plan must document the justification for the exposure model used by a PEM study (the selection of field characteristics, meter type and placement, and summary measures). Inclusion of this element in the study plan encourages the investigator to consider and document the exposure model, any assumptions associated with that model, and the rationale for the selection of the particular exposure model. Addressing these issues will also support the estimation of uncertainty that is recommended in a subsequent guideline.

5.2.3 Study Design

Prior to developing specific protocols, the components of the study design should be addressed on a general level. The approach taken to various design questions can be outlined and evaluated in the study plan. Components of the study design may include: selection of measured field parameters, instrumentation, sampling strategy, data collection protocols, data management procedures, anticipated data analysis strategies and overall study documentation. The study design should indicate how the components will meet the objectives of the study within the available resources. If appropriate, the study design should also include an estimate of the power of the study and indicate its ability to reach conclusions with stated levels of confidence.

The study design should address specific issues related to the proposed EMF PEM study. For example, an assumption of a paucity of highly exposed subjects within a group may suggest that a stratified sample be employed, rather than a simple random sample. Details of the methodology to achieve this end would be presented in the specific protocols.

The lack of consensus on a health-related EMF exposure metric requires the investigator to evaluate many possible field characteristics and exposure measures. The dynamic nature of EMF exposures may dictate that time-series exposure data be obtained by the study. In this case, the use of data loggers, instead of accumulators, often results in a considerable volume of data, requiring appropriate procedures for data collection and data management. Identification, evaluation, and documentation of study design choices in the study plan provides direction in the subsequent development of protocols.

Often a brief walk-through survey of potential subject environments and review of subject activities can identify important design issues and suggest feasible solutions for inclusion in the study plan. The value of these preliminary observations can be enhanced by obtaining magnetic field measurements with a hand-held meter during the survey.

5.2.4 Subject Issues

There are three important subject issues to consider in an EMF PEM study. First, measurement protocols may be such that they require approval from a Human Subjects Committee or equivalent review body. Whether such approval is required or not, a consent form signed by the subject, indicating their willingness to participate and their understanding of the purpose of the study should be developed and routinely used. Participation may also require permission from a parent/guardian or supervisor or employer.

Second, distribution of PEM results to subjects should be a part of the study design. Considerations include the extent and format of the results that are released and the timing of release of the data. Ideally, to be responsive to the subject's need for information, distribution of data to a subject should be as soon as possible after they are collected. Preferably, the subject's PEM results should be distributed along with some more general PEM information, to provide perspective. To avoid possible influence on subsequent measurements collected by this or other subjects, results should be released only after all measurements for an affiliated group of subjects have been conducted.

Finally, a plan for maintaining the anonymity of subjects in reporting study results will also be required. Whether the data retain identifying information is a matter which the investigator must address with their organization. The resolution of all these issues will affect subject selection, data collection, data management, documentation and archival plans.

5.2.5 Quality Assurance

To ensure the quality, integrity, and security of data, a comprehensive plan for quality assurance is required. This plan will ultimately be reflected in many components of the study design, including: sampling procedures, instrument calibration and performance verification, data collection, data transfer, data entry, data management, and data analysis. A general description of planned quality assurance measures should be included in each of these aspects of the study plan.

5.2.6 Uncertainty Evaluation

In PEM, and other types of studies, uncertainty results from two distinct sources. One is compromises in a study design which come about because of practical considerations such as a limited sample size or use of instruments which, by nature, are imprecise. These uncertainties are known and often can be quantified. For example, the size which is practical, given the available resources, in combination with estimates of variability and certain assumptions about the distribution of PEM can be used to compute confidence intervals for PEM summary measures. Similarly, the accuracy of the instruments which are used to collect PEM should be known and reported. This ensures that modest differences between the PEM for individuals or groups which might be the result of imprecision in the PEM instrument are not misinterpreted.

The other manifestation of uncertainty results from shortcomings in the implementation of the study protocols. Often these shortcomings are known, for example, when the solicitation of subjects results in a high rate of refusals. Though the shortcomings may be known, quantifying their impact on the study results may be difficult or impossible. Shortcomings in the implementation of the study protocols may only be suspected, for example, when a subject is asked to wear a PEM instrument during the workday and inspection of the time-series measurements indicates a substantial period with little or no variation in the measurements. Though this suggests that the subject may have violated study protocols and not worn the instrument, this violation can not be proven. In this circumstance the data are suspect and uncertainty in the study results is introduced, but the nature and extent of the uncertainty is difficult to gauge and extremely difficult to quantify.

The sources of uncertainty in a PEM study should be identified and, if possible, their impact should be estimated. The study plan should describe the limitations of the sampling and data collection procedures, and uncertainties introduced by the choice of instruments, exposure model and known study implementation shortcomings. The study plan should state the exposure estimates that are to be derived from the study and the degree of precision in those estimates that is desired. For example, the study's objective might be to estimate the mean 60 Hz resultant magnetic field exposure (or some other field characteristic) for a population to within 0.5 mG (Based on a 95% confidence interval).

Ultimately, estimates of uncertainty should be generated from the measurements themselves and combined with known limitations in the study design and shortcomings in implementation to provide a statement of overall uncertainty in study results. In general, risk can be characterized as the product of potency (probability of a health effect at a given dose) and exposure [Hawkins et al., 1992]. Because the potency of EMF is not currently known, statements of uncertainty for EMF risk assessment are ambiguous by definition. Estimates of overall uncertainty in EMF studies are therefore limited to estimates of uncertainty in exposure. These can be generated from knowledge of the measurement process, sampling procedures, data collection, exposure models, and study assumptions.

Failure to account for measurement errors and other sources of uncertainty can result in lowered estimates of risk in epidemiology studies. For example, the epidemiology study of the largest population with the highest exposure to radon reported only a modest overall association and dose-response relationship with lung cancer [Pershagen et al., 1994]. However, when the uncertainties relating to measurement error and missing data were addressed by Monte Carlo methods, a substantial increase in the estimated risk was observed [Largarde et al., 1997].

Knowledge of the sources of uncertainty during the design phase can guide efforts to reduce variability in study results. Estimates of uncertainty can also be used to compute the anticipated statistical power of a study design and to evaluate the likely confidence in study results.

5.2.7 Archival Plan

The archival plan should describe how the data will be documented and archived. This may entail a standard written report and retention of forms with descriptive information and raw data files for compliance measurements. For other monitoring programs, the written report may be expanded considerably to include a more rigorous record of sampling procedures, instrument calibration and performance verification, data collection, data transfer, data entry, data management, and data analysis. Archiving measurement data and forms may also require a more structured design, such as entry into a computerized data base.

5.3 Recommendations

When planning an EMF PEM project, investigators are urged to employ the following basic steps:

1) **Develop a clearly stated purpose for the EMF PEM study, and**
2) **Complete a written study plan before developing specific protocols or beginning measurements.**

The written study plan should address the following study elements:

- Resources/Assessment
- Exposure Model
- Study Design
- Subject Issues
- Quality Assurance
- Uncertainty Evaluation
- Archival Plan

The cornerstone of this general approach and the specific protocols that will follow is the statement of purpose for the project. Only with such a statement can the specific guidelines and associated PEM methodologies be used to produce and implement a study design that meets a project's objectives.

Preparing a written study plan will ensure that the important issues of exposure assessment have been considered prior to developing and implementing specific protocols. To guide the process of preparing a study plan, the checklist shown in Table 5.2 identifies issues to be considered for each element.

Table 5.2
EMF Exposure Assessment General Guidelines Checklist

This checklist is intended to facilitate the creation of an effective study plan for an EMF PEM project. It offers a simple reference to the issues that should be addressed when creating a plan. It does not indicate how or to what extent to address the issues; its purpose is to ensure that each issue is considered. The descriptions of the study elements provide detail on suggested information and options. Not all issues will be applicable to every project.

Recommendation	Issue
1. Purpose of study	Exposure characterization: Individuals ___ Groups ___ Epidemiological exposure classification Compliance monitoring ___ Response to enquiry ___ Other (specify) ___
2. Written study plan	Contents: Purpose of study ___ 1. Resource assessment ___ 2. Exposure model ___ 3. Study design ___ 4. Subject issues ___ 5. Quality assurance ___ 6. Uncertainty analysis ___ 7. Archival plan ___

Recommendation	Issue
Study Element	Issue
1. Resource assessment	Organization:
	Agreement on purpose ___
	General allocation of resources ___
	Personnel:
	Level of expertise ___
	Number ___
	Level of effort ___
	Management structure and plan ___
	Financial:
	Allocation of resources ___
	Protocol development
	Initial costs ___
	Data collection ___
	Data analysis ___
	Reporting ___
	Cost per exposure unit ___
	Total cost ___
	Subjects:
	Number ___
	Availability ___
	Instrumentation
	Type ___
2. Exposure model	Measured field parameter(s) ___
	Link to exposure ___
	Summary measure(s) ___
	Assumptions ___
	Justification ___

Recommendation	Issue	
3. Study design	Measured field characteristics	___
	Instrumentation:	
	Type	___
	Number	___
	Placement	___
	Sampling strategy	___
	Sites	___
	Subjects	___
	Data collection	___
	Data management	___
	Data analysis	___
	Documentation	___
	Project Management	___
4. Subject issues	Human subjects approval	___
	Subject consent form	___
	Release of data to subjects	___
	Anonymity of subjects	___
	Recruiting	___
	Organizational support	___
5. Quality assurance	Sample selection	___
	Instrumentation	___
	Data collection	___
	Data transfer (Measurements and forms)	___
	Data entry	___
	Data management	___
	Data analysis	___
6. Uncertainty evaluation	Biological potency (unknown for EMF)	___
	Exposure	
	Measurement errors	___
	Exposure variability	___
	Models	___
	Study limitations	___
7. Archival plan	Documentation	___
	Raw data	___
	Other data products	___

6

SPECIFIC GUIDELINES FOR EMF PEM STUDY DESIGN

The purposes of the EMF PEM specific guidelines are:

- to identify decisions inherent in designing detailed protocols for an EMF PEM study,
- to provide information that assists in making informed decisions, and
- to provide specific guidance in study design, where possible.

Design decisions for individual studies will be based on:

- the stated purpose of the study,
- the elements of the written study plan, and
- the circumstances specific to the study's implementation.

A statement of the study's purpose and a written study plan result from adhering to the general recommendations described in Section 5. The specific guidelines presented here emphasize specific issues related to study protocols and implementation. Guidelines for subject issues, quality assurance, uncertainty analyses, and archival plans are also provided. The specific guidelines presented in this section were based on a review of the EMF PEM literature, experience with EMF PEM projects and knowledge of EMF. Ultimately, the decisions reached on these issues will depend on the objectives and resources of the individual project, technical considerations, and the circumstances under which the study will be conducted.

The possible data to be collected and recorded in an EMF PEM study can be divided into four categories: subject information; location and activity information; magnetic field characteristics; and electric field characteristics. Determining the level of detail and specific data to be collected in each of these categories occurs during the development of the study design. The characterization of subjects and of location/activity data was discussed in Section 3.

6.1 Study Design: Field and Measurement Data

Magnetic and electric field characteristics warranting possible inclusion in EMF PEM studies were identified from knowledge of these fields and previous research. These field characteristics were then evaluated in terms of the available instrumentation, hypothetical biological significance, practicality of measurements, and nature of exposures. The advantages and disadvantages of including each field characteristic were identified. The considerations associated with each exposure parameter are displayed in the matrix shown in Table 6.1 and summarized below.

Magnetic and electric fields can be characterized by measures of magnitude, spectral content, polarization, orientation and static field. The issues associated with measurement of each of these characteristics are discussed, for both magnetic and electric fields along with types of instruments, temporal patterns, and transients.

6.1.1 Magnetic Field Characteristics

Magnitude. Environmental ac magnetic fields at a single frequency are elliptically polarized due to the presence of multiple sources with different electrical phases [Deno, 1976]. The magnitude of an elliptically polarized field is defined by the magnitude of the field component along the major axis of the ellipse. Determination of this component requires orientation of a single coil perpendicular to this axis or simultaneous measurements of the amplitude and phase of three orthogonal components of the field. The former is impractical for PEM and the latter requires a sophisticated data recording system which is currently unavailable for PEM.

Table 6.1
Field Parameter Evaluation Matrix for Inclusion in PEM Studies: a) Magnetic Field; b) Electric Field; c) Other Field Parameters.

Parameter	Exposure Indices	Hypothetical Biological Significance	PEM Instrument Availability†	Type of Measurement	Advantages	Disadvantages	Priority
a) Magnetic Field							
Magnitude 50/60-Hz Broadband	TWA, peak, statistical descriptors	Classic dose-response Induced current Resonance phenomena	 Yes Yes	 Accumulated Time-series	Instrumentation fully mature		Mandatory
Spectral content Broadband Narrowband Waveform	TWA, peak, statistical descriptors relative to 50/60 Hz	Resonance phenomena Induced current	 Yes Yes No	Time-series	Can capture broadband harmonics easily	Detailed spectral information requires large system or slow sampling rate	Optional
Polarization	Ellipticity	Unknown	No			Highly variable Instrumentation not portable	Not recommended
Orientation To subject To static field To reference	Angle, projection perpendicular and parallel to reference	Resonance phenomena	No			Highly variable Instrumentation not portable	Not recommended
Static magnetic field	Magnitude and orientation	Orientation affects resonance phenomena	Yes	Accumulated	Simple instrument Relatively stable field	Requires additional instrument	Optional

Parameter	Exposure Indices	Hypothetical Biological Significance	PEM Instrument Availability†	Type of Measurement	Advantages	Disadvantages	Priority
b) Electric Field							
Magnitude 50/60-Hz Broadband	TWA, peak statistical descriptors	Classic dose-response Induced current Perception by subject	 Yes No	Accumulated Time-series	Single-channel measurement	Perturbed field measured Comparison of exposures difficult Difficult to interpret	Optional
Spectral content Broadband Narrowband Waveform	TWA, peak statistical descriptors relative to 50/60 Hz	Induced current	 Yes Yes No	Time-series	Single-channel measurement	Perturbed field measured Comparison of exposures difficult Difficult to interpret	Optional
Polarization	Ellipticity	Unknown	N/A			Not applicable for PEM	Not recommended
Orientation	Angle of unperturbed field	Unknown	N/A			Not applicable for PEM	Not recommended
Static electric field	TWA, peak	Perception	N/A			Highly variable	Not recommended

Parameter	Exposure Indices	Hypothetical Biological Significance	PEM Instrument Availability†	Type of Measurement	Advantages	Disadvantages	Priority
c) Other Field Parameters							
Temporal patterns	Difference between successive measurements Variability	Coherence effects	Yes	Time-series		Requires time series & analysis algorithms	Optimal
Transients Magnetic field Electric field	Number per unit time	Transient induced currents	 No No	Accumulating		Meter not available	Not recommended

† PEM instrumentation currently available or used extensively in past studies.

A practical indicator of field magnitude is the resultant field, defined as the square root of the sum of the squares of the amplitude of the three orthogonal components of the field. Calculation of the resultant field entails the measurement of only the amplitudes of these three orthogonal components. For this practical reason, the resultant field has been accepted as the measure of field magnitude in PEM studies, with the understanding that it places an upper limit on the magnitude of the magnetic field.

The resultant of the magnetic field can be measured for a single frequency or over a range of frequencies depending on the designed bandwidth of the PEM instrument. Typical bandwidth for PEM instruments is either: broadband including the power frequency (say, 40 to 800 Hz); or narrowband limited to the power frequency (50 or 60 Hz).

Frequency content. The frequency content of the magnetic field can be derived from spectral analysis of the waveform or the use of meter with variable narrowband response. Other frequencies that might be of interest for PEM are associated with power supply frequencies in specific settings such as 400 Hz for aircraft and 25 Hz for transportation systems. Static magnetic field is discussed separately below because it generally requires different instrument technology.

Polarization of a single frequency field vector is generally characterized by the ellipticity of the field which varies from 0 (linear polarization) to 1 (circular polarization). As with magnitude, polarization can be determined from the careful orientation of a single coil or from amplitude and phase measurements of the three orthogonal field components at a single frequency. Current PEM instrumentation is not capable of measuring the polarization of magnetic fields.

Orientation of the ac field must be measured relative to the body of the subject, relative to the earth's static magnetic field, or relative to some other reference. The instrument must be properly positioned, relative to the reference, for measurement of the orientation of the ac magnetic field. This makes PEM of orientation of the ac field impractical: as the subject moves the frame of reference for the instrument changes. Measurement of the orientation of the ac field relative to the environmental static field (geomagnetic plus other static field sources) requires a simultaneous measurement of the orientation of both the ac and static fields.

Static field. The static field can be characterized by both a magnitude and a direction. Direction can be measured with respect to fixed direction (for example, the azimuth and declination for the geomagnetic field) or with respect to a vector whose direction varies such as the ac field. The magnitude and direction of the static field can be affected by the presence of ferromagnetic objects so a measurement at a single location may not sufficiently describe the field at a measurement site.

In a PEM study, determining the direction of the static field is problematic, as it is for orientation of the ac field: movement by the subject changes the instrument's frame of reference.

6.1.2 Electric Field Characteristics

Magnitude. Electric fields are perturbed by any object which conducts electricity, including the human body. Because of this perturbation, the electric field is always oriented perpendicular to the surface of the body and its magnitude can be determined with a single electrode. The measured quantity is the perturbed electric field at the location of the electrode on the body, which is affected by the posture of the subject, the orientation of the subject's body relative to the electric field sources, and the location of the meter on the body. Thus, the PEM meter does not record the unperturbed field which is both used in exposure guidelines and preferred when describing electric field exposures in general. To transform PEM of electric field to an equivalent unperturbed electric field is difficult and extremely uncertain. Therefore comparisons between the measured electric field exposures within a study may be proper, but comparisons between the exposures measured by studies with different protocols are probably improper.

As with magnetic field, electric field can be measured on either a broadband or narrowband basis depending on the design of the instrument.

Spectral content. The frequency content of the electric field is a function of the frequency content of the voltage on the source of the field. Like magnetic fields, it can be determined from spectral analysis or from meters with variable narrowband response.

Polarization. The electric field of a single frequency produced by multiple three-phase sources is elliptically polarized in space. However, this polarization cannot be measured with PEM instrumentation because the field is perpendicular at the surface of the body where measurements are taken and has only one component.

Orientation. The orientation of the unperturbed electric field depends on the location of both the field's sources and the grounded conductive objects that are present. Orientation can not be determined from measurements made at the surface of the body and it is not relevant to PEM measurements.

Static field. Environmental static electric fields are produced by natural atmospheric sources, dc voltage sources, and accumulated charges such as those generated when walking across a carpet on a dry day. Fields from these sources can be extremely variable over space and time. The technology for measuring static electric fields has not been incorporated into PEM instruments.

6.1.3 Other Field Parameters

Type of measurements. Instrumentation is available to accumulate magnetic or electric field data and produce a single summary statistic or a set of summary statistics characterizing the fields during the measurement period. Simple accumulating meters produce a time-weighted average or mean of measurements over the period. Other more sophisticated digital storage accumulating meters report the maximum field and in some cases other statistics such as standard deviation, minimum, and number of measurements above specified levels. Data loggers store a series of measurements over the time period. Analysis of the time-series measurements is required to produce summary statistics and to examine temporal patterns in the data. Time-series measurements can be used to produce the same statistics as accumulating instruments, but the summary data recorded by accumulating meters can not be used to re-construct time-series measurements.

Temporal patterns. Temporal variability in electric and magnetic fields contribute to the variable nature of exposures. Change in exposure can occur over seconds, minutes, hours or seasons due to changing field sources and movement of the subject. Examples of temporal patterns that might be of interest as indices of exposure are: a count of the number of exposures, or amount of time, at field levels above specified thresholds; the number of times that the field changed by a specified amount; or the number and duration of periods of relatively constant field. Temporal patterns have been hypothesized as a possible factor in biological effects. The generation and retention of time-series data is necessary for examination of temporal patterns of exposures. Data loggers can provide time-series data, accumulating PEM meters can not.

Transients. Switching currents and voltages can result in transient fields characterized by rapid changes in field amplitude over time frames much shorter than a single cycle at 60 Hz. Current PEM instrument technology does not permit the measurement of such events. However, their mention as possible magnetic field parameters for future PEM is warranted because of hypotheses that transients associated with electric energy supply and use could have biological significance. Furthermore, instrumentation that counts the occurrence of transient magnetic field events in two amplitude ranges has recently been developed and could be reduced in size and adapted for PEM in the future.

6.1.4 Recommendations for Field and Measurement Data

Based on the information presented in the three previous sections, recommendations for inclusion of field characteristics in PEM studies were established. The categories for inclusion of field characteristics are: mandatory, optional and not-recommended. The actual selection of characteristics for collection during a PEM study will depend on the purpose and scope of the study. For example, a characteristic should be included, even if it is "not recommended", when it is related to a hypothesis being tested by a study. The priorities for the inclusion of field characteristics are intended to allow comparison with previous research efforts, while providing flexibility to meet the requirements of future studies.

Field characteristics are placed in the three categories as follows:

Mandatory:

- resultant magnetic field (magnitude; broadband or 50/60-Hz)
  (Note: Sufficient data should be collected to compute a time-weighted-average exposure for comparison with other studies.)

Optional:

- magnitude of electric field (broadband or 50/60-Hz);
- magnetic and/or electric field spectral content (harmonic component relative to the fundamental frequency component);
- static magnetic field; and
- temporal field patterns (time-series PEM)

Not recommended at this time:

- magnetic and electric field polarization;
- magnetic and electric field orientation;
- static electric field; and
- magnetic and electric transients.

The process of developing a PEM study design should consider the following issues when selecting field characteristics for measurement: 1) purpose of the study, 2) available resources, and 3) the priorities recommended here for inclusion of field characteristics

6.2 Study Design: Instrumentation

Although PE meters have been available from several sources in the past, at present there are only two manufacturers producing PE meters suitable for EMF studies. Several models of EMDEX meters are available from Enertech Consultants of Campbell, CA. Combinova of Sweden offers a PEM instrument, the FD-3, which is available from their representative in Southampton, PA. Characteristics of these instruments are listed in Table 6.2. Characteristics of two other meters that are no longer commercially available, are also described in Table 6.2. All meters rely on three orthogonally oriented sensors for measurements of magnetic field. The characteristics and operation of EMF meters are discussed in the IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters - 10 Hz to 3 kHz [IEEE, 1995].

6.2.1 Selection

The selection of a particular meter depends on the purpose and protocols for the study. The first decision is whether time-series measurements are required (series of individual measurements are stored at regular intervals) or whether an accumulating meter will be adequate (summary statistics only, not individual measurements). Time-series instruments permit the data to be divided into periods that can be delimited by entries in a diary or by other record-keeping methods.

Table 6.2
Available EMF PEM Instrumentation

Model Mfr.†	Meter Type	Size, cm	Mass, g	Field Metric(s)	Battery Life, days	Data Storage	Sampling Interval, seconds	Band-width, Hz	Range, mG	Features
AMEX-3D Enertech[1]	Accum-ulating	10.2 x 5.1 x 2.5	114	Cumulative field	14-24	E-cell	Continuous integration	35 -1000	0.1 - 150	
EMDEX II Enertech[1]	Time-series	16.8 x 6.6 x 3.8	341	rms orthogonal field components, rms resultant (broadband or broadband and harmonics)	Alkaline: 1.5-7 Lithium: 4-21	156Kb or 512Kb	1.5 -300	Broadband 40 - 800 Harmonic 100 - 800	Standard 0.1 - 3000 High Field 4 - 120,000	Event mark; Extra channel; programmable; Std. & High Field versions
EMDEX Lite Enertech[1]	Time-series	12 x 6 x 2.5	170	rms resultant	Alkaline: ≤ 120 Lithium: ≤ 400	128Kb	4 -1200	40 - 1000	Standard 0.1 - 700 High Field 5 - 70,000	Std. & High Field versions; programmable
EMDEX Mate Enertech[1]	Accum-ulating	11.7 x 7.1 x 3.8	230	rms resultant	Alkaline: 2 Lithium: 4	≤ 2 days	0.5	40 - 1000	0.1 - 1000	Displays accumulated results
FD-3 Combinova[2]	Time-series	20.5 x 7.0 x 3.5	290		1.25	60,000 measurements	1 - 600	20 - 2000	0.1 - 1000	Manual operation

Model Mfr.†	Meter Type	Size, cm	Mass, g	Field Metric(s)	Battery Life, days	Data Storage	Sampling Interval, seconds	Band-width, Hz	Range, mG	Features
Dosimeter 378101 Positron[3]	Time-series in 16 bins	15.2 x 7.6 x 2.5	230	rms orthogonal field components		18 days @ 60 s	60	60	.06 - 4000	
SPECLITE Innovatum[4]	Time-series of spectra	12.0 x 6.0 x 2.5		rms orthogonal field components in 30 frequency bands	1.67	1300 spectra	60, 120, 180	40 - 1000 in 30 bands	.2 - 375 Adjustable	Manual trigger

† See list of PE meter manufacturers below, commercial availability reported.

PE meter manufacturers:

1 Enertech Consultants
300 Orchard Drive, Suite 132
Campbell, CA 95008
USA
(408) 866-7279
PE meters: AMEX-3D, EMDEX II, EMDEX Lite, EMDEX Mate

2. Combinova
Fresforsstigen 22-24
Box 20050, S-161 02
Bromma, SWEDEN
+46-(0)8-627 93 10
+46-(0)8-29 59 85
PE meter: System FD-3

North American representative
Ergonomics, Inc.
P. O. Box 964
Southampton, PA 18966
(215) 357-5124
Fax: (215) 364-7582

3. Positron Industries, Inc.
5101 Buchanan St.
Montreal, Quebec H4P 2R9
CANADA
(514) 345-2200
PE meter: Dosimeter 378,101 (not commercially available)

4. Innovatum, Inc.
2020 Southwest Freeway, Suite 203
Houston, TX 77098
USA
(713) 526 6333
PE meter: SPECLITE (not commercially available)

Accumulating meters provide statistical descriptors of exposure for the data collection period. In the simplest device, an electrolytic cell accumulates electric charge over time to represent a time integral of a signal current from the sensors (the AMEX-3D in Table 6.2). The accumulated charge is proportional to the time-integrated exposure which can be converted to magnetic field in mG-hr or µT-hr, and a time-weighted average can be computed by dividing by the total time of data collection. Microprocessor-based accumulating meters can compute and store descriptors, such as maximum and minimum, and the descriptors needed to calculate mean, standard deviation, etc. (For example, the EMDEX Mate in Table 6.2) Where resources do not permit more expensive instrumentation, accumulating meters can offer an efficient and cost-effective way to characterize both average and peak exposures.

Time-series measurements are necessary to capture temporal variations in exposure and to establish links between exposures and activities or locations. The particular choice of time-series meter will depend on the desired mechanism for demarcation of activities and locations. Linkage of activities and locations to specific measurements can be facilitated by the use of event marks placed in the data stream. Display of clock time by the meter can assist subjects in recording accurate time with respect to the data recording.

Other decisions regarding meter selection are the size of the meter that will be acceptable to the subjects and whether magnetic field characteristics beyond the resultant field are required. The choice of sampling interval for the meter will be driven by the types of exposures that are anticipated and by deployment time. Exposures in occupational environments tend to be more variable than in residential settings. Therefore a shorter sampling interval in the former may be warranted to capture anticipated short-term field variability. The length of time that an instrument can collect data is limited by either data storage capacity or battery life. The limit imposed by storage capacity will depend on the sampling interval, the number of recorded parameters, and available memory. Battery life will depend on the sampling interval, type of battery, and possibly the parameters that are recorded.

6.2.2 Meter Placement

Ideally, the location of a PEM meter should be selected to coincide with the site of a biologically active dose. For EMF this is not feasible primarily because there is no recognized biological mechanism that relates exposure to health outcomes. The field measured by a meter is the field at the location of the meter. Extrapolation of this measured field to other body locations or to averages for the whole body (or other volumes) requires modeling of exposures. Verification of exposure models can take the form of additional measurements or calculations. For example, Delpizzo [1993] demonstrated that for certain environments, the chest location provided the most reliable estimates of whole body average exposures. The selection of the measurement location on the body should therefore recognize the purpose of the measurements and, if applicable, the means by which the measured values will be extrapolated by modeling to a defined exposure or to a hypothetical biologically significant dose.

Study purposes may indicate that a specific body location for the measurements is preferable. However the final choice must recognize and accommodate the needs of subjects. For example, if an hypothesis relating to exposure to specific parts of the body is being tested or if compliance with guidelines for exposure to specific parts of the body is being monitored, then meter placement should attempt to capture exposures at those locations. However, meter placement must consider acceptability to the wearer: if the subject can't or won't wear the meter, no PEM will be obtained.

Generally, given the absence of a known site of biologic relevance for EMF, the placement of PEM meters should be based on acceptability to the subject while still meeting the needs of the study for exposure modeling. Many PEM studies require that a subject wear a meter for a period of time that can extend from hours to days. In order to ensure valid measurements over these long periods it is essential that the subject wear the instrument according to study protocols and that the subjects do so without modifying their behavior.

Often the final selection of a meter and a meter location involve tradeoffs among the several factors described below. (See the literature review in Section 2 for examples of how various studies dealt with these issues.)

Safety of subject. The safety of a subject should not be jeopardized by wearing the PEM meter. Knowledge of the subjects expected activities and design of the meter carrying system can anticipate and mitigate possible hazardous situations. The subjects should also be instructed to remove the meter if, in their opinion, wearing it may compromise their safety. Selection of the meter location and carrying system may require approval by the subjects or someone representing their interest: e. g., human subjects committee, union safety committee, etc.

Status of subject. Age, gender, occupation, and other factors can affect where and how to carry a PEM meter. Most adults may be able to wear a meter in a belted waist pouch, however this location might be unacceptable for children and women late in pregnancy. Workers in certain occupations may be hampered in their activities by a meter worn at the waist but not one placed in a shirt pocket or pouch on the chest. It may be preferable for small children to carry a meter in a backpack rather than a belted pouch.

Activities of subject. Subjects in a PEM study may engage in activities that could be affected by the location of the meter. The range of activities for subjects should be anticipated or surveyed and the implications of meter placement considered. Will wearing the meter at the proposed location impact activities? Will the activities affect the security of the meter? Are there activities when the subjects should not wear the meter? Do subjects routinely wear clothing or use tools that could affect measurements? For example, belts with large steel buckles or tools located close to meters can affect field measurements.

Measurement period. The amount of time and environments where a subject wears a PEM meter can also impact the acceptability of a meter location and carrying system.

Obviously, the longer the meter is worn and the more places the subject goes, the more important it is to use a comfortable and unobtrusive measurement system.

Size of instrument. To provide flexibility in placing the meter on the body and to minimize interference with subject activities, the smallest meter that meets the needs of the study should be used. The nature of the meter selected for PEM will, to some extent, determine its size; meters capable of recording time-series data are generally larger than accumulating meters.

Carrying system. Simple PEM meters are small enough to be carried like other personal sampling devices. They can be placed in a shirt pocket, worn on a wrist strap, or clipped on a belt. However, full-function, commercially available PEM data loggers are too large to be carried this way, and must be placed in a separate carrying pouch, such as a fanny-pack or knapsack. To accommodate these larger meters and to provide uniformity in sampling location for small meters, a standard carrying pouch should be used for all PEM meters.

Pouches are typically available from the meter manufacturer or may be purchased ready-made (camera bags, knapsacks, fanny packs, etc.). However, for some projects, it may be preferable to have the carrying pouches custom fabricated to meet the specific needs of the project. This can usually be done for a modest cost, yet results in substantial gains in acceptance by the subject and adherence to protocols. For example, chest pouches for carrying data loggers were fabricated out of special fabric to meet safety requirements when monitoring electric utility live-line workers [Bracken, T. D. et al., 1994a].

Record-keeping requirements. Time/activity (or time/location) record-keeping by the subject may directly involve the PEM meter (e.g., pushing a button on the data logger), or the carrying system may be used to store the subject's activity diary. Thus, the need to access the meter while it is worn may influence the selection of meter location.

A location or locations for the PEM meter in the event it is not worn must also be selected. The selection of the not-worn location depends on several factors:

Subject convenience. The not-worn location must be convenient to the subject's activities both when they remove the meter and when they put it back on. For example, if the subject is to wear the meter only when at home, then the not-worn location should be in a location convenient to the entry and exit point of the house.

Subject reliability. The not-worn location should be selected so that the subject remembers to leave it at the location when the meter is taken off and remembers to retrieve it when it is to be worn again. In some cases, it is helpful to place reminder notes at strategic locations around the house or other site where PEM are being taken.

Purpose of the not-worn measurements. The not-worn location should be selected to respect the purpose of the measurements collected, if any, while the meter is not worn. For example, if the not-worn measurements are to be used to characterize background field levels, then the selected location should be well away from localized sources. Alternatively, if the not-worn measurements are to characterize exposures when the subject is in bed, then when the meter is not worn it should be placed at a location close to the bed but away from sources that do not contribute to fields at the bed.

Security. The not-worn location should be selected to ensure the physical security of the meter and the integrity of the data collection process. Thus, when the meter is not worn it should be placed where access is limited and it is out of harm's way, especially pets and curious children or adults.

Prior to implementation of the measurement protocols, the acceptability and repeatability of the selected meter locations and carrying system should be thoroughly tested in pilot studies. The pilot studies should utilize naive subjects that are similar to the study population and take place in settings similar to those targeted by the study.

6.2.3 Other Instrumentation

PEM studies often require or can be enhanced by the use of other instruments besides the PEM meter that is worn by the subject. In particular, area survey measurements of magnetic or electric fields are often performed. The purposes for such measurements include: assessing the range of field levels expected in a location or near a source prior to PEM; characterizing fields from a source with respect to distance and operating state (on or off); ensuring that the not-worn location for a PEM meter is free from the influence of nearby sources; and quantifying field characteristics that are not captured with the PEM meter. In the case of electric fields, area survey measurements may be the sole means of reliably determining unperturbed field levels in a location.

Depending on the purpose of the area survey measurements and the capability of the PEM meter, measurements can be conducted with the PEM meter itself or another instrument can be used. PEM meters generally collect only magnitude (resultant) information about magnetic fields. Other instrumentation will be required if the area survey is to measure additional field characteristics. For example, a single-axis magnetic-field survey meter can be used to determine field orientation. The investigator may wish to characterize the frequency content, polarization, and/or orientation of the magnetic field at some location of interest. Wave-capture instruments have been used to collect such data [Bracken, T. D. et al., 1994a; Rankin and Bracken, 1994]. Other instruments are also available to capture frequency spectra.

Quality assurance for meter performance takes place in several contexts (see Section 6.7). Calibration of PEM meters is best performed by the instrument manufacturer in facilities which are designed for this purpose and traceable to national standards. However, verification that PEM meters are operating within measurement accuracy tolerances should occur routinely during PEM data collection and may require additional equipment. Verification of magnetic field meters requires a means of generating a known magnetic field from a 120 V outlet [IEEE Power Engineering Society, 1995]. Both single-axis coils and three-axis systems have been fabricated for use with several types of meters by instrument manufacturers and investigators. The design of a verification system depends on available resources and the number of meters that must be verified. A three-axis field generation system can expedite the verification of meter accuracy. No special equipment is required to verify the functionality of magnetic-field PEM meters during data collection. Local sources such as computers or desk lamps are adequate for this purpose.

Verification of performance for of electric field meters requires a parallel-plate exposure system with a high-voltage power supply [IEEE Power Engineering Society, 1995]. Functionality can be confirmed with a flourescent lamp or other unshielded voltage source.

PEM studies often include time-activity record-keeping (see Section 6.4). Diaries and questionnaires are the traditional methods for collecting subject location and activity information. However, electronic recording instruments can also be employed for this purpose. One approach is to use a voltage to indicate the location of the subject. [Pretorius, 1993]. Using a multi-position switch, the subject selects the position (voltage) corresponding to the environment they occupy or their activity. The voltage is then recorded by the PEM datalogger or an auxiliary data logger. A device used in PEM for air pollutants employs a range finder to determine whether a subject is indoors, outdoors or in transit based on the height of the ceiling. This information is then recorded by a datalogger [Moschandreas et al., 1994].

Electronic scanning of bar codes or other electronic tags can improve the efficiency of recording activity and location information. The TimeWand™ and DuraWand™ bar code scanning systems (Videx, Inc., Corvallis, OR) have been used to record location and task information in EMF PEM studies. In one study, subjects employed a small pocket-size bar code scanner that time-stamped and stored each bar code scan to record their activities [Sahl et al., 1993]. In another study, an observer used the same technology to simultaneously record the activities and locations of up to six electric utility line workers [Bracken, T. D. et al., 1994a].

Emerging technologies employing tags that can be read electronically may also have applications in automatic time-activity record-keeping during PEM studies. This approach may be particularly appropriate in occupational environments, where subjects change locations frequently and manual recording in diaries or scanning of bar codes can quickly become a burden.

It is necessary to ensure that these auxiliary devices will function in the magnetic field environments anticipated during PEM. This is of particular concern for occupational environments where high fields are known to exist: e. g., static fields in magnetic resonance imaging facilities and ac fields near de-magnetizers. Pilot tests should be used to determine the compatibility of all instrumentation with the anticipated environment as well as test their use in PEM protocols.

6.2.4 Future Developments

Advancements in EMF PEM instrumentation will be driven to a large extent by biological research. If a biological mechanism for EMF-related health effects can be established, then meters can be designed to capture the appropriate field exposure characteristic(s). However, until then, it will be necessary to utilize instruments that emphasize field magnitude for EMF PEM.

Many capabilities that would be desirable in commercially available PEM instruments have been incorporated in prototypes or in meters with limited distribution. Enhancements that are desirable for EMF PEM meters include: packaging improvements, performance improvements, increased field characterization capability, and improved time-activity recording capabilities. Some specific improvements include:

Meter size. The physical size of present meters can be burdensome to some PEM subjects, especially women and children. Therefore a reduction in meter size would be beneficial for PEM meters in general, and especially for meters which record time-series data and event mark on the data stream.

Clock display. The ability to easily display time of day on PEM dataloggers is a considerable benefit in studies when time-activity information is being collected concurrently with the magnetic field data. The clock time displayed by the PEM meter is linked directly to the time-series data it is collecting. The time recorded by the subject is also linked to the data without the need for synchronization of different clocks or computers.

Frequency content. The capability to record specific frequencies or frequency spectra at short intervals (<10 seconds) would allow characterization of exposures to more than power frequency or broad spectrum magnetic fields.

Transient field exposures. Transients related to electric current switching constitute higher frequency fields than are normally recorded during EMF PEM using existing meters. There is considerable interest in characterizing exposures to these short duration (<1/60 second) magnetic field pulses. Therefore a proven method for quantifying and recording personal exposures to transient fields is needed. Ideally, the transient events should be time-tagged and linked to traditional magnetic field PEM and time-activity information.

Time-activity record-keeping. Characterization of EMF exposures has often included the concurrent collection of time-activity information. Integration of a time-activity record-keeping capability into a PEM data logger could simplify and enhance the quality of data collection. Similarly, any technologies that automate time-activity recording would further enhance data collection.

6.2.5 Recommendations for Instrumentation

The process of study design should consider the following activities related to <u>instrumentation</u>:

1) Select an accumulating or time-series meter based on study purpose, data requirements, and available resources.

2) Confirm that PEM meter specifications are acceptable in terms of range of measured field level, sampling interval, data storage capacity, battery life, event mark capability, display characteristics, etc.

3) Select where and how the meter will be worn by subjects based on subject acceptance and the exposure model employed by the study. Factors to consider in meter placement include: safety, likely activities of subject, size of meter, and any associated subject record-keeping.

4) Select where the PEM meter will be placed when it is not worn based on the study purpose, convenience for the subject, and security issues.

5) Determine additional instruments that will be required for other purposes such as time-activity record-keeping and calibration verification.

6) Perform pilot studies using the proposed instrumentation.

6.3 Study Design: Sampling Strategies

The study plan indicates the purpose of the study, whether it is to: 1) estimate some exposure summary measure within a specified degree of precision, 2) determine whether subgroups have differing exposure, or 3) take some action if the sample demonstrates specified results. Sampling strategies to accomplish these ends vary greatly in their complexity. The ultimate sampling plan for a study is impacted by the nature of the subjects, their exposure scenarios, the presence of exposure groups, exposure variability, and available resources. The sampling plan specifies the sampling frame, type of sample, sample size, and sample parameters. It also recognizes analytic implications of the design and constraints placed by limited resources.

6.3.1 Subjects

The objectives of the PEM study must clearly identify the population of interest. The subjects to be measured should be described in terms of the attributes detailed in Section 3. This and subsequent steps in developing a sampling plan can greatly benefit from a preliminary survey of the areas frequented by subjects and brief observations of the activities of potential subjects.

The sampled population may differ from the population of interest due to convenience, logistics or other practical considerations. For example, a list of employees may not be current. The investigator must recognize such differences when reporting results and generalize only to the sampled population. Information about the differences between the sampled and total populations can aid the investigator in hypothesizing the extent to which the study results apply to the population of interest. It is important to plan in advance for data collection that will allow relevant comparisons between the sampled and total populations.

6.3.2 Exposure Scenarios

The exposure component stratification tables (Section 3.4) or an equivalent approach should be used to identify: what environments and sources will be encountered by subjects; which environments will be included in measurements; how the environments, tasks and sources that subjects experience affect their EMF exposures; and can the subjects be separated into groups with similar exposures. In some settings it may be difficult or impossible to identify subject characteristics that are highly correlated with exposure.

6.3.3 Exposure Groups

Information about the subjects and their expected exposures can be used to divide them into groups for sampling purposes. Preferably, the subjects in a group should have similar EMF exposures and constitute homogeneous exposure groups (HEG). However, selection of HEGs for EMF exposures is not an easy task [Kromhout et al., 1995]. EMF exposures can be highly variable within traditional HEGs, such as job categories. Therefore, it may only be practical to select groups to facilitate the logistics of data collection.

6.3.4 Exposure Variability

Reason and statistical considerations argue that if the PEM for a subject are quite variable then more PEM are necessary to obtain a given level of precision in exposure estimates. Similarly, when attempting to characterize the exposure of a population of subjects, if the PEM are quite variable between the subjects then more PEM are required to obtain a given level of precision in estimates for the group. These components of variability, within subject and between subject, are central factors in developing an appropriate sampling strategy.

Simplistically, if the investigator expects greater variability in exposure between subjects than within subjects, the study design should aim to sample more subjects for shorter, but still representative, periods of time. Variability is the issue of concern, not strictly exposure magnitude. That is, the estimation of high, relatively constant exposure requires no more PEM than low, relatively constant exposure.

Often, when designing the sampling strategy, exposure variability for a population is not known and must be estimated. A variety of approaches can be taken to estimate variability including: using the results of other studies of similar populations, executing small pilot studies on the population, or making assumptions about the distributions of PEM for the subjects in the population.

6.3.5 Sampling Frame

It is critically important to obtain a proper sampling frame from which to ultimately draw subjects. The sampling frame can be simple (a listing of employees at a manufacturing plant) or complex (matched controls for a epidemiologic study). Each subject must be listed once and only once in the sampling frame to ensure equal probability of selection. For example, when employing random digit dialing one must be careful to avoid over-representing more affluent homes with multiple phone numbers. Even the simple, obvious sampling frame may have limitations (new hires may be omitted and sick, injured or vacationing workers may be unavailable). The study plan must identify the sampling frame to be used and determine and characterize any of its shortcomings.

6.3.6 Types of Sampling Designs

The approach to selecting groups and type of sampling for an EMF PEM study is no different than for studies monitoring other exposures. Random, convenience or targeted sampling may be used. However, EMF exposures tend to be right-skewed with most measurements occurring at relatively low field values, making it difficult to capture infrequent high-field exposures. It may be necessary to go beyond a simple random sample and target activities, individuals or groups where such exposures are likely to occur.

Simple Random Sample: Once the sampling frame is determined, subjects can, for example, be assigned sequential numbers. A random number generator or random number table can then be used to produce a series of random numbers which range from 1 to the number of subjects in the sampling frame. A subject whose number is next on the random list is selected and this is repeated until the desired number of subjects is obtained. A subject is not permitted to be selected twice. This "sampling without replacement" may require correction factors in some statistics, especially if the sample size is large relative to the population (say, if one third or one fourth of the population was sampled). A similar procedure assigns a random number to each subject, sorts the subjects by their random number, and selects subjects based on the order of this random list. This approach precludes selection of a subject twice. These techniques are known as simple random sampling.

Systematic Sample: A sample can also be obtained by determining the fraction of subjects in the sampling frame which will be selected for the study, say one fiftieth. A random number table can be used to determine the first subject to be selected by providing a random number between 1 and 50, say 17. Thereafter every fiftieth subject on the list is selected: 17, 67, 117, 167, 217, etc. This approach, known as a systematic sample, amounts to randomly selecting a subject from the first k subjects and then systematically selecting each kth subject thereafter. If volunteers are being sought and refusals are likely, this procedure must be adjusted to produce a sufficiently large preliminary sample. In addition, care must be exercised when soliciting subjects to avoid an over-representation of subjects from a certain portion of the sampling frame, for example to avoid selecting subjects primarily from the beginning of an alphabetical list. If the list is ordered in some important way or if there is a cyclic pattern in the list, then care must be used when employing a systematic sampling technique.

Stratified Sample: There are techniques for possibly increasing the efficiency of a study's sampling strategy. Efficiencies may be gained by segmenting (stratifying) the population into subpopulations, based on factors which result in more homogeneous exposure groups. The dimensions used in the stratification must be based on information which is available for the entire population in order for this technique to be most helpful. Stratification using natural dimensions is strongly preferred, for example subject's job category or type of residence.

The sample size used when sampling from a stratum may be based on the proportion of the total population in the stratum. This proportional stratified sampling results in a sample which is similar to that produced by simple random sampling or systematic sampling but this technique is more likely to ensure proper representation of the stratum groups in the resulting sample.

An investigator may wish to select a different fraction of subjects from each stratum, because of increased exposure variability or cost in some strata, or for other reasons. When the sampling fractions of the strata are not equal, the resulting sampling strategy is referred to as disproportionate stratified sampling.

Cluster Sample: Another strategic option for sampling is known as cluster sampling. When using this technique the investigator first determines a basis for defining clusters of subjects such as cities for a residential PEM study, schools for PEM of children, or manufacturing plants for occupational PEM. Then a random sample of the clusters is selected and a random sampling of the subjects within each of the selected clusters completes the process. Here, the factors defining the clusters are selected to maintain heterogeneity within clusters and minimize between cluster variability. This technique is used principally when a sampling frame of subjects is unavailable or to reduce the logistics and, hence, costs of collecting PEM.

Cluster sampling results in less precise estimates than other sampling techniques. This affects both the precision with which a study can estimate exposures and a study's ability to compare exposures between groups of subjects. Proper consideration of the implications of the reduced precision of cluster sampling may require the assistance of a qualified statistician.

Multistage Sample: These techniques can be combined into multistage processes. For example, in a residential PEM study, clusters can be defined by Census Metropolitan Areas, the clusters might be stratified by region or residential electricity consumption, and the study clusters can be selected using a simple random sample within stratum. Subject residences might then be selected using systematic sampling based on the residential customer lists of local utilities [Rankin and Bracken, 1994].

6.3.7 Overall Sample Size

The determination of appropriate sample sizes is driven by the nature and extent of the analyses to be performed in achieving the study objectives. If the study intends to estimate an exposure summary measure to within a specified degree of precision then the amount of error which will be tolerated has been detailed in the study plan. The investigator constructs an equation which determines the sample size within the desired precision. Often this equation contains elements which must be estimated including: population and subpopulation sizes, PEM variability and cost of PEM by subject type. If multiple summary measures are to be addressed then more than one set of sample size computations may be necessary. See, for example, [Cochran, 1977]. This process may require the assistance of a statistician.

The objective of the study might be to determine whether subgroups have differing exposure, that is whether there is an association between the factors attributable to the subgroups and their subject's PEM. Here the researcher must specify the desired power of the test to be used, that is its ability to demonstrate an association which is truly present. Again, the investigator constructs an appropriate equation, estimates any unknown elements, and produces an estimated sample size. See, for example, [Cochran, 1977; Cohen, 1988].

When stratified sampling is employed, the sample size for a stratum may be based in part on the variability of exposures within the stratum and the cost of obtaining PEM for its subjects. In general, for a given stratum, a larger sample should be taken if: 1) the stratum contains a larger number of subjects, 2) the exposures in the stratum are more variable (as measured by standard deviation), or 3) sampling is cheaper in the stratum. This approach is referred to as a Neyman Allocation [Cochran, 1977] and its use in optimizing sample sizes across strata may require the assistance of a statistician.

6.3.8 Sampling Parameters

For many physical and chemical environmental agents, biological and health research offers guidance in the selection of sampling plans. For example, acute effects occurring at high exposures suggest rapid sampling over short duration to capture the peak exposures, whereas chronic effects associated with low level exposures over extended periods suggest collecting data over days, weeks or even years. No mechanism has been established that links EMF exposure with a health related outcome. Consequently, EMF sampling plans often must capture as much exposure information as possible given the resources available. They have tended to examine exposures using relatively rapid sampling rates (seconds) over lengthy periods (hours). However, in many cases, analysis of exposures has been limited to examination of the time-weighted average over a work day or 24-hour day.

Sampling interval: The sampling interval for a time-series PE meter should be selected to match the variability of the magnetic fields in the environment where the meter will be worn. For example, residential magnetic fields are relatively stable and a 10-second sampling interval is sufficient to capture field variation. In an occupational setting where a subject may move in and out of areas with high fields, a shorter interval, say 1.5 or 3 seconds, may be appropriate. Sahl et al. [1991] found that daily occupational exposure measures of central tendency, variation and exceedance fractions were not affected as the sampling interval for EMF PE measurements ranged from 1.5 to 60 seconds. However, the maximum measured value generally decreased as the interval between measurements increased.

Duration of sample: The length of the measurement period should be sufficient to capture cyclic patterns associated with subject activities and source variability. Common measurement periods for EMF PE measurements are the work day or a 24-hour day. However, if characterization of exposures during a task or activity is the objective, then a shorter duration would be appropriate. This criterion for duration of sample applies to both accumulating and time-series PE meters.

Frequency of samples: The number and frequency of repeated samples for subjects, in lieu of continuous monitoring, can be determined by the need to capture long-term variability of exposures, such as the variability associated with seasonal trends in activities and/or sources.

6.3.9 Analytic Implications

When stratified or cluster sampling is used the investigator must exercise caution in analyzing the results across groups, especially if disproportionate sampling techniques were used. Within group analyses are comparable to those appropriate for simple random or systematic samples. Some of these same analyses, when performed across groups, are proper for proportional samples (although weighting schemes may be required in certain instances). However, fewer traditional analyses are appropriate for disproportionate or targeted samples, even when weighting schemes are employed. In addition, cluster sampling is less statistically efficient than simple random sampling, and this must be considered when performing inferential tests. In summary, the simplest analyses of complex sampling designs and more complex analyses of the simplest sampling designs are well-understood. However, more complex analyses of more complex sampling designs require the review and assistance of a qualified statistician.

6.3.10 Resource Constraints

Whether determining the sample size necessary to properly estimate an exposure summary measure or addressing the association between exposure and subject attributes, an investigator often finds that the resources available for the study cannot provide the necessary sample size. An investigator in such a situation has several options, including: reducing the overhead associated with study implementation, simplifying measurement protocols and/or instrumentation, reducing the number and/or length of measurement periods, relaxing the precision or power required of the study statistical analyses, targeting one or more subpopulations, reducing the study's logistical requirements, and seeking or awaiting additional resources.

6.3.11 Recommendations for Sampling Strategies

The process of study design should include the following activities related to sampling strategies:

1) Develop a sampling strategy based on the following steps:
    1) Identify and characterize the subjects;
    2) Characterize the environments and exposure components for subjects;
    3) Stratify the subjects into exposure groups, if appropriate;
    4) Develop sampling plan(s) for subject groups that describe the sampling frame, type of sample, sample size, and sampling parameters; and
    5) Adjust the plan to accommodate logistical and resource limitations while addressing study objectives.

2) Perform pilot studies of sampling protocols.

6.4 Study Design: Time-Activity Record-Keeping

6.4.1 Introduction

Data on human activity patterns are collected as a part of EMF personal exposure protocols in order to answer basic questions about the causes and durations of exposure. The term activity pattern pertains to human activities and locations and their positions on the time continuum. Certain locations may be of special importance because they contain EMF sources. Likewise, certain activities may be particularly important because they involve the use of EMF sources. Nevertheless, the concept of activity pattern refers to a global complex of actions, locations and times, not only to those associated with particular sources. In the context of these guidelines, the goal of activity pattern assessment is to ascertain the nature of activities when EMF exposure measurements are taken.

Observations and record-keeping of activity patterns in PEM protocols are generally limited to a defined set of environments and subjects and to fixed periods of study. The characteristics of the subjects and their environments, and of the sources and the fields they generate, define the tasks of activity pattern measurement and the nature of the protocols needed to accomplish those tasks. Complicated environments, highly variable cycles of activity, and extremely mobile subjects, present special logistical problems for activity pattern measurement. Because sources are generally localized, it may be necessary to keep close track of a subject's proximity to sources and the associated times.

To design a protocol for collecting such data, investigators must attend to the basic purposes of the study, the resources available, and the nature of the subjects and their environments. Section 6.4.2 discusses the main types of activity pattern protocols and provides guidelines for selecting a protocol that will achieve study objectives. Section 6.4.3 discusses issues of implementation, given that a particular type of protocol has been selected. Section 6.4.4 gives examples of data collection tools appropriate for various protocols.

6.4.2 Selecting an Activity Pattern Protocol

Activity pattern protocols can be classified according to the timing of data collection in relation to the PEM period. Prospective protocols involve data collection before the PEM period and are necessarily confined to predictions about activity patterns during the PEM period rather than observations. In concurrent protocols, data on activity patterns are observed and recorded throughout the PEM period. Retrospective protocols initiate data collection on activity patterns after the PEM period and rely on recall. In each case, there is usually some attempt to make a connection between the EMF data collected during the PEM period and the activity patterns during the same time period. These designs are further subdivided by whether the data on activity patterns are provided by the PEM subject or by an observer or interviewer, giving a total of six different protocol types:

- Prospective protocols
    - Subject Questionnaire (PSQ)
    - Interview (PI)

- Concurrent protocols
    - Subject Diary (SI)
    - Observer Log (OL)

- Retrospective protocols
    - Subject Questionnaire (RSQ)
    - Interview (RI)

Table 6.3 compares these protocols in relation to two basic dimensions: the quality of the activity pattern data and the costs of implementation. These comparisons are summarized below.

Table 6.3

Evaluation of Activity Pattern Protocols: a) Quality of activity pattern and EMF source data; b) Costs of activity pattern protocol

Temporal Order	Prospective (Activity pattern data collected before PEM period)		Concurrent (Activity pattern data collected during PEM period)		Retrospective (Activity pattern data collected after PEM period)	
Data Collection Method	**Subject Questionnaire (1)**	**Interview (2)**	**Subject Diary (3)**	**Observer Log (4)**	**Subject Questionnaire (5)**	**Interview (6)**
a) Quality of Activity Pattern and EMF Source Data						
Subject versus Interview/ Observer	Problems of question interpretation; High rate of response errors.	Interviewer can explain questions according to guidelines and elicit answers.	Record-keeping may interrupt the flow of activity and vice versa.	Advantage of a dedicated observer; Recording does not directly affect subject's activities or locations.	Same as (1)	Same as (2)
Major Sources of Errors	Problems of coding multiple and complex activities and locations; Problems forecasting activities and locations or estimating events and times due to unpredictability.		Difficulty in applying coding scheme for activities, locations, and sources; Inaccurate recording of times and activity patterns; Ambiguity about initiation of events and changes in status, in particular for subject diaries.		Problems of coding multiple and complex activities and locations; Faulty recall of times and events during PEM period.	
Influence of Protocol on Subject	Forecast may affect subject's activities, and locations during PEM period.		Subject's record-keeping may affect his or her activities and locations.	Presence of an observer may affect subject's activities and locations.	Knowledge that retrospective questions will be asked may affect subject's activities and/or locations during PEM period.	
Validation Issues	Association of prospective reports and/or pre-identified exposure groups with characteristics of PEM time series.		Linkage of event or interval reports with PEM time series.		Correlation between aspects of PEM time series and retrospective exposure reports and/or post-factum exposure groups.	

Temporal Order	**Prospective (Activity pattern data collected before PEM period)**		**Concurrent (Activity pattern data collected during PEM period)**		**Retrospective (Activity pattern data collected after PEM period)**	
Data Collection Method	**Subject Questionnaire (1)**	**Interview (2)**	**Subject Diary (3)**	**Observer Log (4)**	**Subject Questionnaire (5)**	**Interview (6)**
b) Costs of Activity Pattern Protocol						
Costs of Activity Pattern Recording	Moderate up-front costs of question design.	Question design and interviewer labor; Relatively high costs.	Moderate costs of diary forms design.	Diary design and labor; Costs that depend on number of subjects that can be observed per observer.	Same as (1)	Same as (2)
Subject Burden	Moderate		High	Low	Moderate	
			Automated methods may reduce burden for subject or observer.			
Pilot Studies and Expert Panels	Identification of activities, locations and subject groups, and development of an adequate coding scheme, may require an expert panel or pilot studies that make preliminary observations of subjects.		Same as (1) and (2); Presence of observers and concurrent recording may permit more flexible coding schemes for activities and locations.		Same as (1) and (2)	

- Subjects versus observers or interviewers. For making comparisons between subject questionnaires and interviews in prospective and retrospective protocols, the principal issue is whether or not an interviewer is necessary to interpret questions and assist the subject in responding. Fully self-administered questionnaires must be constructed very carefully because no one is available to answer a subject's questions or resolve uncertainties. In concurrent designs, the observer has an advantage over the subject when record-keeping competes with the subject's other duties. In addition, observers can produce a greater level of detail and consistency in coding activity patterns and may add new codes when necessary.

- Generic and design-specific sources of errors in the measurement of activity patterns. Generic problems for all protocols include fuzzy categories, and potential misclassification of activity patterns for PEM and activity pattern assessment. The match between activity pattern data and actual activity patterns during the PEM period may be less than perfect for several reasons. In many cases it may be difficult to select and identify EMF-related activities, especially if the sources are hidden. Prospective designs are subject to forecast errors, especially in settings where activities are non-routine or otherwise unpredictable. Concurrent designs can provide highly accurate logs of activities and locations, if the recording instructions are clear and the subjects and/or observers are well-trained. Retrospective designs rely on subject recall and may be subject to recency bias—a tendency for recent events to be reported more reliably than earlier events.

- Influence of the protocol on the subject's behavior. This is an issue for any design if knowledge of the protocol produces atypical activity patterns during the PEM period. A concurrent design with an unobtrusive observer or use of automated methods can mitigate this problem.

- Opportunities for validation of activity pattern data. Concurrent designs provide the best opportunity for validating activity pattern through comparison of EMF time-series with records of specific exposure-related events. This type of validation is possible to a lesser extent in retrospective designs. In prospective designs, it may be possible to validate activity pattern forecasts by incorporating a retrospective rating by subjects of the accuracy of their forecasts.

- Costs and subject burdens of activity pattern data collection. In general, interviewer or observer-based protocols are more costly to implement than subject-based protocols due to labor expenses. Subject burden tends to be moderate in non-concurrent designs that rely on extensive self-reporting and very high in concurrent designs using diaries. In some cases, it may be possible to substantially reduce subject burden or eliminate observer expense via automated recording.

- Use of pilot studies and expert panels to develop coding schemes and recording methods. An important component of an activity pattern protocol is the scheme used to classify activities, locations, and sources. Studies involving complex environments and activities may require preliminary observations to determine how to code activities and locations and to record changes in subject status. This is a particularly important consideration in designs which rely solely on subjects since confusions about categories lead directly to errors of reporting.

The main issues involved in choosing a type of activity pattern protocol are organized in the form of a simplified decision tree in Table 6.4.

The first issue to be decided is the nature and extent of the link desired between activity pattern data and PEM. If a strong link is needed, the protocol should be selected from among the concurrent designs. If a weaker link between PEM and activity patterns will suffice, then a retrospective design may be chosen. A prospective design is appropriate if

Table 6.4
Simplified Decision Tree for Choosing an Activity Pattern Protocol

SIMPLIFIED DECISION TREE FOR CHOOSING AN ACTIVITY PATTERN PROTOCOL												
Extent of link required between PEM & activities	Direct link to time-series PEM				Association of activities with PEM period				No link required			
Will subjects be a consistent source of accurate data?	Yes		No		Yes		No		Yes		No	
Are resources for observer and/or interviewer available?	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
	⬇	⬇	⬇	⇩	⬇	⬇	⬇	⇩	⬇	⬇	⬇	⇩
Suggested protocol(s)	OL SD	SD	OL	SD OL	RI RSQ	RSQ	RI	RI RSQ	PI RI PSQ RSQ	PSQ RSQ	PI RI	PSQ RSQ PI RI

Abbreviations and symbols:	OL	Observer Log
	SD	Subject Diary
	PI	Prospective Interview
	RI	Retrospective Interview
	PSQ	Prospective Subject Questionnaire
	RSQ	Retrospective Subject Questionnaire
	⬇	Recommended protocols
	⇩	Choice of protocol depends on relative importance of issues

there is no need to link the activity patterns directly with PEM time-series data or if a link is desired and the activities, locations, and times are extremely predictable.

The next issue pertains to the capability of the subjects to provide accurate reports of activity patterns in the PEM period on their own under any of the three types of designs. Subjects may lack that capability because they find the task too demanding or confusing, because they lack sufficient time to record the information, or because they can't remember what happened without prompts and reminders. Some of the variability in the subject's capacity to report accurately is under the control of the investigator. For instance, a well-constructed self-administered questionnaire can sometimes substitute quite well for an interview. In general, a lack of faith in the subject's ability to make reliable reports leads to a choice of observer or interviewer-based protocols.

The final question in this simplified decision tree deals with resource limitations. Large budgets make the choice of the relatively expensive observer/interviewer designs easier. Cost limitations bias the choice of protocol toward subject-based data collection, even though accuracy may be compromised.

In certain cases, answering the three questions of Table 6.4 leads straightforwardly to a unique choice of protocol type. Thus a subject diary is called for if a direct link between activity patterns and PEM data is required, the subject can do the record-keeping reliably, and there aren't enough resources to hire a dedicated observer. On the other hand, some conditions justify a choice between several acceptable designs based on considerations not included in the chart. This is sometimes the case in making choices between subject questionnaires and interviews in non-concurrent designs. Yet other conditions may force an uneasy choice between alternative protocols none of which is fully appropriate. In such cases (e.g., between a subject diary and observer log when subjects are not reliable and observers not affordable), the chart indicates that the selection of a protocol depends on the relative importance of opposing considerations.

Table 6.4 is intended as a guide to making protocol decisions, not as a set of rules. The decision tree will point in the right direction in most cases, but the actual choice of protocol type must be made by the investigator with relation to detailed knowledge of the research environment. Finally, we note that there is no prohibition against mixed protocols. For example, it may well be desirable to use observer logs for one part of a PEM study and retrospective questionnaires for another component. The questions in Table 6.4 should then be directed to the circumstances of the particular study component.

6.4.3 Implementing an Activity Pattern Protocol

Coding Activities and Locations. In the context of this report, the purpose of an activity pattern protocol is to determine the nature of exposures during the PEM period. If P(t) is a time-series of EMF measurements for a given field characteristic and $P(t)=fA(t),L(t)$ approximates the functional relation between that characteristic and subject's time-series of activities A(t) and locations L(t), then the task of an activity pattern protocol is to provide enough information about A(t) and L(t) to interpret those aspects of P(t) the investigators deem important. When the recording device accumulates measurements rather than providing a time-series, the same logic applies without the time index— i.e., the expression is P=f(A,L) where it is understood that P is a summary of the series of measurements.

As indicated in the previous section, the choice of an activity pattern protocol depends on how closely PEM measures need to be linked to activity patterns. Whatever design is chosen, collecting data about activity patterns requires prior decisions about the classification of activities and locations. Classification or coding schemes for activities and locations can be compared along several dimensions. Three important distinctions are:

1) the level of detail of the coding scheme;
2) the extent to which classes of activities and locations are linked to specific micro-environments; and

3) the extent to which EMF sources or source use are embedded into the coding scheme.

The very extensive coding schemes used in studies of air pollution exposure (and discussed in Section 3 above) are examples of highly detailed classifications of activities and locations that are applicable to randomly selected subjects from the general population and the environments they inhabit in their everyday lives. Although these coding schemes have limited application for EMF studies, they provide an illustration of hierarchical classification and an introduction to the generic problem of choosing a level of detail for coding. For example, in a study cited in the EPA Exposure Factors Handbook [United States Environmental Protection Agency, 1989], the activity category "personal care" includes such subcategories as "washing/dressing", "medical care--adults", "help and care", "meals at home", "meals out", "nights sleep", and "naps/resting". The location "home" in the California Air Resources Board surveys was subdivided into "bedroom", "kitchen", "bathroom", etc. The level of detail in data collection does not always match the level of detail in data use. For example, in air pollution exposure studies, subjects may be asked to provide information about locations and activities in their own words. These raw data are then aggregated into codes after data collection.

The choice of a level of detail in coding depends in a general way on the relation between exposure variations and the categories which characterize activities and locations. It is normally desirable to choose a coding scheme which maximizes between-category variations and minimizes within-category variations in the parameter of interest (for example, resultant magnetic field).

When EMF studies are conducted in specific locations (e.g., schools, offices and other workplaces, outside locations) it is possible and desirable to incorporate specific microenvironments into the definition of location codes. In this case, location codes can be defined unambiguously as specific locations on a map of the site and such maps may be incorporated into the data collection protocol.

Because EMF sources tend to be localized, it is often desirable to embed source information into location codes and to incorporate source use into activity codes. Thus locations can be defined in terms of sources, as in the "computer room" of a school or research facility or the "welding area" of a fabrication shop. Activity codes can be organized around use of specific known sources (e.g., "using a hair dryer", "operating an arc welder", "using the computer at home", etc.).

Any coding scheme for activity patterns represents a compromise between what is needed in order to understand aspects of the collection of EMF measures and what data can be collected in practice. A coding scheme can fail in principle because it combines activities and locations with diverse implications for exposure. A review of existing coding schemes and consultation with expert panels can help to avoid some of the most obvious problems. Site visits are indispensable for assessments of specific environments. A coding system can fail in practice because it can't be used effectively by subjects, interviewers, or observers. To avoid this outcome, it may be necessary to pilot test proposed systems of classification under field conditions.

Asking Questions About Activity Patterns During the PEM Period. In prospective and retrospective designs, information about activity patterns during the PEM period is collected either by interviewing the subject or by asking the subject to complete a self-administered questionnaire. Although such questions can be written in many different ways, certain guidelines are relevant to most question forms that are appropriate to activity pattern assessment.

- Make sure that questions which refer to particular types of activities, locations and sources are written in a language most subjects can understand and interpret in the same way. Choose words for activities and locations that take advantage of the way most subjects use the language. Remember that most questionnaires and interviews assume eighth grade language skills. Don't ask the subject to make subtle distinctions between activities, locations, and sources without giving proper definitions or cues. When asking about activities or locations in a specific microenvironment, use maps, photographs, or similar devices to designate particular activity pattern components. The only way to determine in advance whether or not such questions are working properly is to pretest them and to conduct debriefing sessions with a sample of subjects. It is recognized that the cost of conducting pretests may sometimes challenge the budget limits for a particular project.

- Whenever possible, link questions about activities, locations, sources and times together so that they correspondent to actual experiences. Attempt to use the memory link between what subjects do and when and where they do it, to increase the reliability of recall or forecast. In some cases, the initial question can refer to a location ("did you spend any time in location A during the measurement day?"), an activity ("did you engage in activity X during the measurement day?"), a time ("what were you doing during the lunch hour?"), or a source or use of a source ("did you use the lathe any time during the measurement day?"). Given an affirmative response to the lead question, other activity pattern components can be assessed with follow-up questions ("while you were in location A, did you use any equipment?"). When asking one question is contingent on the answer to a previous question, the questionnaire will need to be formatted so that the skip patterns are extremely clear to the subject.

- Choose a time frame for asking activity pattern questions and stick to it. The time reference for activity pattern data can vary depending on the general nature of the protocol. The possibilities include:
    1) a binary yes/no response about actual or expected locations, activities, or sources during the PEM period,
    2) an estimate of the duration of time associated with an activity pattern,
    3) approximate placement of activities and locations on intervals of a time line, and

4) estimated begin and end times for specific activities and locations.

All of these may be used in the same interview or questionnaire, but the time frame must be clearly indicated for each series of questions and great care must be taken to ensure that the subjects understand any shift in time frame. Avoid asking questions that lead to a spurious sense of accuracy (e.g., asking for exact numbers of minutes where a broad interval of time is more realistic).

- Avoid the most common mistakes of questionnaire and interview protocol design:
    1) make the form easy to look at and easy to fill out; don't crowd the questions on a page, paper is cheap;
    2) questions which ask about a general class of events followed by specific questions about each type (e.g., a single question about any appliance use, followed by questions about specific appliances) make it too easy to skip out of an entire series, risking loss of relevant information; for this reason, special care should be taken to format the questionnaire so that the lists are not too long and the skip patterns are very easy to follow;
    3) use precoded response categories rather than fill-ins or open-ended responses when possible; use open-ended questions when seeking to elicit responses which can't be anticipated in advance, e.g., in pretest stages of questionnaire development;
    4) consider using "don't know", "can't predict" or "can't remember" response categories for pretest work to locate problem questions; try to avoid these devices in final questionnaire and interview protocols;
    5) keep questionnaires and interviews as brief as possible, consistent with the minimum information requirements of the protocol; and
    6) when a long series of questions about locations, sources, etc. is necessary, avoid following it by another long series; try to make the questionnaire or interview an interesting experience.

- In interview protocols, prepare written instructions on how to ask questions and use these materials to train interviewers. Written item-by-item instructions on how to conduct interviews help to standardize the interview process and to increase the comparability of responses. These include specifications of: 1) the intent of the question, 2) how to help the subject understand the question, and 3) what to do when the subject has difficulty responding. Writing specifications is a time-consuming but revealing exercise for the investigator and is a necessary ingredient of interviewer training.

Data Recording in Diaries and Logs. Accurate concurrent entry of activity pattern information in diaries or log requires: 1) unambiguous codes for activities, locations, and sources, 2) clear designations of the events which trigger recording of activity pattern information, including begin and end times, and 3) forms which facilitate recording data in the detail required by the protocol. The following principles apply.

- Activity pattern codes should be written in language that the subject or observer can understand and interpret consistently. The same considerations apply here as in the case of questionnaires and interviews.

- Make the log or diary form easy to use: 1) where possible, precode the activity, location, and source categories; 2) bind the pages for easy access and choose a size which balances portability with ease of recording; 3) if exceptions to the coding conventions occur frequently, leave room for notes and comments; and 4) design the rules for log or diary entry (see below) so that the maximum number of entries is consistent with a reasonable burden on subjects or observers.

- Prepare written instructions for observers or subjects. This should be required for every log or diary protocol. The instructions include: 1) definitions of activity pattern codes, where necessary, 2) very careful designation of the events which initiate entry into the diary or log (e.g., a change of location or activity or a specific time as in interval diaries which require recording concurrent activity patterns every x minutes or retrospective reporting on activity patterns at fixed intervals) and 3) instructions about what to do if an entry is missed, if there is a gap between the end of one event and the beginning of another, or if the instrument is not being worn.

- Debrief subjects after the PEM period. Go over the activity pattern record with the subject as soon as possible after the PEM period. Ask about questionable entries and gaps in the record so that corrections can be made if necessary. If time-series plots of EMF measurements are available, use the features of the time-series, especially the location of peak values, to direct debriefing questions.

In most cases, the main components of a diary or log protocol pertaining to activity pattern recording should be pretested under conditions which approximate those encountered during data collection.

6.4.4 Some Examples of Activity Pattern Data Collection Tools

In what follows, we discuss and briefly illustrate three types of data collection tools that may prove useful in collecting activity pattern information in PEM studies. These are: 1) list-based retrospective questionnaires, 2) interviewer-administered retrospective diaries, and 3) recording forms for concurrent diaries.

- List-based retrospective questionnaires. This type of questionnaire takes the form of a matrix in which the rows consist of lists pertaining to locations, sources and source use, or activities and the columns consist of questions about uses and times. The following is an illustrative questionnaire fragment adapted for PEM studies from a residential exposure study in which the questions did not refer to a particular PEM period.

The following questions deal with your use of electrical equipment at home while you were wearing the meter. For each type of equipment, please indicate (a) whether you did or didn't use this equipment while you were wearing the meter; and (b) If you did use the equipment, for how many minutes did you use it?"

This type of question can be used with location and activity classifications as well as EMF sources and can be augmented by asking the subject to locate the event in time (e.g., a.m. versus p.m., approximate start time). How well this question works depends to a large extent on the completeness and understandability of the activity pattern categories. Although "Other Specify: ______________" may be used for unlisted items, it is better to anticipate and list them explicitly to ensure comparability of the responses across subjects. Because any listed item may be used several times during the PEM period, asking subjects to give start times may prove burdensome.

- Retrospective interviewer-administered diary. This strategy has been used in several time-use surveys of the general population but can be adapted for use in reconstructing the activity patterns during the PEM period as well. Here is an example:

Now I'd like you to tell me about what you did when you wore the meter. Start when you first put on the meter and go through the entire period while you wore it. I'll be asking you to tell me

-What you were doing,
-Where you were,
-Whether or not you used any electrical equipment
-What time you started doing something else.

This example is interviewer-dependent because it presumes no precoded categories and allows subjects to report their activity patterns in their own words. In this situation, the interviewer can probe for additional information when subject reports are not sufficiently clear for post-interview coding. The retrospective diary strategy is best employed immediately after PEM periods of relatively short duration (i.e., less than 24 hours). This particular example begins the diary reconstruction with a question about activity (what you were doing), but it could just as well have started with a location question (where you were). In many cases, it may be possible to use precoded categories for activities, locations and sources.

- Concurrent subject diary. An example of a subject diary or log book is given in Figure 6.1. This represents a form of concurrent diary characterized by: 1) time and event marker recording designed to provide a direct link to EMF time-series measurements and 2) a limited number of location codes, some of which are characterized by proximity to known EMF sources. This type of recording device is appropriate when the activity-pattern categories, in this case referenced by locations, can be defined clearly and specified in advance.

6.4.5 Recommendations for Time-activity Record-keeping

The process of study design should consider the following issues related to time-activity record-keeping:

1) Use the exposure component stratification tables or an equivalent method to determine the level of time-activity recording that is necessary.

2) Evaluate the available activity pattern protocols (Table 6.4) and select a methodology for recording time-activity information: diary, self-administered or interview questionnaire; and retrospective, prospective or concurrent.

Figure 6.1
Example of concurrent subject diary and instructions

INSTRUCTIONS FOR VOLUNTEERS

KEEPING YOUR DIARY:

We need to know where you are while you are wearing the EMDEX. Make an entry in the diary whenever you change locations as follows:

1. Remove the diary and pen from the pouch.
2. Enter the time displayed in the pouch window in the diary.
3. Push the "EVENT" button on the EMDEX by pressing the circle on the outside of the pouch.
4. Enter the Event number shown on the LCD.
5. Enter the new location.
6. Enter any comments you have.

If you forget to make an entry when changing locations, then make the appropriate entry of the new location, and estimate and enter the time you moved to that location. You should not push the "EVENT" button. Instead, write "est" (estimate) in the "Event Number" column.

The locations to record include:

SC - School-Classroom
SN - School- Not in classroom
H - Home
T - Travel (including, walking, biking, riding)
W - Work
O - Other
ZZ - Sleeping
XX - Not wearing meter (other than sleeping)

See other side for meter wearing instructions

VOLUNTEER'S DIARY

EMDEX Serial # ________

Subject Code __________

Engineer: Pam Bittner Phone: 458-6893

Date Started: ______

Date to be Returned: ______

Time	Event Number	Location	Comments
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
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:			
:			
:			
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Figure 6.1 continued

INSTRUCTIONS FOR VOLUNTEERS

WEARING YOUR EMDEX:

Wear the EMDEX for a minimum of 24 hours beginning when you receive the meter.

Do not wear the EMDEX if it is likely to damage the instrument (i.e. vigorous exercise, showering, etc.), or adversely effect your safety. If you have to remove the EMDEX, place it in a safe place and make an "XX" entry in the diary.

While sleeping, place the EMDEX next to your bedside, but away from an electrical appliances, such as a clock or radio. Make a "ZZ" entry in your diary.

If you don't understand any of these instructions, you may call the engineer listed on the diary.

See other side for instructions on keeping your diary

VOLUNTEER'S DIARY

CONTINUED FROM OTHER SIDE

EMDEX Serial # ________

Subject Code ________

Date: ___ ___ ___ ___

Time	Event Number	Location	Comments
:			
:			
:			
:			
:			
:			
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3) Design a coding scheme for activities and locations, incorporating to the extent practical, distinctions in activity patterns which may be related to EMF exposure.

4) For prospective and retrospective designs, develop questionnaires that are clear and appropriate for the subjects and for determining activity patterns; for interviews, include written instructions on how to administer the questionnaire.

5) For concurrent diaries, develop unambiguous diaries with clear instructions for their use and use a format that facilitates the accurate recording of time-activity data.

6) Perform pilot studies of the activity pattern recording protocols, including the use of naive subjects.

6.5 Study Design: Data Management

In an EMF PEM study, as in any other type of study, procedures must be implemented to ensure the integrity and validity of the data as it migrates from the meters in the field, to a data base, through an analysis and ultimately to a reported exposure. With currently available instrumentation, it is possible to collect large quantities of EMF PEM data. Therefore a comprehensive data management plan should be thoroughly tested and in place prior to beginning data collection. Standard procedures in such a plan include unique naming and labeling conventions for files and forms, ensuring reliable linkages between forms and files, provisions for maintaining audit trails, and maintaining multiple copies of the data for security during transit and storage.

6.5.1 Data Forms

Many different factors can influence or contribute to EMF exposures. These include: time-of-day, load current, equipment present, equipment duty cycle, make and model of equipment, subject location, subject activity, etc. Attention must be paid to identifying and recording those factors pertinent to the study objectives. All data collected during observation of a subject (forms and data files) should be linked by a unique number or code. This code appears on all forms collected during the observation. The code should also be incorporated into the PEM file name and ideally, within the file itself.

6.5.2 File Naming

An EMF PEM study can generate numerous data files. A file-naming convention that provides unique file names for these data files must be employed. Generally, a system is developed that incorporates descriptive aspects of the study design such as subject identification number, date, location, type of measurement and/or instrument serial number. The file-naming conventions of the computer operating system will dictate the most appropriate scheme. In the case of studies involving multiple observations of a subject, care must be taken to ensure that the year is included in dates or that the visit number is included in the unique identifying information.

6.5.3 Security

Back-up copies of all data collected at an observation should be made as soon as practical after completing the observation. This back-up includes copies of all paper forms and computer files. The back-up copies and originals should be shipped and stored separately to avoid loss or damage to the observation's entire data.

6.5.4 Analysis

The data generated in a PEM study can be voluminous. A strategy to organize, analyze and summarize the data and provide comprehensive descriptions of the results is an important part of a study plan. The time periods associated with data collection employing a data logger should be identified and summaries generated for those periods deemed appropriate by the investigator. These time periods will often be related to the time-activity information that is being collected. Possible time periods worthy of summarization include: the entire measurement period for a subject, a work or school day, the time spent in an environment, and/or the time spent performing a task.

When using a data logger for PEM, the summary measures within each period can be computed from the time-series data. Possible summary statistics include: measures of central tendency, such as the arithmetic and geometric means and the median; measures of variability such as the standard deviation variance, and range (maximum minus minimum); extremes such as minimum, maximum; indicators of the nature of the distribution such as percentiles (e.g. every tenth percentile, 10, 20, etc.); and the fraction of the time period with exposures above specific levels such as 1, 2, 5 or 10 mG. A host of additional summary statistics can be drawn from time-series data. The study objectives and any hypotheses being tested will dictate the appropriate summaries. The mean exposure for a period is the most common descriptor used for analyses across subjects or across periods within subject. The distribution of exposure means for most PEM is skewed with most values occurring at low field levels. Therefore a log-transformation of the means has often been used to produce a distribution that approximates a normal distribution.

6.5.5 Recommendations for Data Management

The study design process should consider the following activities related to data management:

1) Identify all types of data that will be collected and recorded to meet the objectives of the study.

2) Develop form-labeling and file-naming systems that will uniquely identify the content and source of data and reliably link the forms and files.

3) Develop procedures for ensuring the integrity and physical security of all data.

4) Develop a plan for analyzing the data, including, for time-series data, the identification and documentation of time periods to be summarized; anticipated transformations of the data; summary measures associated with the exposure model; and proposed descriptive and inferential analyses.

5) Develop a plan for reporting the methods and results of data analysis.

6.6 Subject Issues

6.6.1 Consent Form

A consent form to be signed by the subject or, in the case of minors, by their parent or guardian, is mandatory for PE studies. It provides prospective subjects with the information necessary to make an informed decision about participation. Consent forms might not be needed when employees or friends are used for pilot studies, where informal consent is obtained. However, when subjects are recruited, even for pilot studies, the use of consent forms becomes essential.

The consent form provides information about:

- who is conducting the study;
- the purpose of the study;
- the procedures to be used in the study;
- the risks and benefits associated with participation in the study;
- how confidentiality will be maintained; and
- other information about and conditions for participation that should be disclosed prior to obtaining consent.

Studies using human subjects that are performed at large institutions or under government sponsorship often require approval by a human subjects committee. Development of an acceptable consent form will be part of the approval process. An example of a consent form is included in the data collection materials for the Pilot Studies contained in Appendix C.

6.6.2 Confidentiality

The confidentiality of each subjects' identity should be maintained by study investigators during data collection, data management, analysis and reporting The Privacy Act of 1974 (P.L. 93-579) is designed to protect personal information from public disclosure. Federal agencies must take steps to safeguard the collection, use, and storage of such data. For many purposes, prior consent of the individual is required before collecting data. Epidemiologic research is exempted, however, so long as the privacy of the information is protected.

In PEM studies confidentiality can be assured through the assignment of identification numbers and the restriction of identifying subject information to those in the data collection process that need to know. Usually these are the personnel in the field who contact and interact with subjects. Data file names and forms can be constructed using these same identification numbers. Data files and data collection forms must be purged of any identifying information. If data are to be sent to subjects after the study, then a confidential link between subject name and identification number must be maintained and purged after the data are sent.

6.6.3 Access to Data

As indicated in the general guidelines of Section 5, PE subjects should be given the opportunity to receive information about the nature of their measurements. In order to minimize any impact on data collection, especially when measurements for a subject are to be repeated, it is preferable to distribute data to subjects only after all data have been collected.

Software often provided by the manufacturer with PEM data loggers can be used to generate field versus time plots which graphically show the field levels encountered by the subject. An alternative is to provide statistical summaries of a subject's data either alone or along with the plot. Again the software usually provided with the PEM meter can be used to generate the necessary summary report or a custom report can be generated during analysis.

Because the retrieval of meters and forms may occur during a short time period, say at the end of a work shift, it may not be convenient to generate and distribute reports to subjects at that time. One method of managing the distribution of data to subjects is to mail the results to who request them. Additional explanatory materials can also be included with the measurement data. These materials might include study-specific information, such as a summary of results for all subjects, and/or general information about EMF.

6.6.4 Instructions and Debriefing

Delivering clear instructions to subjects regarding data collection protocols is essential. Besides educating the subjects it serves to motivate them to adhere to the protocols. The instructions should include sufficient information for the subject to understand the context of the measurements, what is expected of them, and who to contact if there are questions or concerns. Information on the purpose of the study, although included on the consent form, may need to be repeated when the meter is delivered to the subject.

Immediately prior to the measurement period, the subjects should be instructed in the protocols and given the opportunity to practice performing them. A set of written instructions should be left with the subject for reference. The instructions should include a list of persons to contact in the event of questions or concerns which may arise while performing the measurements. The instructions should describe the protocols in appropriate detail and be written in a manner that can be readily understood by the subject. Pilot testing of the instructions and forms should be performed prior to full-scale implementation.

The procedure for retrieval of the meter should be established with the subject during deployment of the meter. During retrieval the subject should be debriefed to confirm that study protocols were followed and to identify any problems or questions that the subject had. If time permits, and if it will not impact future data collection, the subject can review his measurement data at the time of retrieval.

6.6.5 Interference

The potential for the subject to interface with the collection of valid PE data exists for any PEM study. There are several steps that can be taken to discourage subjects from deliberately altering their behavior or otherwise influencing the PEM. The meter should be reasonably tamper proof. There should be no switches or buttons accessible to the subject that are not essential to executing the protocol.

Any display feature on the PE meter should be masked or programmed not to display magnetic field levels. A magnetic field display can encourage subject curiosity about high readings. It can also provide feedback on field levels that might result in changes in the subject's behavior patterns. It may be possible to program the meter to display time for use in keeping a time-activity diary. In any event a display should provide some indication to the subject that the meter is functioning.

6.6.6 Recommendations for Subject Issues

The following activities should be considered to address subject issues:

1) Determine the approvals required for participation of subjects (e. g., human subjects committee, employer consent, parent/guardian consent, simple consent form) and develop the forms necessary to obtain informed consent.

2) Develop the procedures necessary to maintain the confidentiality of subjects.

3) Develop clear, unambiguous PEM protocol instructions for the subjects.

4) Develop a plan to provide their measurement data to subjects.

5) Develop PEM protocols that minimize the possibility of violations.

6) Perform pilot studies to test the demands of the protocols on the subjects.

6.7 Quality Assurance

Quality assurance (QA) procedures should be developed for various components of the study design. Most QA will consist of generally accepted procedures for ensuring the quality, integrity, and security of the data. Specific recommendations for EMF PEM studies are related to instrumentation and data collection.

6.7.1 Instrumentation QA

For EMF PEM instrumentation there should be functional checks prior to each deployment and periodic calibration verification checks at less frequent intervals. (See Section 6.2.3 for a discussion of the equipment required for calibration verification.) Calibration of the instruments is best done by the manufacturer and can be performed at the beginning and end of a large study or on an annual, or somewhat less frequent, basis.

6.7.2 Data Collection QA

EMF PEM are subject to influence by subject activities and by changes in external sources. To ensure that unusual measurements or measurement patterns represent actual exposures, data should be reviewed immediately after collection to confirm the consistency of field measurements with the activities and/or environments reported by the subject. Verifying the validity of EMF measurement data should be a continuous process throughout the analysis phase of a project.

6.7.3 Recommendations for QA

The following recommendations relate to establishing a quality assurance plan for an EMF PEM study:

1) Implement appropriate generally accepted QA procedures for the sampling process, data collection, data management, data analysis, and reporting.

2) Implement a plan for verifying calibration and confirming the functionality of PEM meters on a regular basis.

3) Develop methods for assessing the consistency of the PEM with reported activities and the completeness of all data soon after completion of an observation.

4) Introduce automated and/or manual procedures for verifying the accuracy of the data entered into data bases.

5) Perform sufficient pilot studies to become confident in the validity and consistency of data collection processes prior to beginning measurements.

6.8 Uncertainty Evaluation

Uncertainties will be present in all studies as a result of study design compromises and shortcomings in study implementation. These can include: practical considerations which compel the investigator to implement a less than ideal study design, limitations in instrumentation, errors in implementing study procedures, and possible protocol violations. Some of these uncertainties will be known, some will be suspected, and some will be unknown. When known or suspected the uncertainties should be enumerated and, if possible, their impact on study results should be quantified and reported. This is in keeping with the goal of providing an estimate of overall uncertainty for the PEM and the study results.

A written study plan, developed according to the second general guideline, should provide estimates of anticipated uncertainty for the PEM. After data are collected and analyzed, the measurements can be used to describe the observed uncertainty in the study results. Both the estimated and observed uncertainties are of value and recommendations are developed here for both.

The following actions should be considered when performing an uncertainty evaluation for an EMF PEM study:

1) Determine whether the expected uncertainty is acceptable in light of the study purpose.

2) Plan to provide an estimate of overall observed uncertainty in the EMF PEM results.

3) Quantify the observed uncertainty introduced by various factors such as: sampling procedures, instrument imprecision, measurement processes, and other data collection efforts.

4) Implement validation procedures and obtain feedback from subjects to identify the presence of protocol violations and quantify, if possible, their impact on study results.

6.9 Archival Plan

The general plan for archiving process-related materials and study results should be completed in detail. To accomplish this the investigator should develop a specific archival plan of:

- raw data, including measurements and forms;
- processed data such as summaries and spreadsheets;
- study documents; and
- procedural tools such as written protocols, instructions to data collectors and subjects, and software tools.

7

PILOT STUDIES

7.1 Overview

Two PEM pilot studies were performed to test the recommended guidelines in occupational and non-occupational settings. The non-occupational pilot study involved 50 high school students from three classes at two schools. The occupational study involved eleven professional and production employees at an instrumentation manufacturing plant. Emphasis was placed on testing methodologies for collecting activity-pattern data.

The general recommendations presented in Section 3 were utilized to develop the design for each study. The investigator developed the purpose of the studies and then methodically examined each of the seven study elements in a study plan. Based on the outline developed in the study plan, specific protocols were developed.

The results of the pilot studies include: information about the use of the PEM recommended guidelines; field evaluation of the recommended methods for obtaining time-activity data; and evaluation of the study process by participants. In addition, the PEM data from the non-occupational pilot study will be included in the RAPID EMF Database.

Summaries of the two pilot studies are given in this section along with recommendations developed as a result of those studies. A complete report on the pilot studies including data collection forms is included as Appendix C.

7.2 Pilot 1: High school physics students

7.2.1 Purpose

The primary purpose of the first pilot study was:

- to test the recommended guidelines in a non-occupational setting, with particular attention to the collection of activity-pattern data.

The enthusiastic response of teachers to the project resulted in a much greater participation rate than expected. Two secondary objectives were therefore adopted:

- to provide an educational opportunity for the students, and
- to gather a set of data appropriate for inclusion in the Rapid EMF Measurements Database.

Three types of data were gathered in order to allow exposure stratification: 1) magnetic field PEM; 2) concurrent information about the activities/locations of the subjects; and 3) participant personal information. In order to demonstrate and test the recommended PEM guidelines related to collection of time-activity data, location data were collected using three methods: personal diaries, retrospective questionnaires, and prospective questionnaires.

7.2.2 Methodology

The investigator met with each participating class approximately one week before the intended measurement period to solicit volunteers. The volunteer nature and confidentiality of the project were emphasized and parental consent forms were distributed. The number of participants who could wear meters was limited by the number of meters available, thirteen per class. However, all students kept a diary as part of the class assignment, regardless of whether they volunteered to wear a meter or not.

Participation was as follows:

Study Group	Kept Diary and Wore Meter	Kept Diary Only
School A, Class #1	9	9
School A, Class #2	9	7
School B	13	3

Personal exposure measurements were made with EMDEX II meters manufactured by Enertech Consultants of Campbell, CA. The meters were set to display either the battery status or elapsed time, rather than the magnetic field reading. The EMDEX meters were worn by the participants in a pouch secured by a waist belt. The meters were distributed for a period of either 24 hours or 48 hours, depending on whether the class met on successive or alternate days. The sampling schedule for each class was:

Study Group	Sampling Interval	Sample Period
School A, Class #1	One-minute	24 hours
School A, Class #2	One-minute	48 hours
School B, Class #1	1.5-seconds or Five-seconds	24 hours

Time-activity information for the students was stratified by location, as follows:

Student Location/activity Strata	
At School: Classroom	At Work
At School: Not in Classroom	Other Location
At Home	Sleeping
Traveling	Not Wearing Meter

Students documented their activities (locations) using two methods: by personal diary and by questionnaire. All students in every class completed a diary, including those students who did not volunteer to wear a PE meter. In addition, each student gave an estimate of the time spent in each location by completing either a retrospective or prospective questionnaire.

Questions regarding basic information about each participant were included on the prospective and respective questionnaire forms. This data included: school grade; age; gender; residence type (apartment or single-family home); job description during study period; and primary method of travel during study period.

Upon completion, all students filled out a short evaluation survey on their participation.

Several steps were taken throughout the pilot study to ensure the reliability of the data: instruments were calibrated prior to and after the project; the functionality of each instrument was verified before each use; forms were designed to be clear, succinct and straightforward; the investigator emphasized the importance of data accuracy and explained the protocol for documenting missed events; each participant was assigned a unique identifying number which appeared on all forms and data files; and the magnetic field data were reviewed immediately after collection. Copies of the EMDEX files and of all forms were forwarded to project headquarters for production of summary files.

Time-activity information was obtained from the dairies and the questionnaires. The diary data were linked to event marks in the data associated with each change in location. The cumulative time reported by the diary for each location was calculated for each student. Cumulative time in each location as reported in the questionnaires was also computed for each student. A percentage of time misclassified by the questionnaire relative to the diary was computed.

PEM were summarized by location and by school class. Summary measures were computed for the total time each person spent in a given location. These included: number of samples, time, arithmetic mean exposure, median, maximum, geometric mean and standard deviation. These results were combined to provide the average and the maximum magnetic field exposure for each class by location.

7.2.3 Results

Students successfully recorded information about their locations while monitoring magnetic field exposure. However, a common error in the time-activity record-keeping involved accounting for sleep time: ten students omitted sleep time either in their diary, their questionnaire, or both. The errors occured in all three classes, but were most prevalent in the students completing the prospective questionnaire. The exposure data were corrected by the investigator. Results were compiled with both uncorrected and corrected data.

The retrospective questionnaire provided more reliable information than the prospective questionnaire. In retrospective questionnaires 2.6%-3.5% of time was misclassified, while in prospective questionnaires 9.8% of time was misclassified. The retrospective questionnaires were completed immediately following the measurement period, which assisted recall, as confirmed by the participant evaluations.

Analysis of the exposure data indicated that for each class, the overall average exposure was 0.7 to 0.8 milligauss (mG). Maximum exposure was 10 mG for one group and about 190 mG for the other two groups. Average exposures were 0.2 to 0.4 mG in School A and about 0.9 mG in School B. The highest exposure measured within a school was 110 mG. Information contained in the diaries and other forms will allow analysis by gender, age, residential type, and transportation type.

7.3 Pilot 2: Instrument Manufacturing Employees

7.3.1 Purpose

The primary purpose of the second pilot study was:

- to test the recommended guidelines in an occupational setting, with particular attention to the collection of activity-pattern data.

The location of the pilot was an instrument manufacturing facility in the San Francisco Bay area. The small company had a diversified work force with both professional staff and production personnel. An effort was made to assure that this study tested a different set of methods than those tested in the first pilot study.

7.3.2 Methodology

Exposure data was collected for two groups. Time-activity data were acquired with three methods: Professional employees completed concurrent diaries while wearing exposure meters and also completed retrospective questionnaires; the activities and locations of production workers were monitored by an observer while they wore an exposure meter.

Activities of the professional employees were stratified by more specific location definitions than used for the first pilot study. This approach attempted to address possible differences in magnetic field levels in sub-environments within the broader environment of the entire manufacturing facility. To develop a list of sub-environments for the site, the investigator toured the facility prior to the date of measurements. These sub-environments were:

Occupational Activity/Location Sub-environments	
In Administration	In Manufacturing
In Common Areas	In Purchasing
At Participant's Desk	In Test & Repair
In Education Area: Classroom	In ETK
In Education Area: Lab	Using Equipment
In Engineering	Out of Building
In Lunchroom	Not Wearing Meter

The locations of production employees were recorded by the observer within the boundaries of the sub-environment in which they worked — either Manufacturing or Test & Repair. These two sub-environments were divided by a grid system.

Personal exposure measurements were recorded using EMDEX II meters manufactured by Enertech Consultants of Campbell, CA. The meters were set to display either the battery status or elapsed time, rather than the magnetic field reading.
The sampling interval was three seconds. The EMDEX meters were worn by the subjects in a pouch secured by a waist belt.

The meters were distributed to seven professional employees individually in the morning and worn for most of the work day. Four production employees wore EMDEX meters for a period of approximately 1¼ to 1½ hours. Two employees in the

Test and Repair area were monitored simultaneously, followed by two employees in the Manufacturing area.

All professional employees completed a time-activity diary. The specific PEM guidelines recommend that time-activity categories be magnetic field- based, to the extent possible. Therefore, in addition to identifying the sub-environment within the facility, the employees were requested to indicate the type of equipment being used when a "Using equipment" entry was made in the diary. Each professional employee gave an estimate of the total time spent in each location using a retrospective questionnaire immediately upon completion of the measurement period.

The activities of the production employees were recorded by an observer. The stratification of activity/location was based on a grid of the local work area. Each time the participant moved from one grid-section to another, the movement and new location were documented. Departure from the observed area was also recorded. The grid was arbitrarily geometric and was not associated with activities or sources. The production employees were not requested to estimate their activities in a questionnaire.

Participants were identified by job classification and gender, which was determined during the initial interview. They were all given the opportunity to comment on their participation in an evaluation survey.

Several steps were taken throughout the pilot study to ensure the reliability of the data: calibration of instruments was verified prior to and after the project; the functionality of each axis of the meter was verified prior to measurements; forms were designed to be clear, succinct and straightforward; the investigator emphasized the importance of data accuracy to participants; the data were reviewed immediately following collection; each participant was assigned a unique six-digit code that was recorded on all forms and data files; and PE measurement EMDEX files were reviewed for quality and backed up on floppy disks before being sent to project headquarters for production of summary files.

Time-activity information was collected from the diaries and the questionnaires of the professional workers. Cumulative time in each location was calculated for each employee from both sources. With such a small sample, the time-activity information from the questionnaires was not sufficient for detailed analysis.

PEM were summarized by location by employee based on diary information. Summary measures were computed for the total time each person spent in a given location. These included: number of samples, time, arithmetic mean, median, maximum, geometric mean and standard deviation. This information was further aggregated to provide the time-weighted average and the maximum for the professional employees by location. The quantity and quality of data collected for the production employees was insufficient for analysis.

The average exposure for all professional employees during the study was 0.9 mG. One significant contributor to time-weighted average exposure appeared to be an outside building supply transformer near which a few employees stood during smoking breaks. The highest measured exposure of 224 mG occurred when an employee walked behind a dot-matrix printer to retrieve a report. Two employees had substantially higher mean exposures than the other five employees: 1.26 mG and 2.06 mG versus .49-.74 mG for the other seven employees. These two employees worked in the same general area and were exposed to the fields from the same printer.

7.4 Evaluation of Recommendations

A draft of the recommended guidelines for PEM was used to design and perform the pilot studies. Evaluation of the recommendations occurred throughout the pilot studies. Detailed suggestions for changes are described in detail in Appendix C.

General observations about the value of the recommendations in developing and performing the two pilot studies were:

- The general recommendations provided a valuable template for preparing a study plan based on the project purpose and resources.
- The importance of the written study plan and protocol, emphasized throughout the guidelines, was clear in the pilot studies. The written protocol outline guided the details of implementation, and in one case where the outline was not at hand, instruction details were missed.
- The importance and value of pilot studies recommended in the guidelines were re-enforced. During these studies, departures and needed changes from the original study design were identified: these included subject capabilities, instrument deployment, subject instruction , observer capability, diary formats, data collection schedules, and questionnaire formats. In short, the pilot studies demonstrated the necessity of such preliminary efforts in PEM studies.
- The guidelines recommend relating the activities/locations selected for time-activity pattern data collection to magnetic field exposure. This was found to be difficult in practice. Fully implementing such a strategy requires a knowledge of the expected sources and magnitudes of exposure, and may entail such a detailed stratification of activities or locations that data collection becomes burdensome. Therefore developing an activity stratification scheme requires a balance between information gained and subject acceptance.
- A similar balance between activity/location complexity and practicality must be struck when using observers. For the observer method to succeed, objective, clearly defined observable locations (zones, sub-environments, micro-environments, etc.) preferably related to exposure, must be identified in the

study design and understood by the observers. The observation process was unsuccessful in the second pilot study because the grid-based locations were not readily discernable or linked to activities and exposures..

- The use of questionnaires as a means of ascertaining time-activity information was outlined in the guidelines and demonstrated in the pilot studies. The pilot studies confirmed that retrospective questionnaires provide more reliable information than prospective questionnaires. However, in this case, the retrospective questionnaire responses were affected by assisted recall: that is, the subjects had filled out diaries prior to completing the questionnaire. Responses to the two types of questionnaire indicated the need to thoroughly test various formats prior to implementation.

8

RECOMMENDATIONS

The recommended guidelines for EMF PEM studies which were described throughout this document are summarized below. Descriptions of each topic, supporting discussions, and suggested procedures for the implementation of specific protocols are included in the previous sections.

8.1 General Guidelines

When planning an EMF PEM project, investigators are urged to employ the following basic steps:

1. **Develop a clearly stated purpose for the EMF PEM study; and**

2. **Complete a written study plan before developing specific protocols or beginning measurements.**

The written study plan is a general descriptive document and should address the following elements of an EMF PEM study:

- Resource Assessment
- Exposure Model
- Study Design
- Subject Issues
- Quality Assurance
- Uncertainty Evaluation
- Archival Plan

8.2 Specific Guidelines

Specific guidelines are recommended for developing detailed protocols for various elements of a PEM study. These specific guidelines are:

8.2.1 Study Design

The process of designing a PEM study design should consider the following activity when selecting field characteristics for measurement:

1) Select the field characteristics to be measured based on the purpose of the study, available resources, and the priorities recommended here for inclusion of field characteristics.

Mandatory:

- time-weighted average (TWA) resultant field (broadband or 50/60-Hz) for the measurement period of interest (task, shift, day, week, etc.).

Optional:

- time-series measurements,
- core group of descriptors for the measurement period: minimum, maximum, median, arithmetic mean, standard deviation, geometric mean, and various percentiles (99, 98, 95, 90, 80, etc.);
- frequency content (magnitude of harmonic relative to magnitude of the fundamental frequency component of the field, magnitude of other specific frequency components); and
- time-weighted average and maximum of static field.

Not recommended at this time:

- transients;

- field polarization;
- field orientation; and
- field vertical and horizontal components.

The process of study design should include the following activities related to <u>instrumentation</u>:

1) Select an accumulating or time-series meter based on study purpose, data requirements, and available resources;

2) Confirm that PEM meter specifications are acceptable in terms of range, sampling interval, data storage capacity, battery life, event mark capability, display characteristics, etc.

3) Select where and how the meter will be worn by subjects based on subject acceptance and the applicable exposure model. Other factors that enter in meter placement are: safety, activities of subject, size of meter, and record-keeping requirements.

4) Select where the PEM meter will be placed when it is not worn based on the study purpose, convenience for the subject and security issues.

5) Determine any other instruments that will be required for other purposes such as time-activity record-keeping and calibration verification.

6) Perform pilot studies using the proposed instrumentation.

The process of study design should consider the following activities related to <u>sampling strategies</u>:

1) Develop a sampling strategy based on the following steps:
    a) Identify and characterize the subjects;
    b) Characterize the environments and exposure components for subjects;
    c) Stratify the subjects into exposure groups, if necessary;
    d) Develop sampling plan(s) for subject groups; and
    e) Select sampling parameters such as interval between measurements, duration of measurement period, and frequency of measurement periods.

2) Perform pilot studies of sampling protocols.

The process of study design should consider the following activities related to <u>time-activity record-keeping</u>:

1) Use the exposure component stratification tables or an equivalent method to determine the level of time-activity recording that is necessary.

2) Evaluate the available activity pattern protocols (Table 6.4) and select a methodology for recording time-activity information: diary, self-administered or interview or questionnaire; retrospective, prospective or concurrent.

3) Design a coding scheme for activities and locations, incorporating to the extent practical; distinctions in activity patterns which may be related to EMF exposure.

4) For prospective and retrospective designs, develop questionnaires that are clear and appropriate for the subjects and for determining activity patterns; for interviewers, include written instructions on how to administer the questionnaire.

5) For concurrent diaries, develop unambiguous diaries with clear instructions for their use and in a format that facilitates the accurate recording of time-activity data.

6) Perform pilot studies of the activity pattern recording protocols, including the use of naive subjects.

The study design process should consider the following activities related to <u>data management</u>:

1) Identify all types of data that will be collected and recorded to meet the objectives of the study.

2) Develop form-labeling and file-naming systems that will uniquely identify the content and source of data.

3) Develop procedures for ensuring the integrity and physical security of all forms of data.

4) Develop a plan for analyzing the data, including the identification and documentation of time periods to be summarized, any transformations of the data, summary measures associated with the exposure model, and proposed descriptive and inferential analyses.

5) Develop a plan for reporting the methods and results of data analysis.

8.2.2 Subject Issues

The following activities should be considered to address subject issues:

1) Determine the organizational approvals required for participation of subjects (e.g., human subjects committee, employer consent, parent/guardian consent, simple consent form) and develop the applications and forms to obtain consent.

2) Develop the procedures necessary to maintain the confidentiality of subjects.

3) Develop clear, unambiguous PEM protocol instructions for the subjects.

4) Develop a plan and the to provide measurement data to subjects.

5) Develop PEM protocols that minimize the possibility of violations.

6) Perform pilot studies to test the demands of the protocols.

8.2.3 Quality Assurance

The following recommendations relate to establishing a quality assurance plan for an EMF PEM study:

1) Implement appropriate generally accepted procedures for the sampling process, data collection, data management, and data analysis

2) Implement a plan for verifying calibration and confirming the functionality of PEM meters on a regular basis.

3) Develop methods for assessing the consistency of the PEM and the completeness of all data soon after completion of the collection process.

4) Introduce automated and/or manual procedures for verifying the accuracy of the data entered into data bases.

5) Perform sufficient pilot studies to become provide confident in the validity and consistency of data collection processes prior to beginning measurements.

8.2.4 Uncertainty Evaluation

The following actions should be considered when performing an uncertainty evaluation for an EMF PEM study:

1) Determine whether the estimated uncertainty is acceptable in light of the study purpose.

2) Estimate the power of the study to detect differences in exposure given the estimated variability of PEM.

3) Plan to provide an estimate of overall observed uncertainty in the EMF PEM results.

4) Quantify the observed uncertainty introduced by various factors such as: sampling procedures, instrument imprecision, measurement processes, and other data collection efforts.

5) Implement validation procedures and obtain feedback from subjects to identify the presence of protocol violations and quantify, if possible, their impact on study results.

8.2.5 Archival Plan

The plan developed in the written study plan for archiving the raw data and intermediate work products along with the process-related materials associated with a project should be completed in detail. To accomplish this the investigator should consider the following activity:

1) Develop specific plans for archival of:
    a) raw data, including measurements and forms;
    b) processed data such as summaries and spreadsheets;
    c) study documents; and
    d) other study materials such as written protocols, instructions to subjects and data collectors, and software tools.

8.3 Pilot Studies

The recommended use of pilot studies to test and demonstrate protocols is pervasive in the specific guidelines. Therefore an explicit recommendation for EMF PEM studies is:

> Include pilot studies at <u>all levels</u> of the design process.

9

REFERENCES

B. Armstrong, G. Thériault, P. Guénel, J. Deadman, M. Goldberg, and P. Heroux, "Association Between Exposure to Pulsed Electromagnetic Fields and Cancer in Electric Utility Workers in Quebec, Canada, and France," *American Journal of Epidemiology*. Vol. 140, 9, pp. 805-820 (1994).

F. Barnes, H. Wachtel, D. Savitz, and J. Fuller, "Use of Wiring Configuration and Wiring Codes for Estimating Externally Generated Electric and Magnetic Fields," *Bioelectromagnetics*. Vol. 10, 1, pp. 13-21 (1989).

J. D. Bowman, E. Sobel, S. J. London, D. C. Thomas, D. H. Garabrant, N. Pearce, and J. M. Peters. *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. Electric Power Research Institute, Palo Alto, CA 1992.

M. B. Bracken, K. Belanger, K. Hellenbrand, L. Dlugosz, T. R. Holford, J.-E. McSharry, K. Addesso, and B. Leaderer, "Exposure to Electromagnetic Fields During Pregnancy With Emphasis On Electrically Heated Beds: Association With Birthweight and Intrauterine Growth Retardation," *Epidemiology*. Vol. 6, 3, pp. 263-270 (1995).

T. D. Bracken. *Comparison of Electrical Field Exposure Monitoring Instrumentation*. EPRI EA-4085, Project 799-19, Final Report, June 1985. Electric Power Research Institute, Palo Alto, CA 1985.

T. D. Bracken. *Analysis of BPA Occupational Electric Field Exposure Data*. Final Report. Bonneville Power Administration, Vancouver, WA 1986.

T. D. Bracken. *The EMDEX Project: Technology Transfer and Occupational Measurements, Volumes 1-3 Interim Report. EPRI Report EN-7048.* EPRI EN-7048. Electric Power Research Institute, Palo Alto, CA 1990.

T. D. Bracken, "Exposure Assessment for Power Frequency Electric and Magnetic Fields," *American Industrial Hygiene Association Journal.* Vol. 54, 4, pp. 165-177 (1993).

T. D. Bracken, P. Long, G. Rauch, R. Rankin, R. Senior, and F. Dietrich. *PG&E Lineworker EMF Monitoring Study: Final Report.* Pacific Gas & Electric Company, San Francisco, CA 1994a.

T. D. Bracken, R. F. Rankin, R. S. Senior, and J. R. Alldredge. *The EMDEX Project: Residential Study, Final Report.* Electric Power Research Institute, Palo Alto, CA 1994b.

T. D. Bracken, R. F. Rankin, R. S. Senior, J. R. Alldredge, and S. S. Sussman, "Magnetic Field Exposure Among Utility Workers," *Bioelectromagnetics.* Vol. 16, pp. 216-226 (1995).

P. Breysse, P. S. J. Lees, M. A. McDiarmid, and B. Curbow, "ELF Magnetic Field Exposures in an Office Environment," *American Journal of Industrial Medicine.* Vol. 25, 2, pp. 177-185 (1994a).

P. Breysse, G. Matanoski, E. Elliott, M. Francis, W. Kaune, and K. Thomas, "60 Hertz Magnetic Field Exposure Assessment for an Investigation of Leukemia in Telephone Lineworkers," *American Journal of Industrial Medicine.* Vol. 26, 5, pp. 681-691 (1994b).

C. E. Cartwright, P. N. Breysse, and L. Booher, "Magnetic Field Exposures in a Petroleum Refinery," *Applied Occupational and Environmental Hygiene.* Vol. 8, 6, pp. 587-592 (1993).

V. L. Chartier and T. D. Bracken. "Occupational Exposure of High-Voltage Workers to 60-Hz Electric Fields, Part 1: Exposure Instrumentation," *in: Interaction of Biological Systems With Static and ELF Electric and Magnetic Fields.* Twenty-third Hanford Life Sciences Symposium, October 2-4, 1984, Richland, WA. L. E. Anderson, B. J. Kelman, and R. J. Weigel, Editors. Pacific Northwest Laboratory, Richland, WA 1987, pp. 125-134.

W. G. Cochran. *Sampling Techniques.* 3rd. John Wiley & Sons, Inc., New York, NY 1977.

J. Cohen. *Statistical Power Analysis for the Behavioral Sciences.* 2nd. Lawrence Erlbaum Associates, Hillsdale, NJ 1988.

J. E. Deadman, M. Camus, B. G. Armstrong, P. Heroux, D. Cyr, M. Plante, and G. Thériault, "Occupational and Residential 60-Hz Electromagnetic Fields and High Frequency Electric Transients: Exposure Assessment Using a New Dosimeter," *American Industrial Hygiene Association Journal.* Vol. 49, 8, pp. 409-419 (1988).

V. Delpizzo, "Misclassification of ELF Occupational Exposure Resulting from Spatial Variation of the Magnetic Field," *Bioelectromagnetics.* Vol. 14, 2, pp. 117-130 (1993).

D. W. Deno, "Transmission Line Fields," *IEEE Transactions on Power Apparatus and Systems.* Vol. 76, pp. 1600-1611 (1976).

D. W. Deno, "Currents Induced in the Human Body By High Voltage Transmission Line Electric Field -- Measurement and Calculation of Distribution and Dose," *IEEE Transactions on Power Apparatus and Systems.* Vol. 96, 5, pp. 1517-1527 (1977).

D. W. Deno. "Monitoring of Personnel Exposed to a 60-Hz Electric Field," *in: Biological Effects of Extremely Low Frequency Electromagnetic Fields.* 18th Hanford Life Sciences Symposium, Richland, Wash., 1978. R. D. Phillips, Editor. Technical Information Center, U.S. Dept. of Energy, Springfield, VA 1979.

D. W. Deno and M. Silva, "Method for Evaluating Human Exposure to 60 Hz Electric Fields," *IEEE Transactions on Power Apparatus and Systems.* Vol. 103, 7, pp. 1699-1706 (1984).

F. M. Dietrich, W. E. Feero, D. C. Robertson, and R. M. Sicree. *Measurement of Power System Magnetic Fields By Waveform Capture.* EPRI Final Report TR-100061, February 1992. EPRI, Palo Alto, CA 1992.

Enertech Consultants. *EMDEX System Manuals, Volume 1: User's Manual.* EPRI EN-6518. Electric Power Research Institute, Palo Alto, CA 1989a.

Enertech Consultants. *EMDEX System Manuals, Volume 2: Technical Reference Manual.* EPRI EN-6518. Electric Power Research Institute, Palo Alto, CA 1989b.

EPA, "Guidelines for Exposure Assessment," *Federal Register.* Vol. 57, 104, pp. 22888-22889 (1992).

B. Floderus, T. Persson, C. Stenlund, G. Linder, C. Johansson, J. Kiviranta, H. Parsman, M. Lindblom, A. Wennberg, A. Ost, and B. Knave. *Occupational Exposure to Electromagnetic Fields in Relation to Leukemia and Brain Tumors: A Case-Control Study.* PM edition: National Institute of Occupational Health, Solna Sweden. Litohuset, Stockholm 1992.

F. Gamberale, B. Anshelm Olson, P. Eneroth, T. Lindh, and A. Wennberg, "Acute Effects of ELF Electromagnetic Fields: A Field Study of Linesmen Working With 400 KV Power Lines," *British Journal of Industrial Medicine.* Vol. 46, 10, pp. 729-737 (1989).

P. Guénel, J. Nicolau, E. Imbernon, G. Warret, and M. Goldberg, "Design of a Job Exposure Matrix On Electric and Magnetic Fields: Selection of an Efficient Job Classification for Workers in Thermoelectric Power Production Plants," *International Journal of Epidemiology*. Vol. 22, 6, pp. S16-S21 (1993).

J. L. Guttman, F. S. Young, and S. Sussman. "Frequency Response Characterization of the Positron Electromagnetic Dosimeter Pulsed Electromagnetic Field/High-Frequency Transient Channel," *in: 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., Editor. W/L Associates, Ltd., Frederick, MD 1994, p. 91.

N. C. Hawkins, M. A. Jayjock, and J. Lynch, "A Rationale and Framework for Establishing the Quality of Human Exposure Assessments," *American Industrial Hygiene Association Journal.* Vol. 53, 1, pp. 34-41 (1992).

D. L. Henshaw, A. N. Ross, A. P. Fews, and A. W. Preece, "Enhanced Deposition of Radon Daughter Nuclei in the Vicinity of Power Frequency Electromagnetic Fields," *International Journal of Radiation Biology.* Vol. 69, 1, pp. 25-38 (1996).

P. Heroux, "A Dosimeter for Assessment of Exposures to ELF Fields," *Bioelectromagnetics.* Vol. 12, 4, pp. 241-257 (1991).

IEEE. *IEEE Recommended Practice for Instrumentation: Specifications for Magnetic Flux Density and Electric Field Strength Meters--10 Hz to 3 KHz.* IEEE Std 1308-1994. Institute of Electrical and Electronics Engineers, Inc., IEEE, New York 1995.

IEEE AC Fields Working Group, "An Evaluation of Instrumentation Used to Measure AC Power System Magnetic Fields," *IEEE Transactions on Power Delivery*. Vol. 6, 1, pp. 373-383 (1991).

IEEE Power Engineering Society. *IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines*. IEEE Std. 644-1994 (Revision of IEEE Std. 644-1987). Institute of Electrical and Electronics Engineers, Inc., IEEE, New York 1995.

W. T. Kaune and L. E. Zaffanella. *Assessment of Children's Long-Term Exposure to Magnetic Fields (The Enertech Study)*. Electric Power Research Institute, Palo Alto, CA 1992.

W. T. Kaune and L. E. Zaffanella, "Assessing Historical Exposures of Children to Power-Frequency Magnetic Fields," *Journal of Exposure Analysis and Environmental Epidemiology*. Vol. 4, 2, pp. 149-170 (1994).

W. T. Kaune, J. C. Niple, M. J. Liu, and J. M. Silva, "Small Integrating Meter for Assessing Long-Term Exposure to Magnetic Fields," *Bioelectromagnetics*. Vol. 13, pp. 413-427 (1992).

W. T. Kaune, S. D. Darby, S. N. Gardner, Z. Hrubec, R. N. Iriye, and M. S. Linet, "Development of a Protocol for Assessing Time-Weighted-Average Exposures of Young Children to Power-Frequency Magnetic Fields," *Bioelectromagnetics*. Vol. 15, 1, pp. 33-51 (1994).

R. Kavet, J. M. Silva, and D. Thornton, "Magnetic Field Exposure Assessment for Adult Residents of Maine Who Live Near and Far Away from Overhead Transmission Lines," *Bioelectromagnetics*. Vol. 13, 1, pp. 35-55 (1992).

M. D. Koontz, L. L. Mehegan, F. M. Dietrich, and N. L. Nagda. *Assessment of Children's Long-Term Exposure to Magnetic Fields (The Geomet Study).* Electric Power Research Institute, Palo Alto, CA 1992.

H. Kromhout, D. P. Loomis, G. J. Mihlan, L. A. Peipins, R. C. Kleckner, R. Iriye, and D. A. Savitz. "Assessment and Grouping of Occupational Magnetic Field Exposure in Five Electric Utility Companies," *in: From Eyeballing to Statistical Modelling: Methods for Assessment of Occupational Exposure.* H. Kromhout, Editor. Ontwerp van Concepts Prepress, Utrecht 1994, pp. 151-173.

H. Kromhout, D. P. Loomis, G. J. Mihlan, L. A. Peipins, R. C. Kleckner, R. Iriye, and D. A. Savitz, "Assessment and Grouping of Occupational Magnetic Field Exposure in Five Electric Utility Companies," *Scandinavian Journal of Work, Environment and Health.* Vol. 21, 1, pp. 43-50 (1995).

F. Largarde, G. Pershagen, G. Akerblom, et al., "Residential Radon and Lung Cancer in Sweden: Risk Analysis Accounting for Radom Error in the Exposure Assessment," *Health Physics.* Vol. 72, pp. 269-276 (1997).

P. Levallois, D. Gauvin, J. St-Laurent, S. Gingras, and J. E. Deadman, "Electric and Magnetic Field Exposures for People Living Near a 735-Kilovolt Power Line," *Environmental Health Perspectives.* Vol. 103, 9, pp. 832-837 (1995).

S. J. London, D. C. Thomas, J. D. Bowman, E. Sobel, T. C. Cheng, and J. M. Peters, "Exposure to Residential Electric and Magnetic Fields and Risk of Childhood Leukemia," *American Journal of Epidemiology.* Vol. 134, 9, pp. 923-937 (1991).

D. P. Loomis, H. Kromhout, L. A. Peipins, R. C. Kleckner, R. Iriye, and D. A. Savitz, "Sampling Design and Field Methods of a Large, Randomized, Multisite Survey of Occupational Magnetic Field Exposure," *Applied Occupational and Environmental Hygiene.* Vol. 9, 1, pp. 49-52 (1994).

J. R. Lynch. "Measurement of Worker Exposure," *in: Patty's Industrial Hygiene and Toxicology.* L. V. Cralley, L. J. Cralley, Editors. John Wiley & Sons, New York 1979, pp. 217-255.

J. C. Male, W. T. Norris, and M. W. Watts. "Exposure of People to Power-Frequency Electric and Magnetic Fields," *in: Interaction of Biological Systems With Static and ELF Electric and Magnetic Fields.* Twenty-third Hanford Life-Sciences Symposium, October 2-4, 1984, Richland, WA. L. E. Anderson, B. J. Kelman, and R. J. Weigel, Editors. Pacific Northwest Laboratory, Richland, WA 1987, pp. 407-418.

G. M. Matanoski, P. Breysse, E. Elliott, G. I. Obrams, and M. Lynberg. *Leukemia in Telephone Linemen.* EPRI TR-101813, Project 2964-04, Final Report, December 1992. Electric Power Research Institute, Palo Alto, CA 1992.

C. J. Merchant, D. C. Renew, and J. Swanson. *Origins and Magnitudes of Exposure to Power-Frequency Magnetic Fields in the U.K.* National Grid Technology and Science Laboratories, Leatherhead, Surrey, U.K. 1994.

M. Misakian, G. K. Bell, T. D. Bracken, L. H. Fink, K. C. Holte, J. E. Hudson, G. B. Johnson, T. J. McDermott, R. C. Mukherji, R. G. Olsen, G. B. Rauch, S. A. Sebo, J. M. Silva, and P. S. Wong, "A Protocol for Spot Measurements of Residential Power Frequency Magnetic Fields," *IEEE Transactions on Power Delivery.* Vol. 8, 3, pp. 1386-1394 (1993).

D. J. Moschandreas, G. G. Akland, and S. M. Gordon, "The Measurement and Decomposition of Total Exposure Using the Total-Isolated-By-Microenvironment-Exposure (Time) Monitor," *Journal of Exposure Analysis and Environmental Epidemiology*. Vol. 4, 3, pp. 395-407 (1994).

W. C. Nelson, W. R. Ott, and J. P. Robinson. *The National Human Activity Pattern Survey (NHAPS)-Use of Nationwide Activity Data for Human Exposure.* EPA/600/A-94/147. NTIS PB94-197464. U.S. Environmental Protection Agency, Research Triangle Park, NC 1994.

NEMPG (National EMF Measurement Protocol Group). *Power Frequency Magnetic Fields: A Protocol for Conducting Spot Measurements. Part One: Background and Instructions.* Developed by NEMPG; sponsored by American Public Power Association, Edison Electric Institute, National Rural Electric Cooperative Association. NEMPG, Washington, DC 1993.

S. B. Peralta, G. K. Hatanaka, R. R. Scheer, and B. A. Pietrantonio. "Characterization of High Frequency Transient Channel from Electromagnetic Dosimeters," *in: 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., Editor. W/L Associates, Ltd., Frederick, MD 1994, p. 92.

G. Pershagen, G. Akerblom, O. Axelson, et al., "Residential Radon Exposure and Lung Cancer in Sweden," *New England Journal of Medicine.* Vol. 330, pp. 159-164 (1994).

K. L. Philips, M. T. Morandi, D. Oehme, and P. A. Cloutier, "Occupational Exposure to Low Frequency Magnetic Fields in Health Care Facilities," *American Industrial Hygiene Association Journal.* Vol. 56, 7, pp. 677-685 (1995).

P. H. Pretorius. "Assessment of the Historical Magnetic Field Dosages Received By Eskom's Live Line Maintenance Personnel," *in: Proceedings from ESMO-93: The Sixth International Conference On Transmission and Distribution Construction and Live Line Maintenance.* September 12-17, The Riviera Hotel, Las Vegas. D. G. Gela, Editor. The Institute of Electrical and Electronics Engineers, Inc., Piscataway, NJ 1993, pp. 105-116.

D. Rainer, E. Keramidas, R. Petersen, S. Dalal, H. Reinbold, L. Scudieri, G. Zeman, and A. McIntosh. *A Magnetic Field Exposure Measurement Program for the Telecommunications Industry.* Special Report SR-TSV-002341, Issue 1, June 1992. Bellcore and AT&T, New York 1992.

R. F. Rankin and T. D. Bracken. *Association of Wire Code Configuration With Long-Term Average 60-Hz Magnetic Field Exposure: Interim Report On Study Progress.* EPRI TR-104656, Research Project 3533-01, November 1994. EPRI, Palo Alto, CA 1994.

R. F. Rankin, T. D. Bracken, R. I. Kavet, and J. H. Montgomery, "Design and Measurement Protocols for a Multi-Site Study of Residential Magnetic Fields," *Journal of Exposure Analysis and Environmental Epidemiology.* Vol. Submitted for publication, ?, p. ? (1996).

G. B. Rauch, G. Chang, M. Keller, and T. D. Bracken. *Protocol for Measurement of Transmission and Distribution Line Workplace Magnetic Fields By Waveform Capture.* Presented at IEEE/PES Transmission and Distribution Conference, Chicago, IL April 10-15, 1994. IEEE, New York 1994.

D. C. Renew, J. C. Male, and B. J. Maddock. *Power-Frequency Magnetic Fields: Measurement and Exposure Assessment.* 36-105. CIGRE, Paris 1990.

J. D. Sahl, M. A. Kelsh, R. Smith, and D. E. Guggenheim. "Effects of Sampling Rate On Summary Measures for 60-Hertz Magnetic Fields Measured in Work Environments," *in: Project Resumes: The Annual Review of Research On Biological Effects of 50 and 60 Hz Electric and Magnetic Fields, Milwaukee, Wisconsin 30-7 November, 1991.* U.S. Department of Energy, Editor. W/L Associates Ltd., Frederick, MD 1991, pp. A-37.

J. D. Sahl, J. B. Scarfuto, M. A. Kelsh, J. Pinneo, and D. A. Aseltine. "Magnetic Field Exposures Among Electric Utility Workers: Consideration of Occupations, Job Tasks and Facility Type (Meeting Abstract)," *in: BEMS Abstract Book: Fifteenth Annual Meeting.* The Bioelectromagnetics Society, Editor. The Bioelectromagnetics Society, Frederick, MD 1993, pp. 54-55.

J. D. Sahl, M. A. Kelsh, R. W. Smith, and D. A. Aseltine, "Exposure to 60-Hz Magnetic Fields in the Electric Utility Work Environment," *Bioelectromagnetics.* Vol. 15, 1, pp. 21-32 (1994).

D. A. Savitz, T. Ohya, D. P. Loomis, R. S. Senior, T. D. Bracken, and R. L. Howard, "Correlations Among Indices of Electric and Magnetic Field Exposure in Electric Utility Workers," *Bioelectromagnetics.* Vol. 15, 3, pp. 193-204 (1994).

J. M. Silva. *AC Field Exposure Study: Human Exposure to 60-Hz Electric Fields. Interim Report.* Electric Power Research Institute, Palo Alto, CA 1985.

A. Silvers, B. T. Florence, D. L. Rourke, and R. J. Lorimor, "How Children Spend Their Time: A Sample Survey for Use in Exposure and Risk Assessments," *Risk Analysis.* Vol. 14, pp. 931-944 (1994).

J. Skotte. "Exposure to Power-Frequency Electromagnetic Fields in Occupational and Residential Environments in Denmark," *in: Electricity and Magnetism in Biology and Medicine.* Review and research papers presented at The First World Congress for Electricity and Magnetism in Biology and Medicine, Orlando, Florida, 1992. M. Blank, Editor. San Francisco Press, Inc., San Francisco 1993, pp. 868-870.

G. Thériault, M. Goldberg, A. B. Miller, and B. Armstrong. *Joint Electricite De France--Hydro-Quebec--Ontario Hydro Epidemiological Study On the Long Term Effects of Exposure to 50 and 60 Hertz Electric and Magnetic Fields.* Final report. Electricite de France, Hydro-Quebec, Ontario Hydro, Paris, Montreal, Toronto 1994a.

G. Thériault, M. Goldberg, A. B. Miller, B. Armstrong, P. Guénel, J. Deadman, E. Imbernon, T. To, A. Chevalier, D. Cyr, and C. Wall, "Cancer Risks Associated With Occupational Exposure to Magnetic Fields Among Electric Utility Workers in Ontario and Quebec, Canada, and France: 1970-1989," *American Journal of Epidemiology.* Vol. 139, 6, pp. 550-572 (1994b).

United States Environmental Protection Agency. *Exposure Factors Handbook.* Office of Health and Environmental Assessment, Washington, DC 1989.

D. R. Vogt. *A Study of the Domestic 50 Hz Magnetic Field Environment, and Adult Exposure to 50 Hz Magnetic Fields* Master of Science in Engineering. Thesis. University of the Witwatersrand, Johannesburg, South Africa. 1992.

T. B. Wenzl. *Estimating Worker Exposure to Power-Frequency Magnetic Fields.* Dissertation, University of Massachusetts, Lowell. University Microfilms International, Ann Arbor, MI 1992.

N. Wertheimer and E. Leeper, "Electrical Wiring Configurations and Childhood Cancer," *American Journal of Epidemiology.* Vol. 109, pp. 273-284 (1979).

N. Wertheimer and E. Leeper, "Adult Cancer Related to Electrical Wires Near the Home," *International Journal of Epidemiology*. Vol. 11, 4, pp. 345-355 (1982).

J. A. Wiley, J. P. Robinson, Y. T. Cheng, T. Piazza, L. Stork, and K. Pladsen. *Study of Children's Activity Patterns*. Contract No. A733-149, Final Report, September 1991. California Environmental Protection Agency, Sacramento 1991a.

J. A. Wiley, J. P. Robinson, T. Piazza, K. Garrett, K. Cirksena, Y. T. Cheng, and G. Martin. *Activity Patterns of California Residents*. Contract No. A6-177-33, Final Report, May 1991. California Environmental Protection Agency, Sacramento 1991b.

P. S. Wong. *60 Hz Electric Field Exposure Monitoring Program*. Report for B.C. Hydro, 23 October, 1992. Paul Wong International, Inc., Vancouver, BC 1992.

APPENDIX A

EMF Personal Exposure Measurement Literature Summaries

Citation:	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. (EPRI TR-101723, PROJECT 799-27, FINAL REPORT, DECEMBER 1992)
Setting:	Occupational (United States, New Zealand)
Purpose of study:	Exposure characterization, epidemiology
Measured parameter:	Electric field, magnetic field
Metric:	Personal exposure.
Sample:	Magnetic field measurements for 493 "electrical" workers and 163 "nonelectrical" workers; Electric field measurements for 135 "electrical" workers and 42 "nonelectrical" workers. 666 days of measurements.
Subject sampling:	Targeted to occupational category
Instrument model & manufacturer:	EMDEX (three versions: Types A, B, and C)
Type:	Time series data logger
Characteristics:	Magnetic fields; 0.1-255 mG (Type A), 0.1-2000 mG (Types B and C); 35-300 Hz
Sampling rate:	2.5-second intervals
Meter placement:	Placed in a cotton pouch on the waist.
Time-activity recordkeeping:	Observed & self-reported; Tasks were described by the worker and the observer.
Data collection protocols:	For each worker whose exposure was measured, an exposure monitoring sheet was filled out during the day by field personnel observing the worker, and a corresponding employee exposure monitoring sheet was filled out by the worker. For each task performed by the worker throughout the day, the start time, stop time, a task description, and comments were recorded.
Quality assurance:	Data sheets were keypunched using 100% double entry verification techniques, and then checked with computer programs for inconsistencies, missing values, and logical errors.
Distribution of data to subjects:	---
Analysis strategy:	By job category, by task using current and historic estimates of time spent in task.
Exposure indices	
Measures of central tendency:	Workday mean, geometric mean of workday means
Measures of peak or maximum:	---
Measures of variability:	Standard deviation
Indices specific to study:	Time above thresholds: >2.5 mG, >25 mG, >250 mG
Other recorded parameters:	Job category, task
Related citation:	LONDON et al. (1994): EXPOSURE TO MAGNETIC FIELDS AMONG ELECTRICAL WORKERS IN RELATION TO LEUKEMIA RISK IN LOS ANGELES COUNTY. AM. J. OF IND. MED. 26(1, JULY), 47-60.

Citation:	BRACKEN,MB; BELANGER,K; HELLENBRAND,K; DLUGOSZ,L; HOLFORD,TR; MCSHARRY,J-E; ADDESSO,K; LEADERER,B (1995): EXPOSURE TO ELECTROMAGNETIC FIELDS DURING PREGNANCY WITH EMPHASIS ON ELECTRICALLY HEATED BEDS: ASSOCIATION WITH BIRTHWEIGHT AND INTRAUTERINE GROWTH RETARDATION. EPIDEMIOLOGY 6(3, MAY) 263-270.
Setting:	Residential (United States)
Purpose of study:	Epidemiological
Measured parameter:	Magnetic field
Metric:	Survey measurements, long term fixed-location measurements, personal exposure.
Sample:	849 women completed monitoring program.
Subject sampling:	Targeted for women in cohort who used electrically heated beds; randomly selected from non-users of electrically heated beds in cohort
Instrument model & manufacturer:	AMEX-2 (EPRI, Palo Alto, CA) for personal exposure, EMDEX-C (EFM Co., West Stockbridge, MA) for survey and fixed-location measurements
Type:	Integrating single coil meter for personal exposure
Characteristics:	Magnetic field
Sampling rate:	---
Meter placement:	Worn on the wrist, placed on the bedside away from appliances at night.
Time-activity recordkeeping:	---
Data collection protocols:	The study population was interviewed and the respondents were asked to wear an AMEX-2, while awake, over the following 7 days. An EMDEX-C was placed in the center of a room on a chair or stool for a 24-hour measurement. Fields near the bed were calculated based on a model, time-weighted exposure was estimated. Each home was wire coded using the Wertheimer-Leeper protocol.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Examine electric bed use and EMF exposure as risk factors for pregnancy outcome
Exposure indices	
Measures of central tendency:	Seven day averages for single coil device stratified by group: <1 mG; 1.0-1.9 mG; ≥2 mG
Measures of peak or maximum:	≥2.0 mG
Measures of variability:	---
Indices specific to study:	Quartiles of modeled exposures for electric bed use
Other recorded parameters:	Wire code category, electric bed information, long-term fixed location measurement.
Related citation:	

Citation:	BRACKEN,TD (1986): ANALYSIS OF BPA OCCUPATIONAL ELECTRIC FIELD EXPOSURE DATA. (FINAL REPORT) BONNEVILLE POWER ADMINISTRATION, VANCOUVER, WA. 201 PAGES.
Setting:	Occupational (United States)
Purpose of study:	Exposure characterization
Measured parameter:	Electric field
Metric:	Personal exposure.
Sample:	3,098 workdays by 295 workers.
Subject sampling:	Opportunistic
Instrument model & manufacturer:	Electric Field Exposure Meter (EFEM) developed by Bonneville Power Administration.
Type:	Time spent in seven field intervals
Characteristics:	Electric field; 60 Hz
Sampling rate:	Average field every 4 seconds
Meter placement:	Worn in a shirt pocket.
Time-activity recordkeeping:	Self-reported in 10 categories.
Data collection protocols:	EFEM's and EFEM readers were kept at work locations. An EFEM was picked up by the employee from the battery charger at the beginning of each day and data began accumulating. The EFEM was worn on one location on the body for the whole day. At the end of the day, the counts in each bin were read out and recorded by the employee on the daily exposure card.
Quality assurance:	Forms were reviewed for obvious clerical errors. Data was entered and independently verified to eliminate keypunch errors. Other consistency checks were done on forms and data.
Distribution of data to subjects:	---
Analysis strategy:	Full shift, by task, by environment, within worker, between workers.
Exposure indices	
Measures of central tendency:	Mean, median of estimated accumulated daily exposure
Measures of peak or maximum:	Max. daily exp., 90 %ile
Measures of variability:	
Indices specific to study:	Cumulative exposure time in bins
Other recorded parameters:	Job category; environment; task; line voltage
Related citation:	WONG,PS (1992): 60 Hz ELECTRIC FIELD EXPOSURE MONITORING PROGRAM. PAUL WONG INTERNATIONAL, INC., VANCOUVER, B.C.;
Related citation:	CHARTIER,VL; BRACKEN,TD; CAPON,AS (1985): BPA STUDY OF OCCUPATIONAL EXPOSURE TO 60-Hz ELECTRIC FIELDS. IEEE TRANS. ON POWER APP. AND SYS. 104(3, MARCH), 733-744.
Related citation:	CHARTIER, VL; BRACKEN, TD (1987): OCCUPATIONAL EXPOSURE OF HIGH-VOLTAGE WORKERS TO 60-HZ ELECTRIC FIELDS, PART 1: EXPOSURE INSTRUMENTATION. IN: PROCEEDINGS OF 23RD HANFORD LIFE SCIENCES SYMPOSIUM, OCTOBER 2-4, 1984, RICHLAND, WA. PACIFIC NW LABORATORY, RICHLAND, WA, 125-134.
Related citation:	BRACKEN, TD; CHARTIER, VL (1987): OCCUPATIONAL EXPOSURE OF HIGH-VOLTAGE WORKERS TO 60-HZ ELECTRIC FIELDS, PART 2: ANALYSIS AND RESULTS. IN: PROCEEDINGS OF 23RD HANFORD LIFE SCIENCES SYMPOSIUM, OCTOBER 2-4, 1984, RICHLAND, WA PACIFIC NW LABORATORY, RICHLAND, WA, 395-405.

Citation:	BRACKEN,TD (1990): THE EMDEX PROJECT: TECHNOLOGY TRANSFER AND OCCUPATIONAL MEASUREMENTS, VOLUMES 1-3 INTERIM REPORT. (EPRI EN-7048) ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA.
Setting:	Occupational/Residential (United States; also Canada, Ireland, New Zealand)
Purpose of study:	Exposure characterization of utility workers
Measured parameter:	Electric field (E), magnetic field (B)
Metric:	Personal exposure.
Sample:	2082 days (E); 4382 days (B).
Subject sampling:	Opportunistic
Instrument model & manufacturer:	EMDEX-100 (EPRI, Palo Alto, CA), EMDEX-C (EFM Co., West Stockbridge, MA).
Type:	Time series
Characteristics:	Magnetic field: 60 Hz; electric field
Sampling rate:	Ten-second intervals
Meter placement:	Worn in a belt pouch, usually on the hip.
Time-activity recordkeeping:	Self-reported; Work environments: Substation, transmission, distribution, generation, office, shop, travel, other; Non-work environments: Home, travel, other. Data collection protocols: Field exposure data measured by an EMDEX system were collected by volunteer utility employees at 59 sites in the U.S. and three other countries between October 1988 and September 1989. Volunteers recorded in a simple logbook which of eight Work or three Nonwork environments they occupied.
Quality assurance:	All EMDEX units were formally calibrated 3 times during the project, monthly accuracy checks were made, and the functionality of the EMDEX was confirmed at each initialization. A variety of data quality assurance methods were used.
Distribution of data to subjects:	Determined by individual utility site.
Analysis strategy:	By primary work environment, by occupied environment, by job category, within worker, between workers.
Exposure indices	
Measures of central tendency:	Daily mean, daily median
Measures of peak or maximum:	Maximum, 95th percentile
Measures of variability:	Standard deviation
Indices specific to study:	---
Other recorded parameters:	Job category, primary work environment, occupied environment
Related citation:	BRACKEN et al. (1995): MAGNETIC FIELD EXPOSURE AMONG UTILITY WORKERS. BIOELECTROMAGNETICS 16, 216-226.
Related citation:	SAVITZ et al. (1994): CORRELATIONS AMONG INDICES OF ELECTRIC AND MAGNETIC FIELD EXPOSURE IN ELECTRIC UTILITY WORKERS. BIOELECTROMAGNETICS 15(3), 193-204.

Citation:	BRACKEN,TD; LONG,P; RAUCH,G; RANKIN,R; SENIOR,R; DIETRICH,F (1994): PG&E LINEWORKER EMF MONITORING STUDY. PACIFIC GAS & ELECTRIC CO., SAN FRANCISCO.
Setting:	Occupational (United States)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, survey measurements.
Sample:	1608 person-task observations; 1255 hours of personal exposure data within task.
Subject sampling:	Targeted for line workers performing live line tasks
Instrument model & manufacturer:	EMDEX-II (EnerTech Consultants, Campbell, CA), high and normal range instruments
Type:	Time series data logger
Characteristics:	Magnetic field; 0.1 to 3000 mG (normal range), 4 to 120,000 mG (high range); 40-80
Sampling rate:	1.5-second intervals
Meter placement:	Worn in a chest pouch secured by an over-the-shoulder strap.
Time-activity recordkeeping:	Observed; Bar code scanner used to identify work zone.
Data collection protocols:	Personal exposure data were obtained for lineworkers performing a variety of tasks. Observers recorded the lineworker's location, work method, and task. In addition, spot measurements were made under the span and current on the line was recorded.
Quality assurance:	During the course of PE data collection and management, numerous quality assurance measures were implemented and performed in the field, at data collection headquarters and at project headquarters.
Distribution of data to subjects:	A print-out of data was sent on request.
Analysis strategy:	Analyze measurements by task, by work zone, within worker, between workers
Exposure indices	
Measures of central tendency:	Mean, median of person-tasks
Measures of peak or maximum:	Average & absolute maximum for tasks
Measures of variability:	Standard deviation
Indices specific to study:	Time-integrated average exposure, exceedence fractions for tasks Other recorded parameters: Current on line, task, location, work method, voltage
Related citations:	BRACKEN, TD; RANKIN, RF; LONG, PJ; SENIOR, RS; KELLER, M; GRAY, WS (1994): PG&E LINEWORKER EMF MONITORING STUDY: PERSONAL EXPOSURE MEASUREMENTS. IN: PROJECT ABSTRACTS: THE ANNUAL REVIEW OF RESEARCH ON BIOLOGICAL EFFECTS OF ELECTRIC AND MAGNETIC FIELDS FROM THE GENERATION, DELIVERY & USE OF ELECTRICITY. (ED: W/L ASSOCIATES) W/L ASSOCIATES, LTD., FREDERICK, MD, 34-35.

Citation:	BRACKEN,TD; RANKIN,RF; SENIOR,RS; ALLDREDGE,JR (1994): THE EMDEX PROJECT: RESIDENTIAL STUDY, FINAL REPORT. ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA.
Setting:	Residential (United States, Canada)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, spot measurements, long term fixed-location measurements.
Sample:	1552 measurement visits at 396 houses, 448 days of personal exposure, 3014 days of long term fixed-location measurements.
Subject sampling:	Opportunistic among employees of 39 participating utilities
Instrument model & manufacturer:	EMDEX-100 (EPRI, Palo Alto, CA), EMDEX-C (EFM Co., West Stockbridge, MA), EMDEX-II (EnerTech Consultants, Campbell, CA)
Type:	Time series data logger
Characteristics:	Magnetic field; 40-60 Hz (EMDEX-100), 40-400 Hz (EMDEX-C), 40-800 Hz (EMDEX-II)
Sampling rate:	Ten-second intervals
Meter placement:	PE meter worn on the waist, placed over night next to long term meter in the most frequently occupied non-bedroom.
Time-activity recordkeeping:	Self-reported; Worn, not worn.
Data collection protocols:	Project site coordinators selected up to 12 employee volunteers at each of the 39 participating utilities to evaluate a total of 396 single-family residences. The coordinators made up to six measurement visits per residence over a 26-month period and attempted to enroll equal numbers in each of the five wire code categories. The data collected included point-in-time measurements and long term fixed-location measurements at various locations in each house as well as personal exposure measurements. Since the stratified sampling method introduced a known bias in the distribution of residences across wire codes, the coordinators conducted a supplementary sampling of 650 randomly selected residences to quantify this bias.
Quality assurance:	All forms were reviewed after each visit and before submission to headquarters. A functional check was performed on each EMDEX prior to initialization, and bi-monthly accuracy checks were made. Data plots were also reviewed.
Distribution of data to subjects:	---
Analysis strategy:	Summarize different types of measurements for a house by visit and across visits, analyze summary measures among types of measures and wire code categories
Exposure indices	
Measures of central tendency:	Arithmetic mean, median for houses by wire code category
Measures of peak or maximum:	Maximum, 95%ile
Measures of variability:	Standard deviation, range of visit means, between-visit variance, first difference
Indices specific to study:	First difference between successive measurements
Other recorded parameters:	Wire code category, electrical facility data, house information
Related citation:	

Citation:	BREYSSE,P; LEES,PSJ; MCDIARMID,MA; CURBOW,B (1994): ELF MAGNETIC FIELD EXPOSURES IN AN OFFICE ENVIRONMENT. AMERICAN JOURNAL OF EPIDEMIOLOGY 25:177-185.
Setting:	Occupational (United States)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, survey measurements.
Sample:	15 women, 15 work shifts.
Subject sampling:	Targeted for female employees in payroll department
Instrument model & manufacturer:	EMDEX-C (EFM Co., West Stockbridge, MA), EMDEX-II (EnerTech Consultants, Campbell, CA) for personal exposure; Survey meter: Monitor Industries 42B-1
Type:	Time series data logger
Characteristics:	Magnetic field; 40-400 Hz (EMDEX-C), 40-800 Hz (EMDEX-II)
Sampling rate:	15-second intervals
Meter placement:	Placed in a belted hip pouch, kept close to person if not worn.
Time-activity recordkeeping:	Observed: appliance and equipment use in work area noted to explain highest exposures.
Data collection protocols:	Survey measurements of the office were made, and 15 of the approximately 100 female workers wore an EMDEX C or EMDEX II for a full shift (5.8 to 8 hrs.).
Quality assurance:	Significantly higher fields were investigated for possible sources.
Distribution of data to subjects:	---
Analysis strategy:	Analyze full shift measurements for each worker, group workers for comparison with other workers
Exposure indices	
Measures of central tendency:	Time weighted average of full shift measurements, mean of time weighted average
Measures of peak or maximum:	Maximum
Measures of variability:	Standard deviation
Indices specific to study:	---
Other recorded parameters:	Work area
Related citation:	

Citation:	BREYSSE,P; MATANOSKI,G; ELLIOTT,E; FRANCIS,M; KAUNE,W; THOMAS,K (1994): 60 HERTZ MAGNETIC FIELD EXPOSURE ASSESSMENT FOR AN INVESTIGATION OF LEUKEMIA IN TELEPHONE LINEWORKERS. AM. J. OF IND. MED. 26(5, NOVEMBER), 681-691.
Setting:	Occupational/Residential (United States)
Purpose of study:	Epidemiology
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	204 days.
Subject sampling:	Opportunistic of telephone lineworkers at six facilities
Instrument model & manufacturer:	EMDEX-C (EFM Co., West Stockbridge, MA)
Type:	Time series data logger
Characteristics:	Magnetic field; 40-400 Hz
Sampling rate:	Ten-second intervals
Meter placement:	Worn on the waist.
Time-activity recordkeeping:	Observed; work and non-work, work on lineworker tasks and other work noted on data sheet.
Data collection protocols:	Industrial hygiene measurements of the magnetic fields associated with work activities in different jobs were obtained. Fifteen to 61 individuals in each category participated in personal monitoring wearing the EMDEX-C, which recorded fields at 10-second intervals in the 60 Hertz range. Measurements were also made on 34 employees while off the job in order to evaluate nonwork exposure levels. All measurements were taken under present working conditions.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Daily mean exposure by job category
Exposure indices	
Measures of central tendency:	Mean, median of daily exposures
Measures of peak or maximum:	Maximum, 95%ile
Measures of variability:	Standard deviation, absolute sequential difference, first lag auto correlation coefficients
Indices specific to study:	Avg. time above background (>3.2 mG)
Other recorded parameters:	Work location
Related citation:	MATANOSKI et al. (1992): LEUKEMIA IN TELEPHONE LINEMEN. ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA.
Related citation:	MATANOSKI et al. (1993): LEUKEMIA IN TELEPHONE LINEMEN. AM. J. EPIDEM. 137(6), 609-619.

Citation:	CARTWRIGHT,CE; BREYSSE,PN; BOOHER,L (1993): MAGNETIC FIELD EXPOSURES IN A PETROLEUM REFINERY. APPL OCCUP ENVIRON HYG 8(6), 587-592.
Setting:	Occupational/Residential (United States)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, survey measurements.
Sample:	48 workers, 39 locations. 48 days occupational/17 days non-occupational exposure.
Subject sampling:	Targeted for refinery electrical workers
Instrument model & manufacturer:	EMDEX-C (EFM Co., West Stockbridge, MA); Holaday ELF survey meter.
Type:	Time series
Characteristics:	Magnetic field; – Hz
Sampling rate:	--- (not reported)
Meter placement:	Carried upright in a pouch in front of the waist next to the body.
Time-activity recordkeeping:	Self-reported; Participants were asked to make a note of what equipment they were working near, and when they took lunch or breaks. Nonwork: Appliance use.
Data collection protocols:	Workers wore the EMDEX during 8-hour shifts, and 17 workers made additional home measurements. Area measurements were made at 9 sites in the refinery and at 30 randomly selected sites in the community.
Quality assurance:	Monitored individuals were checked two to three times per shift to ensure that dosimeters were in working order and being worn properly. The EMDEX-Cs were collected at the end of the shift and downloaded promptly.
Distribution of data to subjects:	---
Analysis strategy:	Full shift magnetic fields by job category, by worker for high exposure task
Exposure indices	
Measures of central tendency:	Arithmetic and geometric mean, median of full-shift measurements
Measures of peak or maximum:	Maximum, 90%ile
Measures of variability:	Arithmetic and geometric standard deviation of full-shift measurements
Indices specific to study:	10, 25, 75%iles
Other recorded parameters:	Job category
Related citation:	

Citation:	DEADMAN,JE; CAMUS,M; ARMSTRONG,BG; HEROUX,P; CYR,D; PLANTE,M; THERIAULT,G (1988): OCCUPATIONAL AND RESIDENTIAL 60-HZ ELECTROMAGNETIC FIELDS AND HIGH FREQUENCY ELECTRIC TRANSIENTS: EXPOSURE ASSESSMENT USING A NEW DOSIMETER. AM. IND. HYG. ASSOC. J. 49 (8), 409-419.
Setting:	Occupational/Residential (Canada)
Purpose of study:	Exposure characterization, methodological
Measured parameter:	Electric field, magnetic field, high frequency transients
Metric:	Personal exposure.
Sample:	36 volunteers for – one week.
Subject sampling:	Opportunistic
Instrument model & manufacturer:	Pocket-sized, battery-operated dosimeter
Type:	Time series
Characteristics:	Electric & magnetic fields: 50-60 Hz; transient electric field 5-20 MHZ
Sampling rate:	Once a minute
Meter placement:	Worn next to the body, placed near bed at night away from field sources.
Time-activity recordkeeping:	Self-reported; Subjects reported task/activity, start/stop time, work site, potential sources of exposure, and exact location of dosimeter. Data collection protocols: All participants were asked to wear a dosimeter during a one-week period, from the moment that they dressed after waking up, while at work, and at home until going to bed. They were instructed to place the dosimeter near the bed during the night, away from any point source of E, B and HFTE fields. Workers were also asked to record their activities on daily log sheets.
Quality assurance:	All instruments were extensively calibrated prior to deployment. Written instructions concerning the study, the wearing of the dosimeter, and precautions for avoiding unrepresentative readings were provided.
Distribution of data to subjects:	---
Analysis strategy:	Time weighted average for week; Full shift, by task, by environment, within-person, between-person.
Exposure indices	
Measures of central tendency:	Arithmetic mean within week, geometric mean across weeks
Measures of peak or maximum:	Maximum
Measures of variability:	Geometric standard deviation across weeks
Indices specific to study:	Time-weighted average for week
Other recorded parameters:	Job titles
Related citation:	HEROUX,P (1991): A DOSIMETER FOR ASSESSMENT OF EXPOSURES TO ELF FIELDS. BIOELECTROMAGNETICS 12(4), 241-257.

Citation:	DELPIZZO,V (1993): MISCLASSIFICATION OF ELF OCCUPATIONAL EXPOSURE RESULTING FROM SPATIAL VARIATION OF THE MAGNETIC FIELD. BIOELECTROMAGNETICS 14(2), 117-130.
Setting:	Occupational
Purpose of study:	Methodological
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	41 workers, each wearing a meter in six different locations on the body for 2 hours in workplace. 10-11 days total time
Subject sampling:	Targeted for four occupational groups
Instrument model & manufacturer:	AMEX-3D.(EnerTech Consultants, Campbell, CA)
Type:	Integrating
Characteristics:	Magnetic field; 35-1000 Hz
Sampling rate:	---
Meter placement:	Each subject wore six meters, at the head, chest, abdomen, hip, knee, ankle
Time-activity recordkeeping:	---
Data collection protocols:	Each worker wore the meter for approximately two hours in the work environment.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Integrated exposure by meter locations by occupational category, comparison of hip and chest exposures with whole body average exposure
Exposure indices	
Measures of central tendency:	Mean, median of average exposure
Measures of peak or maximum:	75%ile
Measures of variability:	Standard error of mean
Indices specific to study:	Tertiles, misclassification rates
Other recorded parameters:	Job category
Related citation:	KAUNE et al. (1992): SMALL INTEGRATING METER FOR ASSESSING LONG-TERM EXPOSURE TO MAGNETIC FIELDS. BIOELECTROMAGNETICS 13, 413-427.

Citation:	FLODERUS,B; PERSSON,T; STENLUND,C; LINDER,G; JOHANSSON,C; KIVIRANTA,J; PARSMAN,H; LINDBLOM,M; WENNBERG,A; OST,A; KNAVE,B (1992): OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS IN RELATION TO LEUKEMIA AND BRAIN TUMORS: A CASE-CONTROL STUDY. PM EDITI
Setting:	Occupational/Residential (Sweden)
Purpose of study:	Epidemiology, exposure characterization for occupational case/control study
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	850 cases of leukemia and brain tumors & 1700 controls. 1015 days of exposure
Subject sampling:	Subject or surrogate in same job
Instrument model & manufacturer:	EMDEX-100 (EPRI, Palo Alto, CA), EMDEX-C (EFM Co., West Stockbridge, MA).
Type:	Time series
Characteristics:	Magnetic field; 0.01 µT to 2.5 mT; 50 Hz
Sampling rate:	One-second intervals
Meter placement:	Worn on the waist.
Time-activity recordkeeping:	---
Data collection protocols:	Subjects wore the EMDEX around the waist for a representative workday, and for at least six consecutive hours. Sampling interval was set to 1 second.
Quality assurance:	Calibration at 50 Hz was performed every second month.
Distribution of data to subjects:	---
Analysis strategy:	By job category, between workers.
Exposure indices	
Measures of central tendency:	Arithmetic mean for day, median
Measures of peak or maximum:	Time above 0.20 uT, 90%ile
Measures of variability:	Standard deviation, standard error
Indices specific to study:	Quartiles of average work day
Other recorded parameters:	Job category, age
Related citation:	

Citation:	GAMBERALE,F; ANSHELM OLSON,B; ENEROTH,P; LINDH,T; WENNBERG,A (1989): ACUTE EFFECTS OF ELF ELECTROMAGNETIC FIELDS: A FIELD STUDY OF LINESMEN WORKING WITH 400 KV POWER LINES. BR. J. IND. MED 46(10), 729-737.
Setting:	Occupational (Sweden)
Purpose of study:	Exposure characterization for acute effects study
Measured parameter:	Electric field (E), magnetic field (B)
Metric:	Personal exposure.
Sample:	26 volunteers, two working days each. 22 days(E), 22 days(B)
Subject sampling:	Targeted for specific tasks
Instrument model & manufacturer:	BE-log dosimeter
Type:	Time series
Characteristics:	Magnetic & electric fields; 0.2-200 uT; 0-30 kV/m; 50 Hz
Sampling rate:	Fifteen-second intervals
Meter placement:	Back pack with electric field sensor on hardhat.
Time-activity recordkeeping:	Observed; Simulated inspection of insulators, lunch.
Data collection protocols:	Twenty-six experienced linesmen, aged 25 to 52, were studied during two working days while performing a simulated routine inspection of insulators on steel poles of a 400 kV power line. The powerline was in operation one of the days, and turned off the other day.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	By task, within worker.
Exposure indices	
Measures of central tendency:	Workday mean
Measures of peak or maximum:	---
Measures of variability:	Range of means
Indices specific to study:	---
Other recorded parameters:	Activity
Related citation:	LINDH,T AND ANDERSSON,LI (1988): COMPARISON BETWEEN TWO POWER-FREQUENCY ELECTRIC-FIELD DOSIMETERS. SCAND. J. WORK ENVIRON. HEALTH 14 (SUPPL. 1), 43-45.

Citation:	GUÉNEL,P; NICOLAU,J; IMBERNON,E; WARRET,G; GOLDBERG,M (1993) DESIGN OF A JOB EXPOSURE MATRIX ON ELECTRIC AND MAGNETIC FIELDS: SELECTION OF AN EFFICIENT JOB CLASSIFICATION FOR WORKERS IN THERMOELECTRIC POWER PRODUCTION PLANTS. INTL. J. EPIDEM. 22(6, SUPPL. 2) S16-S21.
Setting:	Occupational (France)
Purpose of study:	Exposure characterization, methodological
Measured parameter:	Electric field, magnetic field
Metric:	Personal exposure.
Sample:	297 workers, 1259 work days
Subject sampling:	Workers at eight randomly-selected generation plants were randomly selected.
Instrument model & manufacturer:	Positron (Positron Industries, Montreal, Quebec, Canada)
Type:	Time series data logger
Characteristics:	Magnetic & electric fields stored in 16 field intervals; 0 to >10000 V/m; 0 to >20
Sampling rate:	One-minute intervals
Meter placement:	Worn in the shirt pocket or at the belt.
Time-activity recordkeeping:	---
Data collection protocols:	Measurements were performed for one full week per worker. Among approximately 50 thermoelectric power plants in the utility, eight were selected at random. All workers in the same plant were measured during the same week. For each plant 20-40 workers were randomly selected for participation. Additionally office workers working outside power plants and gas workers of the utility were included in the survey as a reference group with background exposure to EMF.
Quality assurance:	Dosimeters were tested and calibrated before each use. Each worker's exposure profile was carefully examined and a few were excluded because of dosimeter malfunction.
Distribution of data to subjects:	---
Analysis strategy:	Time weighted average for full shift analyzed by plant, type of plant, occupation. Analysis on log-transformed data within- and between-worker variance; within- and between-group variance
Exposure indices	
Measures of central tendency:	Geometric mean of full-shift averages
Measures of peak or maximum:	---
Measures of variability:	Geometric standard deviation
Indices specific to study:	Ratio of within- and between-worker variance
Other recorded parameters:	---
Related citation:	HEROUX,P (1991): A DOSIMETER FOR ASSESSMENT OF EXPOSURES TO ELF FIELDS. BIOELECTROMAGNETICS 12(4), 241-257.

Citation:	KAUNE,WT; DARBY,SD; GARDNER,SN; HRUBEC,Z; IRIYE,RN; LINET,MS (1994): DEVELOPMENT OF A PROTOCOL FOR ASSESSING TIME-WEIGHTED-AVERAGE EXPOSURES OF YOUNG CHILDREN TO POWER-FREQUENCY MAGNETIC FIELDS. BIOELECTROMAGNETICS 15(1, ED: GREENEBAUM,B.), 33-51.
Setting:	Residential (United States)
Purpose of study:	Methodological
Measured parameter:	Magnetic field
Metric:	Personal exposure, survey measurements, 24-h fixed-location measurements.
Sample:	29 children, 29 days.
Subject sampling:	Opportunistic for children from families of employees of study participants
Instrument model & manufacturer:	AMEX-3D (EnerTech Consultants, Campbell, CA) for personal exposure; EMDEX-C (EFM Co., West Stockbridge, MA) for survey and fixed-location measurements.
Type:	Integrating meter for accumulated exposure
Characteristics:	Magnetic field
Sampling rate:	---
Meter placement:	Worn in pouches sewn to suspenders or belts, or in fabric cubes near infant
Time-activity recordkeeping:	Observed by parents; own bedroom, other bedroom, family room, living room, kitchen, bathroom 1, other bathroom, dining area, basement, front door, front yard, back yard, other
Data collection protocols:	Each child wore meters for 24 hours on a typical weekday, one meter at home, and a second meter at school or daycare. Locations were recorded in activity diaries. Spot and long-term measurements were made at each home and school or daycare with an EMDEX-C.
Quality assurance:	While the details of the protocol were being explained to the parents, the children were encouraged to become familiar with the meter. Neon cards at entrances reminded subjects to change meters, and diaries were reviewed.
Distribution of data to subjects:	---
Analysis strategy:	Compare time weighted average of personal exposure with other measurements by location
Exposure indices	
Measures of central tendency:	Time weighted average personal exposure, arithmetic and geometric mean across residences
Measures of peak or maximum:	
Measures of variability:	Arithmetic and geometric standard deviation
Indices specific to study:	Time spent at various locations
Other recorded parameters:	Location, parents' education levels, wire code category of house
Related citation:	KAUNE et al. (1992): SMALL INTEGRATING METER FOR ASSESSING LONG-TERM EXPOSURE TO MAGNETIC FIELDS. BIOELECTROMAGNETICS 13, 413-427.

Citation:	KAUNE,WT; ZAFFANELLA,LE (1992): ASSESSMENT OF CHILDREN'S LONG-TERM EXPOSURE TO MAGNETIC FIELDS (THE ENERTECH STUDY). ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA. 156 PAGES.
Setting:	Residential (United States)
Purpose of study:	Methodological, exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, spot measurements, 24-h fixed location.
Sample:	35 homes; 35 children, 70 days (two visits, six months apart).
Subject sampling:	Targeted for external sources and ground currents
Instrument model & manufacturer:	AMEX-3D (EnerTech Consultants, Campbell, CA); STAR; STAR/VANA.
Type:	Integrating
Characteristics:	Magnetic field; 0.2 mG to 150 mG; 60 Hz
Sampling rate:	---
Meter placement:	Worn on wrist, placed at foot of bed while asleep, on counter while bathing.
Time-activity recordkeeping:	Self-reported; Two AMEXs used, one while at home, one while at school.
Data collection protocols:	Two AMEX-3D meters and instructions on their use were left with the parent. Parents were asked to place one meter, marked Residential, on the subjects whenever they were not in school. Immediately prior to going to school, the parents were asked to exchange the residential meter with the second meter, marked School. Meters were turned on only when being worn by subjects.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	By environment, within child, between children.
Exposure indices	
Measures of central tendency:	Time weighted average for individual visit; mean and geometric mean of visits; median
Measures of peak or maximum:	---
Measures of variability:	Standard deviation, geometric standard deviation for daily means
Indices specific to study:	---
Other recorded parameters:	Environment, wire code, residential power consumption, utility load
Related citation:	KAUNE,WT AND ZAFFANELLA,LE (1994): ASSESSING HISTORICAL EXPOSURES OF CHILDREN TO POWER-FREQUENCY MAGNETIC FIELDS. J. EXP. ANAL. AND ENV. EPID. 4(2, APRIL-JUNE), 149-170.
Related citation:	KAUNE et al. (1992): SMALL INTEGRATING METER FOR ASSESSING LONG-TERM EXPOSURE TO MAGNETIC FIELDS. BIOELECTROMAGNETICS 13, 413-427.

Citation:	KAVET,ROBERT; SILVA,J MICHAEL; THORNTON,DAVID (1992): MAGNETIC FIELD EXPOSURE ASSESSMENT FOR ADULT RESIDENTS OF MAINE WHO LIVE NEAR AND FAR AWAY FROM OVERHEAD TRANSMISSION LINES. BIOELECTROMAGNETICS 13(1), 35-55.
Setting:	Residential (United States)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, 24-h fixed location, spot measurements.
Sample:	45 adult residents of Maine for 45 days.
Subject sampling:	Targeted
Instrument model & manufacturer:	EMDEX meter (EPRI, Palo Alto, CA) for personal exposure measurements.
Type:	Time series
Characteristics:	Magnetic field; 35-300 Hz
Sampling rate:	Six-second intervals
Meter placement:	Worn on the belt, placed at the foot of the bed when not worn.
Time-activity recordkeeping:	Self-reported; At home, away from home.
Data collection protocols:	Sixty-Hz magnetic field exposures were measured for 45 adult residents of Maine. Thirty of the subjects resided near rights-of-way with either 345- and 115-kV transmission lines, or with only 115-kV transmission lines; fifteen resided far from any transmission lines. Personal exposure data for a single 24-hour period was acquired with the EMDEX. The EMDEX's event-marker button was used to partition exposures into Home and Away components.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	By environment, by wire code category.
Exposure indices	
Measures of central tendency:	Mean within subject, across subjects: at home, away from home, 24-h
Measures of peak or maximum:	---
Measures of variability:	Standard deviation
Indices specific to study:	---
Other recorded parameters:	Wire code category, sex
Related citation:	

Citation:	KOONTZ,MD; MEHEGAN,LL; DIETRICH,FM; NAGDA,NL (1992): ASSESSMENT OF CHILDREN'S LONG-TERM EXPOSURE TO MAGNETIC FIELDS (THE GEOMET STUDY). ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA. 152 PAGES.
Setting:	Residential (United States)
Purpose of study:	Methodological, exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, 48 and 96 h fixed location monitoring for some subjects.
Sample:	28 children in two age groups (8-11 and younger than 4). Two consecutive days with second visit to some subjects; 80 days total.
Subject sampling:	Census tracts were selected based on highest drive-through field measurements and subjects in the tract were solicited by telephone.
Instrument model & manufacturer:	EMDEX (EPRI, Palo Alto, CA) for older children; AMEX and EMDEX for younger children; small, computer-based ERM meters.
Type:	Time series (EMDEX), integrating (AMEX)
Characteristics:	Magnetic field; 30-300 Hz
Sampling rate:	Ten-second intervals
Meter placement:	Worn on the waist, EMDEX carried by parent for young children.
Time-activity recordkeeping:	Self-reported/observed (parent); At home in bed, at home not in bed, at school, at day care center, another building, travel, outside, doing errands.
Data collection protocols:	The children were recruited from four different geographic areas to provide a range of exposure potential. Twelve subjects were personally monitored on two consecutive days in the 1990-1991 winter season and the 1991 spring season; the remaining children were personally monitored on two consecutive days in one of the seasons.
Quality assurance:	Calibration of EMDEX and AMEX monitors was performed in accordance with the ANSI/IEEE standard.
Distribution of data to subjects:	A summary of the research results were provided to participants.
Analysis strategy:	By environment, within child, between children, day-to-day and seasonal variability.
Exposure indices	
Measures of central tendency:	48-h mean
Measures of peak or maximum:	Maximum
Measures of variability:	Standard deviation, standard error, range, 90th minus 10th percentile
Indices specific to study:	Mean between events, percent above 2 mG
Other recorded parameters:	Wire code category
Related citation:	KOONTZ,MD AND DIETRICH,FM (1994): VARIABILITY AND PREDICTABILITY OF CHILDREN'S EXPOSURE TO MAGNETIC FIELDS. J. EXP. ANAL. AND ENV. EPID. 4(3, JULY-SEPTEMBER), 287-307..
Related citation:	KAUNE et al. (1992): SMALL INTEGRATING METER FOR ASSESSING LONG-TERM EXPOSURE TO MAGNETIC FIELDS. BIOELECTROMAGNETICS 13, 413-427

Citation:	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), 43-50.
Setting:	Occupational (United States)
Purpose of study:	Epidemiological
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	2865 workshifts for 2196 workers.
Subject sampling:	Random selection of utility workers from three personal exposure groups
Instrument model & manufacturer:	AMEX-3D (EnerTech Consultants, Campbell, CA)
Type:	Integrating cumulative exposure
Characteristics:	Magnetic field
Sampling rate:	---
Meter placement:	Worn on a pouch around the waist.
Time-activity recordkeeping:	Meter turned on and off at beginning and end of work shift.
Data collection protocols:	All current workers at each company were placed into occupational categories, and individuals within those company-occupational category cells were randomly selected for measurement. A meter was mailed to the selected worker. Each worker was asked to wear an AMEX for one day's work shift. As each meter was returned, it was read and sent out to the next eligible worker.
Quality assurance:	Among the 4,094 attempted measurements, data were lost due to worker absence, worker refusal, procedural errors, instrument failure, failure to meet the calibration criteria, and work shifts of <4 or >12 hours. Programmed algorithms checked for missing or out-of-range values, logical consistency and data entry errors.
Distribution of data to subjects:	---
Analysis strategy:	Analysis of full shift means within group and between groups
Exposure indices	
Measures of central tendency:	Arithmetic and geometric means of time weighted average
Measures of peak or maximum:	95% confidence interval
Measures of variability:	Population standard error, geometric standard deviation, range of individual measurements, within- and between-worker variance
Indices specific to study:	Ratio of 97.5th and 2.5th percentiles
Other recorded parameters:	Job category
Related citation:	SAVITZ,DA AND LOOMIS,DP (1995): MAGNETIC FIELD EXPOSURE IN RELATION TO LEUKEMIA AND BRAIN CANCER MORTALITY AMONG ELECTRIC UTILITY WORKERS. AM. J. EPIDEM. 141(2), 123-134.
Related citation:	LOOMIS et al. (1994): SAMPLING DESIGN AND FIELD METHODS OF A LARGE, RANDOMIZED, MULTISITE SURVEY OF OCCUPATIONAL MAGNETIC FIELD EXPOSURE. APPL. OCC. ENV. HYG. 9(1), 49-52.
Related citation:	LOOMIS et al. (1994): ORGANIZATION AND CLASSIFICATION OF WORK HISTORY DATA IN INDUSTRY-WIDE STUDIES: AN APPLICATION TO THE ELECTRIC POWER INDUSTRY. AM. J. OF IND. MED. 26(3), 413-425.
Related citation:	KAUNE et al. (1992): SMALL INTEGRATING METER FOR ASSESSING LONG-TERM EXPOSURE TO MAGNETIC FIELDS. BIOELECTROMAGNETICS 13, 413-427.

Citation:	LEVALLOIS,P; GAUVIN,D; St-LAURENT,J; GINGRAS,S; DEADMAN,JE (1995): ELECTRIC AND MAGNETIC FIELD EXPOSURES FOR PEOPLE LIVING NEAR A 735-KILOVOLT POWER LINE. ENV. HEALTH PERSP. 103(9, SEPTEMBER) 832-837.
Setting:	Residential (Canada)
Purpose of study:	Exposure characterization
Measured parameter:	Electric field, magnetic field
Metric:	Personal exposure
Sample:	35 adults; 35 days.
Subject sampling:	Targeted for persons living adjacent to 735-kV transmission line
Instrument model & manufacturer:	Positron 378108 (Positron Industries, Montreal, Quebec, Canada)
Type:	Time series data logger records field in one of 16 field intervals
Characteristics:	Magnetic & electric fields; 60 Hz
Sampling rate:	One-minute intervals
Meter placement:	Worn in a pocket, placed close to bed away from sources while asleep.
Time-activity recordkeeping:	Self-reported; At home (waking, sleeping), at work, away from home and work.
Data collection protocols:	Exposure of 18 adults, mostly white-collar workers, living in different bungalows located 190-240 feet from a 735-kV transmission line (exposed subjects) was compared to that of 17 adults living in similar residences far away from any transmission line. Each subject carried a Positron meter for 24 hr during 1 workday, which measured 60-Hz electric and magnetic fields every minute.
Quality assurance:	Meters were calibrated from the start and quality control procedures were ensured during the study. Accuracy of magnetic field measurements were assessed with different levels of emitted magnetic fields.
Distribution of data to subjects:	---
Analysis strategy:	Analyze arithmetic mean exposures of individuals by group and by location
Exposure indices	
Measures of central tendency:	Arithmetic mean, median, geometric mean of arithmetic means within group
Measures of peak or maximum:	Maximum
Measures of variability:	95% confidence interval, percentage of adjacent minutes with measurements differing by at least one bin
Indices specific to study:	Percentage of time above thresholds: 2 mG, 7.8 mG, 20 V/m
Other recorded parameters:	Location, wire code category
Related citation:	HEROUX,P (1991): A DOSIMETER FOR ASSESSMENT OF EXPOSURES TO ELF FIELDS. BIOELECTROMAGNETICS 12(4), 241-257.

Citation:	MALE,JC; NORRIS,WT; WATTS,MW (1987): EXPOSURE OF PEOPLE TO POWER-FREQUENCY ELECTRIC AND MAGNETIC FIELDS. IN: INTERACTION OF BIOLOGICAL SYSTEMS WITH STATIC AND ELF ELECTRIC AND MAGNETIC FIELDS. (TWENTY-THIRD HANFORD LIFE-SCIENCES SYMPOSIUM, OCTOBER 2
Setting:	Occupational/Residential (United Kingdom)
Purpose of study:	Exposure characterization
Measured parameter:	Electric field
Metric:	Personal exposure, spot measurements.
Sample:	287 transmission and distribution workers, measured over two week period with a single-band integrating monitor; 47 workers measured over six day period with a four-band time-histogram monitor. 2870 work days total.
Subject sampling:	Opportunistic
Instrument model & manufacturer:	Small Integrating electric field meter developed by Don Deno.
Type:	Integrating
Characteristics:	Electric field; 50 Hz
Sampling rate:	---
Meter placement:	Worn in an armband sleeve on the upper arm.
Time-activity recordkeeping:	---
Data collection protocols:	Results were obtained for 287 workers, each of whom wore a dosimeter during working hours for a 2-week period. One hundred sixty-six were transmission workers, dealing with plant at 132 kV, 275 kV and 400 kV. The remaining 121 were distribution workers dealing with plant at 132 kV and below.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Between job categories.
Exposure indices	
Measures of central tendency:	Mean and median daily exposure
Measures of peak or maximum:	Maximum
Measures of variability:	
Indices specific to study:	Integrated daily exposure
Other recorded parameters:	Job category, transmission/distribution workers
Related citation:	

Citation:	MERCHANT,CJ; RENEW,DC; SWANSON,J (1994): ORIGINS AND MAGNITUDES OF EXPOSURE TO POWER-FREQUENCY MAGNETIC FIELDS IN THE U.K. NATIONAL GRID TECHNOLOGY AND SCIENCE LABORATORIES, LEATHERHEAD, SURREY, U.K. 8 P.
Setting:	Occupational/Residential (United Kingdom)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	258 electric utility employees, ~214 weeks.
Subject sampling:	Opportunistic among utility personnel
Instrument model & manufacturer:	Positron dosimeter (Positron Industries, Montreal, Quebec, Canada).
Type:	Time series
Characteristics:	Magnetic field; 50 Hz
Sampling rate:	One-minute intervals
Meter placement:	Worn on a belt or strap, placed in bedroom >1 m from appliances at night.
Time-activity recordkeeping:	Self-reported; At home in bed, up-and-about at home, out (not at work or traveling to work), traveling to work, at work, not worn (other than in bed).
Data collection protocols:	Personal exposure monitoring with activity diaries was conducted, and simultaneous long term static measurements were also made at home.
Quality assurance:	Plots of field against time were examined in detail for validity and consistency against well-defined rules, and any anomalies were followed up. Only records which contained >=3 days of credible data are included.
Distribution of data to subjects:	---
Analysis strategy:	Analyses performed on time weighted average of individual's measurements: by environment, by job site, by job description
Exposure indices	
Measures of central tendency:	Arithmetic and geometric means of time weighted averages, mean and median of weekly exposure
Measures of peak or maximum:	95%ile, maximum weekly exposure
Measures of variability:	Ratio: 5th to 95th percentile
Indices specific to study:	---
Other recorded parameters:	Wire code category, home type, job title, job site
Related citation:	HEROUX,P (1991): A DOSIMETER FOR ASSESSMENT OF EXPOSURES TO ELF FIELDS. BIOELECTROMAGNETICS 12(4), 241-257.

Citation:	PHILIPS,KL; MORANDI,MT; OEHME,D; CLOUTIER,PA (1995): OCCUPATIONAL EXPOSURE TO LOW FREQUENCY MAGNETIC FIELDS IN HEALTH CARE FACILITIES. AM. IND. HYG. ASSOC. J. 56(7, July) 677-685.
Setting:	Occupational (United States)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Survey measurements, spot measurements, personal exposure.
Sample:	5 workers at two health care facilities, ~19 hours.
Subject sampling:	Targeted for health workers in specific high field areas
Instrument model & manufacturer:	EMDEX-II (EnerTech Consultants, Campbell, CA) SPECLITE (Innovation Inc., Houston, TX).
Type:	Time series data loggers; EMDEX-II records resultant fields, SPECLITE records frequency spectra
Characteristics:	Magnetic field; broadband 40-800 Hz for EMDEX-II; 40-1000 Hz in 30 frequency bands for SPECLITE
Sampling rate:	1.5 and 3-second intervals for EMDEX-II, one-minute interval for SPECLITE
Meter placement:	Both monitors worn on a pouch around the waist horizontally stacked.
Time-activity recordkeeping:	Observed; Temporal and spatial work patterns were noted to understand observations.
Data collection protocols:	Survey and spot measurements were made in work environments at two hospitals. Personal exposure measurements were made during actual working conditions for 5 health care workers in 3 job categories.
Quality assurance:	The factory calibrations and response of both dosimeters were verified using a square coil.
Distribution of data to subjects:	---
Analysis strategy:	Analyze full shift by environment, time-weighted average, and frequency spectra of cumulative exposure.
Exposure indices	
Measures of central tendency:	Arithmetic and geometric mean within worker and across workers, cumulative exposure within worker
Measures of peak or maximum:	Maximum
Measures of variability:	Time course plots of recorded fields
Indices specific to study:	Number of excursions per hour above thresholds: >10 mG, >20 mG
Other recorded parameters:	Work area
Related citation:	

Citation:	PRETORIUS,PH (1993): ASSESSMENT OF THE HISTORICAL MAGNETIC FIELD DOSAGES RECEIVED BY ESKOM'S LIVE LINE MAINTENANCE PERSONNEL. IN: PROCEEDINGS FROM ESMO-93: THE SIXTH INTERNATIONAL CONFERENCE ON TRANSMISSION AND DISTRIBUTION CONSTRUCTION AND LIVE LIN
Setting:	Occupational (South Africa)
Purpose of study:	Methodology (pilot study)
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	Pilot study of 10 live line workers. –46.5 hours
Subject sampling:	Targeted for live line workers
Instrument model & manufacturer:	Positron 378100 (Positron Industries, Montreal, Quebec, Canada); CATLOG (recorded time spent in 4 categories).
Type:	Time series data logger
Characteristics:	Magnetic field stored in 16 field intervals; 0 to >200 uT
Sampling rate:	Five-second intervals
Meter placement:	Worn in a pouch around the waist.
Time-activity recordkeeping:	Self-entered during measurements; CATLOG recorded time spent on ground, on tower, on conductor, elsewhere. Historical records of time and tasks performing live line work.
Data collection protocols:	Live line workers' exposure to magnetic fields was measured during work on operating transmission lines. Log sheets kept by the workers provided historical information about the time spent and the amount of shifts worked during live line operations.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Exposure time and fields by location; historical annual exposures generated from contemporaneous measurements and crew log sheets
Exposure indices	
Measures of central tendency:	Mean within worker and across workers
Measures of peak or maximum:	Maximum
Measures of variability:	Standard deviation
Indices specific to study:	Minimum, time spent in peak field
Other recorded parameters:	---
Related citation:	HEROUX,P (1991): A DOSIMETER FOR ASSESSMENT OF EXPOSURES TO ELF FIELDS. BIOELECTROMAGNETICS 12(4), 241-257.

Citation:	RAINER,D; KERAMIDAS,E; PETERSEN,R; DALAL,S; REINBOLD,H; SCUDIERI,L; ZEMAN,G; MCINTOSH,A (1992): A MAGNETIC FIELD EXPOSURE MEASUREMENT PROGRAM FOR THE TELECOMMUNICATIONS INDUSTRY. (SPECIAL REPORT SR-TSV-002341, ISSUE 1, JUNE 1992) BELLCORE AND AT&T,
Setting:	Occupational/Residential (United States)
Purpose of study:	Exposure characterization of telephone employees
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	Over 1200 hours of monitoring data from 249 workers on the job and 29 persons in non-work environments. 319 work days, 29 non-work days.
Subject sampling:	Random
Instrument model & manufacturer:	EMDEX-C (EFM Co., West Stockbridge, MA)
Type:	Time series
Characteristics:	Magnetic field; 0.1 mG to 25 G (dynamic range); 30-400 Hz
Sampling rate:	Three-second intervals
Meter placement:	Worn on a belt around the waist, placed next to the bed at night.
Time-activity recordkeeping:	Observed; Telecom. vault, Power utility pole, Customer premise (res. or business), Central office, Work center, Work area protect. setup, Travel, Lunch/break, Other.
Data collection protocols:	Key elements of the study included: Monitoring worker exposures . . . ; A random sampling of workers in the telephone industry (The sampling scheme was designed so that the resulting data could be taken as representative of the industry as a whole); Correlation of exposure intensity with work environment (This was done by filling out machine readable logs of the job tasks performed by each worker during the time the exposure was being monitored); Monitoring worker exposures off the job.
Quality assurance:	A Helmholtz coil calibration system was used. The database software checked for data errors and anomalies.
Distribution of data to subjects:	--
Analysis strategy:	By work environment, within worker, between workers.
Exposure indices	
Measures of central tendency:	Arithmetic mean of workday time weighted averages
Measures of peak or maximum:	Percentiles up to 99
Measures of variability:	Standard error
Indices specific to study:	--
Other recorded parameters:	Environment
Related citation:	

Citation:	RENEW,DC; MALE,JC; MADDOCK,BJ (1990): POWER-FREQUENCY MAGNETIC FIELDS: MEASUREMENT AND EXPOSURE ASSESSMENT. (36-105) CIGRE, PARIS. 8 P.
Setting:	Residential/occupational (United Kingdom)
Purpose of study:	Exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, long-term fixed location.
Sample:	44 volunteers from utility (at time of writing 200 subjects planned) wore meter for one week.
Subject sampling:	Opportunistic
Instrument model & manufacturer:	Dosimeter developed by Institut de Recherche d'HydroQuebec, Montreal, Quebec, Canada (IREQ).
Type:	Sequential storage of field values in 16 logarithmic scaled bins
Characteristics:	Magnetic & electric fields: 50 Hz; high frequency transient electric fields
Sampling rate:	Once a minute
Meter placement:	The PE monitor is placed next to the static monitor over night.
Time-activity recordkeeping:	Self-reported; 5 activity categories: At home in bed, at home up, traveling to/from work, at work, out.
Data collection protocols:	Each volunteer wears one exposure monitor continuously (except while in bed) for a one-week period and leaves a second one in his bedroom for the same period. Each volunteer is given a diary to complete, which allows the measurements to be classified into five activity categories. . . . The home of each volunteer is also visited by a Magnetic Environment Research Vehicle t make outdoor measurements of currents and fields from which indoor fields and exposures will be estimated.
Quality assurance:	The calibration procedures used for the IREQ monitors conform to the ANSI/IEEE Standard. The bin thresholds are calibrated to within +- 2% using a square field coil and instruments with calibrations traceable to NAMAS stds.
Distribution of data to subjects:	---
Analysis strategy:	By environment, by neighborhood, by job site, within worker, between worker, comparison with fixed location measurement.
Exposure indices	
Measures of central tendency:	Time weighted average of rms magnetic field
Measures of peak or maximum:	Maximum
Measures of variability:	Log. standard deviation, range of fields, time in field intervals
Indices specific to study:	Logarithmic exposure index
Other recorded parameters:	Job category, neighborhood, house type, job site
Related citation:	HEROUX,P (1991): A DOSIMETER FOR ASSESSMENT OF EXPOSURES TO ELF FIELDS. BIOELECTROMAGNETICS 12(4), 241-257.

Citation:	SAHL,SD; KELSH,MA; SMITH,RW; ASELTINE,DA (1994): EXPOSURE TO 60 Hz MAGNETIC FIELDS IN THE ELECTRIC UTILITY WORK ENVIRONMENT. BIOELECTROMAGNETICS 15(1), 21-32.
Setting:	Occupational (United States)
Purpose of study:	Exposure characterization for a cancer mortality study
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	770 days, 42378 hours (??).
Subject sampling:	Targeted for craft occupations in 4 utility work environments
Instrument model & manufacturer:	EMDEX-II (EnerTech Consultants, Campbell, CA)
Type:	Time series data logger
Characteristics:	Magnetic field; 40-800 Hz; 0.01-555.5 uT
Sampling rate:	1.5-second intervals
Meter placement:	Worn at the waist.
Time-activity recordkeeping:	Full shift in 1991; bar code scanner was used by subjects in 1992 to record tasks.
Data collection protocols:	The meter was worn at the waist for the full shift. Each worker participated for the full day. A small number of generating station workers participated for consecutive days; otherwise, volunteers participated for only one day.
Quality assurance:	Data were checked . . . . Each data set was labeled, augmented with supplementary occupational and demographic information, and copied. Meters were calibrated at the start, middle, and end of the study. Reliability between meters was checked at the start of each sampling day . . . .
Distribution of data to subjects:	Each volunteer was given an opportunity to review his data.
Analysis strategy:	Data was pooled for occupational categories
Exposure indices	
Measures of central tendency:	Mean, median, geometric mean for occupational category
Measures of peak or maximum:	95%ile, 99%ile
Measures of variability:	Standard deviation
Indices specific to study:	Fraction exceeding 0.5, 1, 5, 10, and 100 uT
Other recorded parameters:	Job category
Related citation:	SAHL et al. (1993): COHORT AND NESTED CASE-CONTROL STUDIES OF HEMATOPOIETIC CANCERS AND BRAIN CANCER AMONG ELECTRIC UTILITY WORKERS. EPIDEMIOLOGY 4(2, MARCH), 104-114.
Related citation:	SAHL, JC; KELSH, MA; SMITH, R; GUGGENHEIM, DE (1991): EFFECTS OF SAMPLING RATE ON SUMMARY MEASURES FOR 60-HERTZ MAGNETIC FIELDS MEASURED IN WORK ENVIRONMENTS. IN: PROJECT ABSTRACTS: THE ANNUAL REVIEW OF RESEARCH ON BIOLOGICAL EFFECTS OF 50 AND 60 HZ ELECTRIC AND MAGNETIC FIELDS, W/L ASSOCIATES LTD., FREDERICK, MD, A-37.
Related citation:	SAHL, JD; SCARFUTO, JB; KELSH, MA; PINNEO, J; ASELTINE, DA (1993): MAGNETIC FIELD EXPOSURES AMONG ELECTRIC UTILITY WORKERS: CONSIDERATION OF OCCUPATIONS, JOB TASKS AND FACILITY TYPE (MEETING ABSTRACT). IN: FIFTEENTH ANNUAL MEETING. THE BIOELECTROMAGNETICS SOCIETY, FREDERICK, MD, 54-55.

Citation:	SILVA,JM (1985): AC FIELD EXPOSURE STUDY: HUMAN EXPOSURE TO 60-Hz ELECTRIC FIELDS. INTERIM REPORT. ELECTRIC POWER RESEARCH INSTITUTE, PALO ALTO, CA. (REPORT EPRI EA-3993)
Setting:	Occupational/Recreational (United States)
Purpose of study:	Exposure characterization, methodological
Measured parameter:	Electric field
Metric:	Personal exposure.
Sample:	~725 peformances of various activities.
Subject sampling:	Targeted
Instrument model & manufacturer:	Vest made of conductive cloth with integrating sensors.
Type:	Integrating
Characteristics:	Electric field; 0-10 kV/m, 0-1 kV/m, 0.2-2 kV/m; Linear response down to ~0.1V/m
Sampling rate:	---
Meter placement:	Worn on torso.
Time-activity recordkeeping:	Observed; A large variety of farming and recreational activities were investigated.
Data collection protocols:	Electric field exposures were measured for various activities at sites throughout the U.S. An activity systems model was developed to evaluate the exposures for specific activities and locations.
Quality assurance:	The computer model used to compute the results treats all information as if i were deterministic rather than stochastic, and makes the assumption that all errors of calculation and data cancel out.
Distribution of data to subjects:	---
Analysis strategy:	By activity and environment.
Exposure indices:	
Measures of central tendency:	Mean, cumulative exposure for activity
Measures of peak or maximum:	Maximum, cumulative exposure for activity
Measures of variability:	Range
Indices specific to study:	Time spent in various field ranges
Other recorded parameters:	Activity; location; Transmission line voltage
Related citation:	DENO,DW AND SILVA,M (1984): METHOD FOR EVALUATING HUMAN EXPOSURE TO 60 Hz ELECTRIC FIELDS. IEEE TRANS. ON POWER APP. AND SYS. 103(7, JULY), 1699-1706.

Citation:	SKOTTE,J (1993): EXPOSURE TO POWER-FREQUENCY ELECTROMAGNETIC FIELDS IN OCCUPATIONAL AND RESIDENTIAL ENVIRONMENTS IN DENMARK. In: ELECTRICITY AND MAGNETISM IN BIOLOGY AND MEDICINE. ED: BLANK,M. SAN FRANCISCO PRESS, INC. SAN FRANCISCO, CA. 868-870.
Setting:	Occupational/Residential (Denmark)
Purpose of study:	Exposure characterization
Measured parameter:	Electric field, magnetic field
Metric:	Personal exposure.
Sample:	301 volunteers, 396 24-h measurements.
Subject sampling:	Opportunistic for electric utility workers and other groups
Instrument model & manufacturer:	Positron (Positron Industries, Montreal, Quebec, Canada)
Type:	Time series data logger records field in one of 16 field intervals
Characteristics:	Magnetic & electric fields; 0.012-200 uT, 0.6-10,000 V/m; 50 Hz; high frequency tr
Sampling rate:	Five-second intervals
Meter placement:	Worn in a belt, removed while asleep.
Time-activity recordkeeping:	Self-reported; At workplace, at home, sleeping, traveling/shopping/etc., 20 work environments for utility workers
Data collection protocols:	PE monitors were worn for 24-hour periods, and activity diaries were kept by the volunteers indicating time in each of 4 general environments and 20 work environments.
Quality assurance:	The dosimeters were tested for calibration, linearity, frequency response, directivity, timing, etc.
Distribution of data to subjects:	---
Analysis strategy:	Analysis of means for individuals for different general environments, by proximity of home to transmission lines
Exposure indices	
Measures of central tendency:	Arithmetic and geometric mean of individual workday means
Measures of peak or maximum:	95%ile
Measures of variability:	Range: 5th to 95th percentile
Indices specific to study:	---
Other recorded parameters:	Proximity to transmission lines
Related citation:	

Citation:	THERIAULT,G; GOLDBERG,M; MILLER,AB; ARMSTRONG,B; GUENEL,P; DEADMAN,J; IMBERNON,E; TO,T; CHEVALLIER,A; CYR,D; WALL,C: 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), 550-572.
Setting:	Occupational (Canada, France)
Purpose of study:	Epidemiology
Measured parameter:	Magnetic field
Metric:	Personal exposure.
Sample:	2,066 workers measured for personal exposure, 1332 weeks.
Subject sampling:	Targeted to achieve representative sample of workers within job category
Instrument model & manufacturer:	Positron 378108 (Positron Industries, Montreal, Quebec, Canada); IREQ meter (prototype of Positron developed by Institut de Recherche d'Hydro-Quebec,
Type:	Time series data logger records field in one of 16 field intervals
Characteristics:	Magnetic field; 50 Hz, 60 Hz
Sampling rate:	One-minute intervals
Meter placement:	Worn on the belt or in a shirt pocket.
Time-activity recordkeeping:	Self-reported; Type, location, and timing of activities, voltages, currents, work techniques, main activities outside work.
Data collection protocols:	A case-control study nested within three cohorts of electrical utility workers at three utilities in Canada and France. Personal exposure measurements were taken for current workers, and a job exposure matrix was derived for the cases. Workers wore a meter for a 5-day work week.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Time weighted average of work time fields by job category, estimates of historical changes in exposure, exposures for individuals constructed from job-exposure matrix
Exposure indices	
Measures of central tendency:	Arithmetic and geometric means of weekly arithmetic means within job category
Measures of peak or maximum:	95% confidence interval
Measures of variability:	Arithmetic and geometric standard deviation
Indices specific to study:	—
Other recorded parameters:	Job title, activity
Related citation:	THERIAULT et al. (1994): JOINT ELECTRICITE DE FRANCE--HYDRO-QUEBEC--ONTARIO HYDRO EPIDEMIOLOGICAL STUDY ON THE LONG TERM EFFECTS OF EXPOSURE TO 50 AND 60 HERTZ ELECTRIC AND MAGNETIC FIELDS (FINAL REPORT). ELECTRICITE DE FRANCE, HYDRO-QUEBEC, ONTARIO HYDRO, PARIS, MONTREAL, TORONTO.

Citation:	WENZL,TB (1992): ESTIMATING WORKER EXPOSURE TO POWER-FREQUENCY MAGNETIC FIELDS. DISSERTATION, UNIVERSITY OF MASSACHUSETTS, LOWELL. UNIVERSITY MICROFILMS INTERNATIONAL, ANN ARBOR, MI.
Setting:	Occupational (United States)
Purpose of study:	Epidemiology, exposure characterization
Measured parameter:	Magnetic field
Metric:	Personal exposure, spot measurements.
Sample:	81 automobile workers; 82 workdays.
Subject sampling:	Opportunistic among automobile plant workers and targeted for demagnetizers.
Instrument model & manufacturer:	EMDEX-C (EFM Co., West Stockbridge, MA)
Type:	Time series data logger
Characteristics:	Magnetic field; 60 Hz
Sampling rate:	Four-second intervals
Meter placement:	Worn on the waist.
Time-activity recordkeeping:	Observed through post-shift interviews; Patterns of use of specific strong magnetic field sources such as demagnetizers.
Data collection protocols:	For a case-control study of brain cancer at a large automobile transmission plant, a strategy was developed to use 2 types of instruments to measure personal exposure to power-frequency magnetic fields. A representative group of 81 workers were asked to wear a data-logging dosimeter for one-half shift apiece. To test a simpler measurement strategy, a hand-held direct-reading instrument was also used, with multiple measurements taken at the head and waist for most workstations.
Quality assurance:	---
Distribution of data to subjects:	---
Analysis strategy:	Within worker, between workers
Exposure indices	
Measures of central tendency:	One-minute averages, half-shift averages, arithmetic and geometric means of one-minute averages
Measures of peak or maximum:	Exceedence factors: >3 mG, >10 mG, 95%ile
Measures of variability:	Percent of adjacent minutes with difference greater than 5 mG, geometric standard deviation
Indices specific to study:	---
Other recorded parameters:	Job category
Related citation:	WENZL,TB et al. (1995): COMPARISONS BETWEEN MAGNETIC FIELD EXPOSURE INDICES IN AN AUTOMOBILE TRANSMISSION PLANT. AM. IND. HYG. ASSOC. J. 56, 341-348.
Related citation:	WENZL, TB; KRIEBEL, D; EISEN, EA; MOURE-ERASO, R (1995): A COMPARISON OF TWO METHODS FOR ESTIMATING AVERAGE EXPOSURE TO POWER-FREQUENCY MAGNETIC FIELDS. APPLIED OCCUPATIONAL AND ENVIRONMENTAL HYGIENE 10 2, FEBRUARY. ZIEGLER, SE, 125-130.

Citation:	WONG,PS (1992): 60 HZ ELECTRIC FIELD EXPOSURE MONITORING PROGRAM. (REPORT FOR B.C. HYDRO, 23 OCTOBER, 1992) PAUL WONG INTERNATIONAL, INC., VANCOUVER, BC. 56 PAGES.
Setting:	Occupational (Canada)
Purpose of study:	Exposure characterization
Measured parameter:	Electric field
Metric:	Personal exposure.
Sample:	Sixteen electricians, each producing an average of 11 man-days of exposure data per month. 1000 days
Subject sampling:	Opportunistic
Instrument model & manufacturer:	Electric Field Exposure Meter (EFEM) (developed by Bonneville Power Administration).
Type:	Time accumulated in nine field intervals
Characteristics:	Electric field; 0 to >36 kV/m in nine intervals; 60 Hz ac
Sampling rate:	Average field every 4 seconds
Meter placement:	Worn in a shirt pocket.
Time-activity recordkeeping:	Self-reported; AC transmission line work (on ground, above ground, de-energized), AC substation yard work (on ground, above ground, de-energized), office/shop/travel/other.
Data collection protocols:	The electricians were requested to wear the EFEM daily and to answer simple questions on a data card at the end of each working day. The questions cover estimated time spent in switchyards with energized and/or de-energized equipment, energized equipment voltage, status of outer clothing, number of nuisance shocks received and EFEM readings. At the end of each two-week period, the collected data cards were forwarded to the R & D Laboratories.
Quality assurance:	69 data cards were rejected because of meaningless EFEM readings and different EFEM sensitivities. Each EFEM was calibrated in the R & D Laboratories.
Distribution of data to subjects:	--
Analysis strategy:	By voltage level across workers.
Exposure indices	
Measures of central tendency:	Mean and median daily accumulated exposure
Measures of peak or maximum:	Maximum, 95%ile
Measures of variability:	Standard deviation
Indices specific to study:	Daily exposure time >0.4 kV/m
Other recorded parameters:	Location, activity, voltage
Related citation:	BRACKEN,TD (1986): ANALYSIS OF BPA OCCUPATIONAL ELECTRIC FIELD EXPOSURE DATA (FINAL REPORT). BONNEVILLE POWER ADMINISTRATION, VANCOUVER, WA.

APPENDIX B

Analysis of Time-activity Survey Data

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Analysis of Time-activity Survey Data

The analysis of data on human activity patterns can be useful in the identification and selection of exposure components— environments, locations and activities — to be included in EMF PEM studies. Toward that end, we examined two probability-based surveys which provide time, location and activity data for a broad sample of adults and children. These surveys were conducted in California during the period 1987-1991 under the sponsorship of the California Air Resources Board (CARB). They are similar with respect to the goals and contents of the University of Michigan's time-activity surveys described in EPA's Exposure Factor Handbook [United States Environmental Protection Agency, 1989]..

Table B.1 gives a summary of the main characteristics of the two ARB surveys. The reader is referred to the published reports for more information about the sampling strategy and field procedures [Wiley et al., 1991a, b]. A summary of the content of each survey is shown in Attachment B1.

The CARB surveys are notable for their combination of probability sampling from a large residential population—persons living in California households-- and computerized telephone interviewing that employs a 24-hour retrospective time-activity diary. Although these surveys were designed to yield population estimates of exposure to air pollutants, they provide possible models for survey identification of important EMF exposure components, as well as survey estimates of EMF exposures for individuals and population aggregates.

The full text of the question used to elicit diary information in the first survey is given below. [This question was modified slightly for the adult informants and 9-11 year olds interviewed in the children's survey.]

"Now, more specifically about how you spent your time YESTERDAY, I'd like to ask you to start with midnight, night before last, and go through the entire 24 hours ending at midnight last night. For each thing you did during that period, I'll be asking you to tell me:

- What you were doing,
- Where you were, and
- What time you turned to something else.

Please tell me about everything you did yesterday in the same order it happened. There shouldn't be any gaps in time between activities."

Responses to these questions were recorded verbatim along with begin and end times. In some cases, the interviewers were allowed to use precoded activity and location categories. After data reduction and coding, the data files for the two surveys included over 100 distinct activity codes, 44 distinct location codes in the adult/teenager survey and 60 location codes in the survey of children. The coding of activities and locations at work lacks detail so that inferences about occupational exposures are necessarily uncertain.

The time-diary responses were intended to provide measures for the analysis of individual and group variations in potential exposure to air pollutants. Because the diary did not attempt to elicit information about exposures directly, inferences about exposure from diary data alone require linkage with other databases containing information about air pollutants present at certain locations and during certain activities. The questionnaire also contained questions -not connected with the diary— about exposure to specific sources of air pollution during the 24 hour period (e.g., use of aerosols, paint products, etc.). The content of the specific exposure questions is indicated in Attachment B1.

Our use of these data in the context of planning EMF PEM studies is motivated by three considerations. First, our analyses of aggregate activities and locations according to subject characteristics illustrate the kind of information that EMF-focused diary surveys are likely to provide. Linked with data on EMF sources pertaining to various locations and activities, the diary information provides the basis for an inference about personal and group variations in EMF exposure. Second, the aggregation demonstrates the construction of measures of possible EMF exposure from activities that involve electric appliances of various kinds. In the CARB data, these pertain to appliance and equipment use in non-work activities and environments. Third, these surveys provide a possible model for how the survey time-diaries might be used, with appropriate modifications, to study variations in potential EMF exposure in the general population.

Recoding of Diary Activities and Locations Used in the CARB Surveys

Our reanalysis of the CARB data uses aggregate codes for both activities and locations. Each aggregate code corresponds to a variable, defined as the number of minutes on the diary day spent doing an aggregate activity or in an aggregate location. These time spent variables sum to 1440 minutes (=24 hours) over all activities (or locations) for each person in the sample. The rules used to combine activities and locations are given in Attachment B2.

The groupings were constructed to a) provide a small number of recognizable categories of locations and activities which b) were occupied or done often enough to justify an analysis of individual or group variations. Table B.2 gives the names of the aggregate activity and location codes for each survey and lists the corresponding variable labels used in the text and tables of Attachments B2 and B3.

Methods of Analysis

Distributions of time spent in aggregate activities and locations were estimated separately for the two surveys and for various subdivisions of the samples. For the purposes of this report, the subgroups were distinguished by gender, age (18-24, 25-34, 35-44, 45-54, and 55+ for adults, 12-14 and 15-17 for teenagers, and 0-2, 3-4, 5-7, and 8-11 for children), type of residence (house, apartment, and other), area (rural, suburban, city), and enrolled in a school (for children only). The distributions of these characteristics in the two surveys are given in Part I of Attachment B3.

The cases in each survey were weighted to adjust for season, day of the week, and unequal probabilities of selection. Variations in the probability of selection are due to different sampling fractions in the geographic strata, differences in numbers of phone lines, and differences in household size.

The summary measures used to describe the distributions of time spent were i) the arithmetic mean, ii) the median, iii) the standard deviation, and iv) the percent of respondents reporting non-zero times. No significance tests or standard errors of estimate are reported. The small number of cases with missing data with respect to demographic characteristics were eliminated from the analysis.

Overview of the Results

The paragraphs below describe the largest and most consistent differences observed among the population subgroups chosen for this analysis. Of these, differentials by age and gender are clearly the most important and the most readily interpretable. For additional details, the reader should consult Attachment B3, Part II, which shows the tables on which this brief account is based.

Gender Differences: Differences between men and women generally follow a pattern which is consistent with the social roles of the sexes. Adult men spend more time at work, more time traveling, and more time outdoors than adult women. Women spend more time at home and at other non-work indoor locations. Smaller versions of these differences occur in the teenage years as well, but they virtually disappear among children. Gender contrasts in locations follow suit, with adult women spending more time in the home, especially the kitchen, and men spending more time away from home and in travel locations. These differences are muted among the younger members of the sample.

Age Differences: These too follow a pattern which is related to differences in activities corresponding to life stages. Time devoted to school activities increase with age until maturity, where it drops nearly to zero. Work time increases with age past puberty, levels off, and finally drops among the oldest respondents as they leave the labor force. Away-from-home activities increase steadily until young adulthood and then remain stationary. The oldest in the sample have a distinctive profile of time use in comparison with other adults: less time at work, more time at home indoors and out, and less time in travel. Correlations between location and age generally confirm this pattern. A mildly curvilinear relation between age and time spent (average number of minutes in the diary day) at home in the kitchen is shown below in Figure B1.

Differences by Type of Residence and Type of Environment: Both survey samples are skewed toward residence in houses rather than apartments. With a few exceptions, differences in activity and location patterns by type of residence do not appear to be significant. Persons living in houses do spend more time outside and in outside activities at all ages than persons living in apartments. Type of environment---rural versus suburban versus urban---has surprisingly little association with time spent in the activity and location categories used for this analysis. However, one difference appears among adult, teenage and child samples: persons living in rural areas spend more time in activities and locations coded as outdoors-at-home.

Possible EMF Exposures in Everyday Non-Work Settings

The activity codes used for the CARB survey provide an opportunity to construct a summary measure of possible EMF exposures related to use of appliances in non-work settings, most often in the home. A variable labeled "POSSEMF" is the sum of minutes during the diary day doing the following activities (possible appliances in parentheses): food preparation (electric stove), cleaning house (vacuum cleaner), washing clothes (washer), dressing and grooming (hair dryer), doing homework (computer), and use of radio. This measure, though undoubtedly indirect and unreliable, provides an example of what could be done with survey data that are targeted toward use of EMF sources.

The distribution of POSSEMF is J-shaped in adult, teenager and child samples, with frequency declining as the number of minutes increases. Figure B2 shows the distribution POSSEMF for the adult sample---here, as in the teenage sample, an average of 93-94 minutes per diary day was spent in activities which may have involved use of electric appliances. The average for children aged 0-11 years is about 35 minutes per day.

In general, POSSEMF is higher for women than men and increases with age. Figure B3 shows the average and standard deviation of minutes in POSSEMF activities during the diary day. There is a sharp increase in average time from infancy through early maturity, with relative stability after age 18. Interestingly, the spread of the distribution follows the same pattern with age as the average.

Activity Pattern Surveys and EMF PEM Studies

The CARB activity pattern surveys provide a model for evaluations of potential EMF exposure in general population samples. Though designed for another purpose, they illustrate the kinds of variations in activity patterns that are likely to be observed in any survey that includes broad coverage of demographic characteristics such as age and sex. To the extent that people's routine activities and locations can be mapped to potential EMF exposures by linkage with other databases, even a relatively untargeted diary of the sort used in the CARB may be a useful tool for EMF studies.

The CARB surveys included a substantial number of questions (see the list in Appendix 4A) dealing with air pollution exposures at any time during the 24-hour reference period. Though not linked with the diary reports, and thus not placed in the time-flow of diary activities and locations, these questions provided valuable information about exposure to specific pollutants. Obviously, analogous direct questions about appliance and equipment use, or proximity to known sources, should be considered for use in surveys dealing with EMF exposures.

A retrospective 24-hour interviewer-administered diary can be adapted for use in EMF studies (with or without a PEM component) by orienting questions toward use of, or proximity to, sources that can be specified in advance by the investigators and easily recognized by respondents. The diary structure, with start and end times for activities and locations associated with source use, is particularly important if the goal is to interpret a time series of measurements obtained from a personal exposure device.

References

Wiley, James A., et al. Activity Patterns of California Residents. Final Report, Contract No. A6-177-33, Research Division, State of California Air Resources Board, May 1991. Available from: CARB, P.O. Box 2815, Sacramento, CA 95812-2815

Wiley, James A., et al. Study of Children's Activity Patterns. Final Report, Contract No. A733-149 , Research Division, State of California Air Resources Board, September 1991. Available from: CARB, P.O. Box 2815, Sacramento, CA 95812-2815

United States Environmental Protection Agency, Exposure Factors Handbook, Office of Health and Environmental Assessment, Washington, D.C., July 1989.

Figure B1
Average time in the kitchen versus age

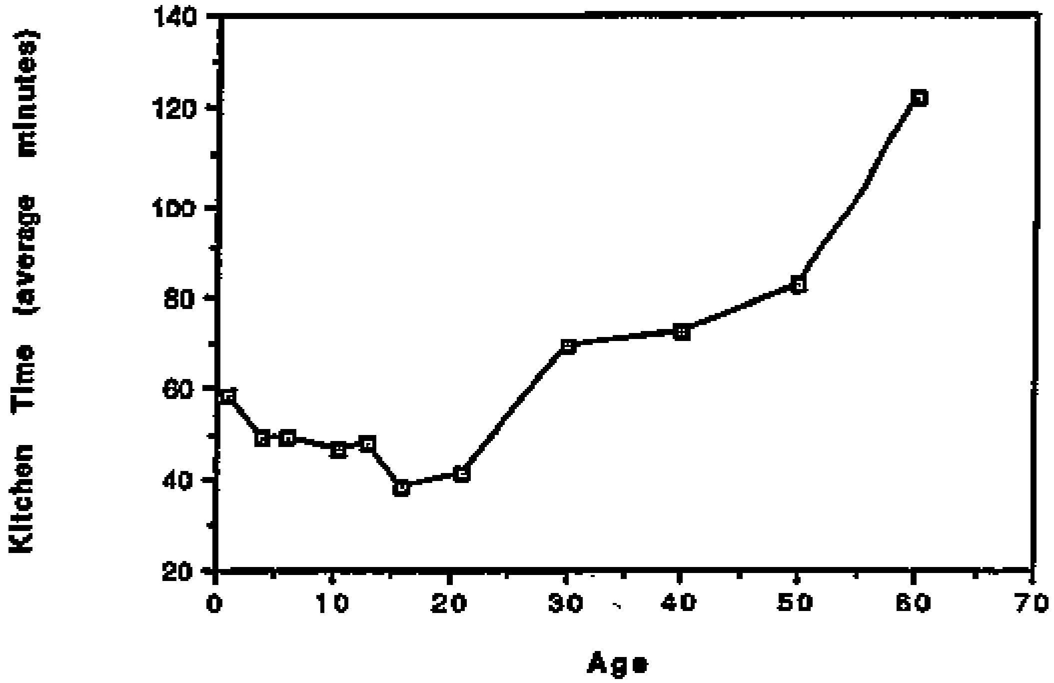

Figure B2
Minutes of possible EMF exposure versus age

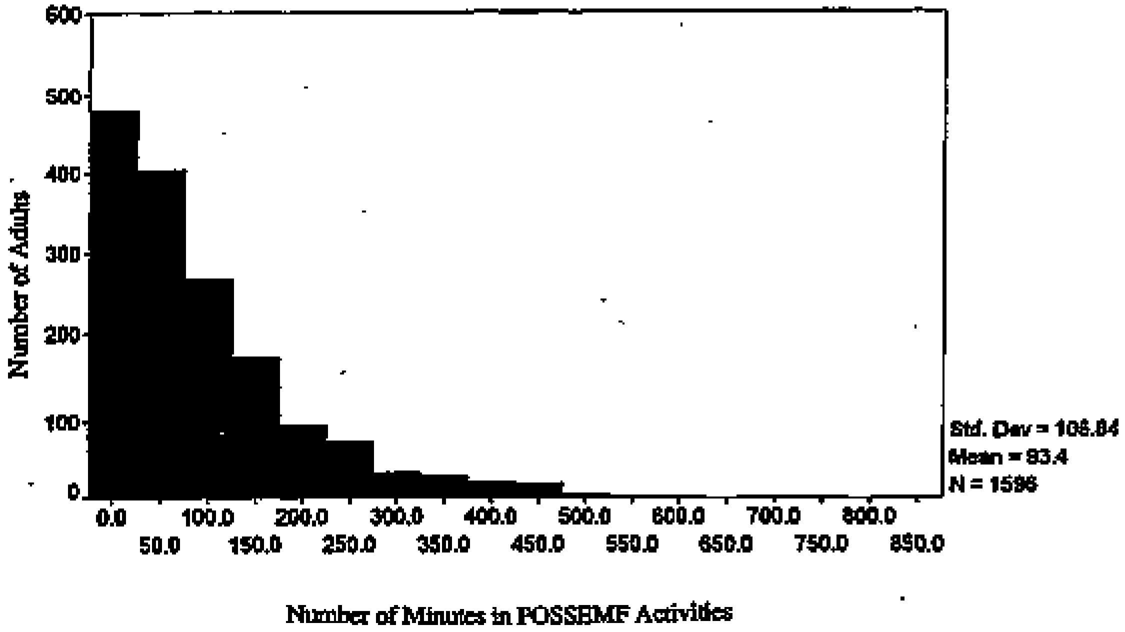

Figure B3
Minutes in possible EMF exposure activities versus age

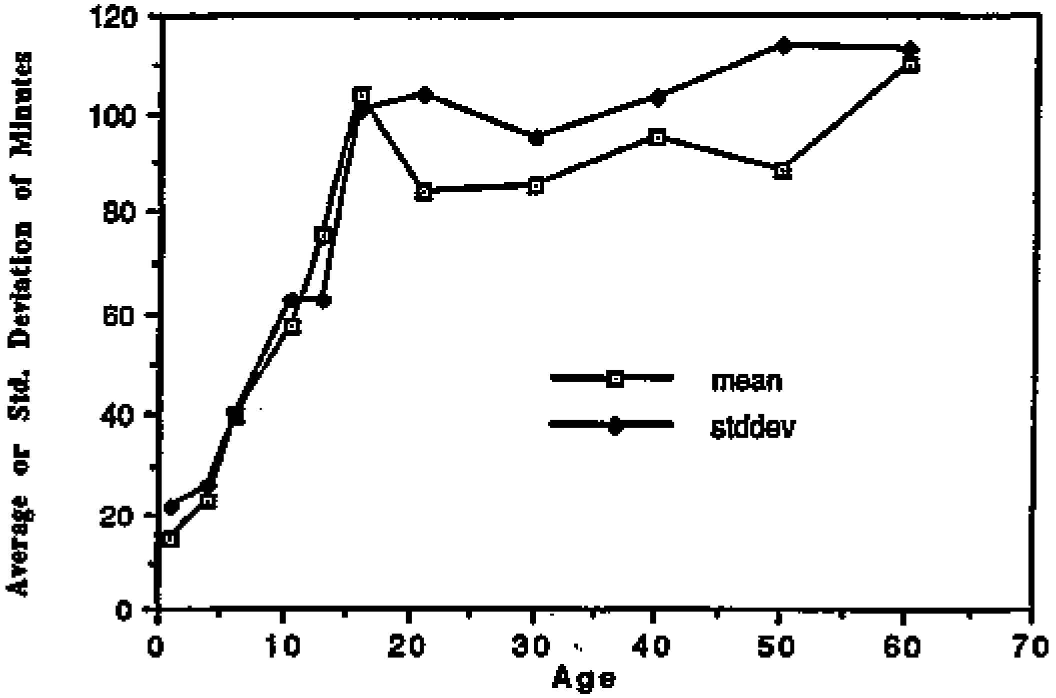

Table B.1
Characteristics of the California Air Resources Board Surveys

California Air Resources Board Survey	Dates of Data Collection	Target Population	Nature of the Sample	Eligible Respondents Who Completed Interview	Source of Activity Pattern Data
Activity Patterns of California Adults	October 1987 to September 1988	Adults and teenagers in English-speaking California households with telephones	Area stratified random-digit dialing sample, randomly selected adult and teenager within household	N=1,396 adults aged 18 or over (60.7% of eligibles) N=194 teenagers aged 12-17 (71.5% of eligibles)	Telephone interview, 24-hour retrospective diary
Study of Children's Activity Patterns	April 1989 to February 1990	Children in English-speaking California households with telephones	Area stratified random-digit dialing sample, randomly selected child within household	N=1,200 children aged 0-11 (77.8% of eligibles)	Telephone interview with adult informant or child 9-11, 24-hour retrospective diary

Table B2
Aggregate codes and variable labels

Aggregate Codes	Adult/Teen Survey Variable Labels Used in Appendices 4B and 4C	Survey of Children Variable Labels Used in Appendices 4B and 4C
1. Activities		
Sleep	SLP, YSLP	SLP
Work	WRK, YWRK	*
In-home Activities	INHOMEA,YINHOMEA	INHOME
Outdoors-at-home acts	OTDR, YOTDR	OTDR
Away-from-home	NONHOME, YNONHOME	NONHOME
School	SCHL, YSCHL	SCHL
Travel	TRAV, YTRAV	TRAV
Possible EMF	POSSEMF, YPOSSEMF	POSSEMF
2. Locations		
Kitchen	KITCH, YKITCH	KITCH
Bedroom	BEDRM, YBEDRM	BEDRM
Other In-home	INHOME, YINHOME	INHOME
Outdoors-at-home	OUTHOME, YOUTHOME	OUTHOME
Indoors, away	INAWAY, YINAWAY	INAWAY
Outdoors, away	OUTAWAY, YOUTAWAY	OUTAWAY
Travel location	TRAVELOC, YTRAVELOC	TRAVELOC
School location	*	SCHLLOC
Daycare location	*	DYCRHS, DYCRCOM

Attachment B1 Question Coverage in the CARB Surveys

Activity Patterns of California Residents	Study of Children's Activity Patterns
Subject characteristics available: Age Gender Type of residence (single family house, apartment, mobile home) Employment Status Occupation (detailed coding) ZIP code, County of residence Rural, suburb, city Schooling (of subj. or parent) Income (of household)	Subject characteristics available: Age Gender Ethnicity Type of residence (single family house, apartment, mobile home) Grade of school ZIP code, County of residence Rural, suburb, city Schooling (of parent) Income (of household)
Activity Categories: Coded from verbatim reports Over 100 distinct activity codes 10 major categories: paid work household work child care obtaining goods and services personal care education and training organizational activities entertainment and social activities recreation communication and passive leisure	Activity Categories: Some precoded categories Over 100 distinct activity codes 10 major categories: paid work household work child care obtaining goods and services personal care education and training organizational activities entertainment and social activities recreation communication and passive leisure
Location Categories: Three major location groupings with 44 unique location codes nested within the general categories: Home (13 specific locations) Other In-transit	Location Categories: Two-stage coding scheme, with some interviewer precoding Six major location groupings with 60 unique location codes nested within the general categories: Home (13 specific locations) School/child care Friend's house Stores, etc. In-transit Other

Activity Patterns of California Residents	Study of Children's Activity Patterns
Specific Exposures:	Specific Exposures:
vehicles in attached garage	vehicles in attached garage
use of mothballs	use of mothballs
toilet bowl deodorizers	toilet bowl deodorizers
scented air fresheners	scented air fresheners
heat turned on---electric, oil, gas	heat turned on---electric, oil, gas
type of heater	type of heater
doors, windows open--minutes	doors, windows open--minutes
fan use, type of fan	fan use, type of fan
air conditioning system and type	air conditioning system and type
have vacuum cleaner (dust)	have vacuum cleaner (dust)
time on floor, carpet	time on floor, carpet
humidifier or vaporizer	humidifier or vaporizer
outside in dirt	outside in dirt
gas station, etc. --minutes	gas station, etc. --minutes
room with oven, etc. --minutes	room with oven, etc. --minutes
glues or adhesives	glues or adhesives
paint products--oil, water based	paint products--oil, water based
pesticides	pesticides
soaps, detergents	soaps, detergents
household cleaning agents	household cleaning agents
aerosol spray products	aerosol spray products
hot shower, hot bath, etc	hot shower, hot bath, etc

Attachment B2: Definitions of Aggregate Activity and Location Categories Used for the Analysis of Time Use for Rapid Project #4

This Appendix shows how the aggregate activity and location variables were defined. The source data (described in greater detail in Section 4.4 above) are taken from two surveys conducted by the Survey Research Center in the late 1980's and sponsored by the California Air Resources Board. They consist of interview and time diary information collected from samples of California residents—adults 18 and over and youth 12-17 years old in the first survey and children 0-11 years in the second.

In general, each aggregate variable is constructed by summing the time spent in its constituent activities or locations. The name of each of aggregate variable is represented in **boldface** type and defined by the SPSS COMPUTE statement that was used to construct the aggregate measure. The rationale and meaning of these aggregate measures is discussed in Section 4.4.

The following notes are provided to indicate how the variable names used below are related to those given in the two widely-distributed codebooks:

a) the variable names in the SPSS system file for the survey entitled "Study of Children's Activity Patterns" are not the same as those used in the codebook. In general, act01 and wc01 in the codebook are actim1 and whtim1 in the SPSS system file. For two and three-digit locations and activities, the transformations are, for example, act22=actim22, act199=actim199, wc33=whtim33 and wc3213=whtm3213. Also note that wc3208=whtim308 and wc3209=whtim309 to keep within the SPSS eight character limit.

b) The code book for the survey entitled "Activity Patterns of California Residents" indicates that all two and three-digit activity codes are mutually exclusive. This is not true. For example, times for act801, act802, and act803 are contained within the variable act80. All aggregate definitions given below were checked for double counting by making a case by case comparison of the total time for activities and locations with the 1440 minutes=24 hour baseline used in the time diary protocol.

ARB Activity Patterns of California Residents
[Sample= Adults 18+ and Children 12-17 years]

A. Definition of Aggregate Activity Variables (time spent in aggregate activity on the diary day)

Adults 18 years and over

```
COMPUTE SLP=act45+act46.
COMPUTE WRK=Sum(act01,act05 to act08).
COMPUTE INHOMEA=Sum(act11,act18 to act24,act26 to act28,
act40 to act43,act48,act75,act83 to act85,act87,act91,act92 to act98).
COMPUTE OTDR=Sum(act13,act15 to act17,act25,act80 to act82)
COMPUTE NONHOME=Sum(act02,act30 to act38,act44,act55,act60 to act68,
act70 to act74,act76 to act78,act86).
COMPUTE SCHL=Sum(act50,act51,act56).
COMPUTE TRAV=Sum(act03,act09,act29,act39,act49,act59,act69,act79,
act89,act99).
COMPUTE POSSEMF=Sum(act10,act12,act14,act47,act54,act88,act90).
```

Youth 12-17 years

```
COMPUTE YSLP=yact45+yact46.
COMPUTE YWRK=Sum(yact01,yact05 to yact08).
COMPUTE YINHOMEA=Sum(yact11,yact18 to yact24,yact26 to yact28,
yact40 to yact43,yact48,yact75,yact83 to yact85,yact87,yact91,yact92 to yact98).
COMPUTE YOTDR=Sum(yact13,yact15 to yact17,yact25,yact80 to yact82)
COMPUTE YNONHOME=Sum(yact02,yact30 to yact38,yact44,yact55,yact60 to yact68,
yact70 to yact74,yact76 to yact78,yact86).
```

```
COMPUTE YSCHL=Sum(yact50,yact51,yact56).
COMPUTE YTRAV=Sum(yact03,yact09,yact29,yact39,yact49,yact59,yact69,yact79,
yact89,yact99).
COMPUTE YPOSSEMF=Sum(yact10,yact12,yact14,yact47,yact54,yact88,yact90).
```

B. Definition of Aggregate Locations (time spent in aggregate location on the diary day)

Adults 18 years and over

```
COMPUTE KITCH = Sum(wc01,wc09) .
COMPUTE BEDRM = wc05 .
COMPUTE INHOME = Sum(wc02 to wc04, wc06 to wc08,wc12,wc13,wc32) .
COMPUTE OUTHOME = Sum(wc10,wc11) .
COMPUTE INAWAY = Sum(wc21 to wc31, wc33, wc35 to wc39) .
COMPUTE OUTAWAY = Sum(wc34,wc40,wc53,wc54,wc59) .
COMPUTE TRAVELOC = Sum(wc51,wc52,wc55 to wc58,wc60,wc61) .
COMPUTE UNKNLOC = wc99 .
```

Youth 12-17 years

```
COMPUTE YKITCH = Sum(ywc01,ywc09) .
COMPUTE YBEDRM = ywc05 .
COMPUTE YINHOME = Sum(ywc02 to ywc04, ywc06 to ywc08,ywc12,ywc13,ywc32) .
COMPUTE YOUTHOME = Sum(ywc10,ywc11) .
COMPUTE YINAWAY = Sum(ywc21 to ywc24,ywc26 to ywc31, ywc33, ywc35 to ywc39) .
COMPUTE YOUTAWAY = Sum(ywc34,ywc40,ywc53,ywc54,ywc59) .
COMPUTE YSCHLLOC=ywc25.
COMPUTE YTRAVLOC = Sum(ywc51,ywc52,ywc55 to ywc58,ywc60,ywc61) .
COMPUTE YUNKNLOC = ywc99 .
```

ARB Study of Children's Activity Patterns
[Children 0-11 years]

A. Definition of Aggregate Activity Variables (time spent in aggregate activity on the diary day)

```
COMPUTE SLP= actim45 + actim46.
COMPUTE INHOME= Sum(actim11,actim18 TO actim24,actim26,actim27,actim41
TO actim43,actim48,actim52,actim75,actim91 TO actim98,actim169,actim474,
actim914,actim954,actim28,actim40,actim83,actim84,actim549,actim875,
actim877,actim879,actim915,actim934,actim937,actim938,actim944,actim971,
actim85,actim87).
COMPUTE OTDR=Sum(actim13,actim15,actim16,actim17,actim25,actim80,actim81,
actim82,actim166,actim1671,actim801,actim811).
COMPUTE NONHOME=Sum(actim2,actim5,actim8,actim30 TO actim38,actim301,actim44,
actim55,actim57,actim60,actim68,actim70 TO actim74,actim76,actim78,actim711,
actim77,actim86,actim88,actim149,actim802,actim803).
COMPUTE SCHL=Sum(actim6,actim50,actim51,actim56,actim58).


COMPUTE TRAV=Sum(actim3,actim9,actim29,actim39,actim49,actim59,actim69,
actim79,actim89,actim99,actim199).
COMPUTE POSSEMF=Sum(actim10,actim12,actim14,actim149,actim47,actim54,actim90).
COMPUTE UNKN=actim1.
```

B. Definition of Aggregate Locations (time spent in aggregate location on the diary day)

```
COMPUTE KITCH=Sum(whtim1,whtim9,whtm3201,whtim309).
COMPUTE BEDRM=Sum(whtim5,whtm3205).
COMPUTE INHOME=Sum(whtim2,whtim3,whtim4,whtim6,whtim7,whtim8,whtim12,
whtim13,whtm3202,whtm3203,whtm3204,whtm3206,whtm3207,whtim308,whtm3212,
whtm3213).
COMPUTE OUTHOME=Sum(whtim10,whtim11,whtm3210,whtm3211).
COMPUTE INAWAY=Sum(whtim21 to whtim24,whtim26 to whtim31,whtim33,whtim35 to whtim37,whtim39).
COMPUTE OUTAWAY=Sum(whtim34,whtim38,whtim40,whtim53,whtim54,whtim59,
whtim63).
COMPUTE SCHLLOC=Sum(whtim251,whtim259).
COMPUTE DYCRHS=whtim253.
COMPUTE DYCRCOM=whtim255.
COMPUTE TRAVELOC=Sum(whtim51,whtim52,whtim55,whtim57,whtim58,whtim60,
whtim69,whtim70).
COMPUTE TRAINLOC=whtim56.
COMPUTE UNKNLOC=whtim998+whtim999.
```

Attachment B3: **Analysis of times spent in actitivies and locations in two California time diary surveys**

I. Subject Attributes and Their Distributions in the Two Surveys

1. Activity Patterns of California Residents, N=1,596 Adults

```
RSEX      ADULT R SEX

                                                          Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

MALE                             1        755     47.3     47.3     47.3
FEMALE                           5        841     52.7     52.7    100.0
                                       -------  -------  -------
                             Total       1596    100.0    100.0

Valid cases     1596      Missing cases       0

AGEREC    Age Categories

                                                          Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

18-24                         1.00        273     17.1     17.3     17.3
25-34                         2.00        409     25.7     25.9     43.2
35-44                         3.00        339     21.3     21.5     64.6
45-54                         4.00        205     12.9     13.0     77.6
55+                           5.00        354     22.2     22.4    100.0
                                .          15      1.0  Missing
                                       -------  -------  -------
                             Total       1596    100.0    100.0

Valid cases     1581      Missing cases      15

RESTYPE   Type of Residence

                                                          Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

House                         1.00       1254     78.6     78.6     78.6
Apartment                     2.00        277     17.4     17.4     96.0
Other                         3.00         64      4.0      4.0    100.0
                                       -------  -------  -------
                             Total       1596    100.0    100.0

Valid cases     1596      Missing cases       0
```

Appendix B

```
AREA      ENVIRONS OF R'S HOME

                                                         Valid     Cum
Value Label                    Value  Frequency  Percent  Percent  Percent

RURAL,                             1        261     16.3     16.7     16.7
SUBURBAN, OR                       3        675     42.3     43.2     59.8
A CITY?                            5        628     39.3     40.2    100.0
DK                                 8         18      1.1  Missing
RF                                 9         15       .9  Missing
                                        -------  -------  -------
                               Total       1596    100.0    100.0

Valid cases     1563      Missing cases      33
```

```
2. Activity Patterns of California Residents,  N=184 Youth aged 11-17
```

```
YSEX      YOUTH R SEX

                                                         Valid     Cum
Value Label                    Value  Frequency  Percent  Percent  Percent

MALE                               1         92     49.9     49.9     49.9
FEMALE                             5         92     50.1     50.1    100.0
                                        -------  -------  -------
                               Total        184    100.0    100.0

Valid cases      184      Missing cases       0
```

```
RECYAGE   Age Group

                                                         Valid     Cum
Value Label                    Value  Frequency  Percent  Percent  Percent

12-14                           1.00         67     36.5     36.7     36.7
15-17                           2.00        116     62.9     63.3    100.0
                                   .          1       .6  Missing
                                        -------  -------  -------
                               Total        184    100.0    100.0

Valid cases      183      Missing cases       1
```

```
RESTYPE    Type of Residence

                                                              Valid     Cum
Value Label                     Value  Frequency  Percent  Percent  Percent

House                            1.00        170     92.3     92.3     92.3
Apartment                        2.00         14      7.5      7.5     99.8
Other                            3.00          0       .2       .2    100.0
                                         -------  -------  -------
                                 Total       184    100.0    100.0

Valid cases      184        Missing cases       0

AREA       ENVIRONS OF R'S HOME

                                                              Valid     Cum
Value Label                     Value  Frequency  Percent  Percent  Percent

RURAL,                              1         39     21.3     21.4     21.4
SUBURBAN, OR                        3         99     53.8     53.9     75.2
A CITY?                             5         45     24.7     24.8    100.0
DK                                  8          0       .2  Missing
                                         -------  -------  -------
                                Total        184    100.0    100.0

Valid cases      184        Missing cases       0
```

3. Study of Children's Activity Patterns, N=1,200 Children aged 0-11

```
RSEX       SEX OF CHILD

                                                              Valid     Cum
Value Label                     Value  Frequency  Percent  Percent  Percent

BOY                                 1        621     51.7     51.7     51.7
GIRL                                2        579     48.3     48.3    100.0
                                         -------  -------  -------
                                Total       1200    100.0    100.0

Valid cases     1200        Missing cases       0
```

```
YAGE      recoded zage

                                                         Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

0 thru 2                      1.00        306     25.5     25.5     25.5
3 or 4                        2.00        231     19.3     19.3     44.7
5 thru 7                      3.00        292     24.4     24.4     69.1
8 thru 11                     4.00        371     30.9     30.9    100.0
                                      -------  -------  -------
                             Total       1200    100.0    100.0

Valid cases     1200      Missing cases       0


RESTYPE   type of residence

                                                         Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

house                         1.00       1018     84.9     84.9     84.9
apartment                     2.00        164     13.7     13.7     98.6
other                         3.00         17      1.4      1.4    100.0
                                      -------  -------  -------
                             Total       1200    100.0    100.0

Valid cases     1200      Missing cases       0


AREA      R'S HOME RURAL, SUBURB OR CITY

                                                         Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

RURAL                            1        221     18.4     18.6     18.6
SUBURBAN                         3        498     41.5     42.1     60.7
A CITY                           5        465     38.8     39.3    100.0
DK                               8         15      1.2  Missing
RF/MD                            9          1       .1  Missing
                                      -------  -------  -------
                             Total       1200    100.0    100.0

Valid cases     1185      Missing cases      15


INSKUL    IS CHILD IN SCHOOL?

                                                         Valid     Cum
Value Label                  Value  Frequency  Percent  Percent  Percent

No                             .00        556     46.4     46.4     46.4
YES                           1.00        644     53.6     53.6    100.0
                                      -------  -------  -------
                             Total       1200    100.0    100.0

Valid cases     1200      Missing cases       0
```

Attachment B3: Analysis of times spent in activities and locations in two California time diary surveys

II. Summaries of the Distributions of Time Spent in Aggregate Activities and Locations Specified by Subject Attributes:

Median, Mean, and Standard Deviation of Time Spent and Percent with Non-Zero Time

Table 1: Adults, 18 and over, Sex by Activities
Table 2: Adults, 18 and over, Age by Activities
Table 3: Adults, 18 and over, Type of Residence by Activities
Table 4: Adults, 18 and over, Type of Environment by Activities
Table 5: Adults, 18 and over, Sex by Locations
Table 6: Adults, 18 and over, Age by Locations
Table 7: Adults, 18 and over, Type of Residence by Locations
Table 8: Adults, 18 and over, Type of Environment by Locations

Table 9: Youth, Aged 11-17, Sex by Activities
Table 10: Youth, Aged 11-17, Age by Activities
Table 11: Youth, Aged 11-17, Type of Residence by Activities
Table 12: Youth, Aged 11-17, Type of Environment by Activities
Table 13: Youth, Aged 11-17, Sex by Locations
Table 14: Youth, Aged 11-17, Age by Locations
Table 15: Youth, Aged 11-17, Type of Residence by Locations
Table 16: Youth, Aged 11-17, Type of Environment by Locations

Table 17: Children, Aged 0-11, Sex by Activities
Table 18: Children, Aged 0-11, Age by Activities
Table 19: Children, Aged 0-11, Type of Residence by Activities
Table 20: Children, Aged 0-11, Type of Environment by Activities
Table 21: Children, Aged 0-11, In school or not by Activities
Table 22: Children, Aged 0-11, Sex by Locations
Table 23: Children, Aged 0-11, Age by Locations
Table 24: Children, Aged 0-11, Type of Residence by Locations
Table 25: Children, Aged 0-11, Type of Environment by Locations
Table 26: Children, Aged 0-11, In School or not by Locations

APPENDIX C

Pilot Studies for RAPID Project 4

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The purpose of performing pilot studies was to test the recommended guidelines in occupational and non-occupational settings. Particular attention was given to testing the guidelines for collecting activity-pattern data.

Two pilot studies were performed. A non-occupational study involved 50 high school students from three classes at two schools, and an occupational study involved eleven professional and production employees at a utility instrumentation manufacturing firm.

A draft version of the General EMF Exposure Assessment Guidelines presented in Section 5 were utilized to develop the design of each pilot study. The investigator addressed each of the basic steps and study elements to methodically establish the study plan and outline the protocols, based on the purpose and resource parameters identified. The worksheets for generating the study plan are shown in Exhibits C.1 and C.2.

The results of the pilot studies included: information about the use of the PEM Guidelines in developing the study design; an evaluation of the use of the methods in the field; and evaluations of the study process by all study participants. In addition, the PEM data from the non-occupational pilot study will be included in the Rapid EMF Measurements Database.

The study designs and the measurement results of the two pilot studies are reviewed individually. Section C.3 assesses the usefulness of the guidelines and discusses the lessons learned from the studies.

C.1 Pilot Study #1: Measurement of exposure of high school physics students

C.1.1 Purpose

The primary purpose of this pilot study was:

- to test the recommended guidelines in a non-occupational setting, with particular attention to the collection of activity-pattern data.

The investigator offered to use the pilot study as a class lesson plan in order to secure the teachers' interest in the project. The enthusiastic response to the project resulted in a much greater participation rate than expected. Two secondary project goals were therefore adopted:

- to provide an educational opportunity for the students, and
- to gather a set of quality data appropriate for inclusion in the Rapid EMF Measurements Database.

C.1.2 Design

Sampling Strategy: Most PEM studies focus on the collection of exposure data. However, because of the three diverse goals of this pilot study, the sampling strategy focus was expanded, and design decisions were not necessarily made to optimize the exposure data collected.

- For the purpose of gathering data for inclusion in the EMF database, the sampling strategy was designed to give an accurate indication of the magnetic field exposure of the subject group in selected environments. Three types of data were gathered in order to allow exposure stratification: 1) magnetic field exposures; 2) concurrent information about the locations of the participants; and 3) subject personal information.

- In order to test the recommended PEM guidelines related to collection of time-activity data, location data were collected using three methods: participant diaries, retrospective questionnaires, and prospective questionnaires.

- In addition, a lesson plan was created from the study to fulfill the educational goals of the project. In two of the three classes, the students were requested to consider or to utilize their personal exposure data in a class assignment. For these students, the sampling interval of the instrument was increased to provide a reasonable number of measurements for their analysis. The sample periods for all classes were based on the class schedules.

Volunteer Solicitation: Selection of volunteers was by convenience and student interest, and was not intended to be random. Physics teachers at eight local high schools were contacted via voice mail. A follow-up letter explained the purpose and basic design of the pilot study. Physics teachers at two schools immediately responded. At School A, the physics teacher requested that both of his two physics classes participate. At School B, only the Advanced Physics class, out of a total of seven classes, participated.

The investigator met with each class approximately one week before the intended measurement period to solicit volunteers. A brief review of the project purpose and design was given, and use of the meters and activity diaries was illustrated. The volunteer nature and confidentiality of the project were emphasized. Consent forms were reviewed and handed out to obtain parental consent for project participation. An example of the Consent Form is shown in Exhibit C.3. The number of participants was limited by the number of meters available, to thirteen per class.

Both teachers required all students to keep an activity diary as part of the class assignment, regardless of whether the student volunteered to wear a meter. This encouraged participation and enhanced the learning opportunities of the project by involving every student.

Participation was as follows:

CLASS	KEPT DIARY AND WORE METER	KEPT DIARY ONLY
SCHOOL A, CLASS #1	9	9
SCHOOL A, CLASS #2	9	7
SCHOOL B	13	3

(At School A, because meters were available, two teachers participated, both keeping a diary and wearing a meter. The data have not been included in this report.)

Instrumentation: Personal exposure measurements were recorded using thirteen EMDEX II meters manufactured by Enertech Consultants of Campbell, CA. Three orthogonal coils measure the magnitudes of vector components of the magnetic field. The instrument computes the resultant magnetic field, defined by the following formula:

$$B_{Resultant} = (B_x^2 + B_y^2 + B_z^2)^{½}$$

where B_x, B_y, and B_z are the magnitudes of the three components of the magnetic field. Measurements are stored in memory for later data transfer. The resultant field in the frequency range from 40 Hz to 800 Hz was measured.

The meters feature an "Event" marker, which introduces a mark in the data when a button on the outside of the instrument is pressed. This feature was used by the students to mark the times of changes in location.

The EMDEX II has a liquid crystal display (LCD). The meters were set to display either the battery status or elapsed time, rather than the magnetic field reading. This was to ensure that the participant's activities were not influenced by the participant's ability to read his/her exposure level on the LCD. (Two participants, in the course of using the controls of the EMDEX to mark the time activities, inadvertently changed the display to show the magnetic field readings. Both students admitted to paying some attention to the meter readings.)

The calibration of each instrument was verified prior to the start of the pilot studies and again after study completion using an Electric Field Measurements Co. Model 117 field generation coil. Prior to each day of monitoring, new batteries were installed and a functional test on each axis of the EMDEX was performed. If the unit failed to respond to a magnetic field in any axis, the meter would not be used. During the study, no unit failed to respond.

Magnetic field data collection: The EMDEX meters were worn by the participants in a pouch secured by a waist belt. The meters were distributed for a period of either 24 hours or 48 hours, based on whether the class was to meet the following day, or two days later. The sampling interval was selected based on the requirements of the lesson plan for each class. The sampling schedule for each class was as follows:

Study Group	Sampling Interval	Sample Period
School A, Class #1	One-minute	24 hours
School A, Class #2	One-minute	48 hours
School B, Class #1	1.5-seconds or Five-seconds	24 hours

At School A, the students referred to their personal data in a class assignment. For these students, a sampling interval of one minute — 1440 samples in 24 hours — was selected, so that each student's database would be manageable, should the student choose to further analyze the data using spreadsheet software. A sampling interval of five seconds — 17280 samples in 24 hours — would have produced too unwieldy a database for individual student analysis.

The students at School B performed no personal analysis, so an interval of five seconds was selected to optimize the information for the EMF database. Ten of the meters were set in error for 1.5-second sampling rather than five-second sampling during the School B study. Seven of these meters terminated data collection after approximately twenty-two hours, presumably because the memory in these meters was insufficient for the selected sampling interval and period. The data up to the point of termination were saved and were included in the database.

Time-activity data collection: Time-activity information for the students was stratified by location, as follows:

At School: Classroom
At School: Not in Classroom
At Home
Traveling
At Work
Other Location

Sleeping
Not Wearing Meter

In addition to the six independent locations, the students recorded when the meter was taken off for sleeping, and when it was taken off for other reasons such as athletic events, showering, etc.

As stated, a primary study goal was to evaluate the recommended time-activity data collection methods. The students therefore documented their activities (location) using two methods: by personal diary and by questionnaire.

Diaries: An example of the diary is presented in Exhibit C.4. All students in every class completed a diary, including those students who did not volunteer to wear a PE meter. The diary was designed to conveniently fit in a pocket of the meter pouch. Instructions for keeping the diary were presented verbally to the class upon meter deployment, and were printed on the diary card for reference. The students were instructed to enter the time, location code, and any relevant notes in the diary each time they changed from one location group to another. They simultaneously pressed the "Event" button on the EMDEX meter, which "marked" the data with the time of the location change.

When the location stratification was developed, "School-Classroom" was discerned from "School-Not in Classroom" so that the students would have the opportunity to practice the time-activity diary input immediately after having been given verbal instructions. This stratification within the "School" location was the greatest reporting burden, according to the first class of students monitored. Because the School A, Class #2 students were monitored for 48 hours, it was felt that this burden was beyond reasonable expectation. The School A, Class #2 students were informed that on the second day of data collection, they need not to separate their school activities into the two locations.

Questionnaires: In addition to maintaining a diary, each student gave an estimate of the time spent in each location in the form of either a retrospective or prospective questionnaire. Examples of the questionnaires are shown in Exhibits C.5 and C.6 respectively.

- School A, Class #1 and School B students completed retrospective questionnaires immediately upon completion of the 24-hour data collection. This questionnaire requested that each student recreate the activities of the past 24 hours in a format similar to that used on the time-activity diaries. The questionnaire also inquired about the use of appliances, the time spent in areas of the home, and basic subject information.

- School A, Class #2 students completed a prospective questionnaire immediately prior to data collection. The students were given the opportunity to estimate their expected times in the selected locations in one of two ways: they could create a list of times and activities in a format similar to the diaries, or they could present the information in a timeline format. The questionnaire also inquired about the anticipated use of appliances, the anticipated time spent in areas of the home, and basic subject information.

Subject Information Collection: Questions regarding basic information about each participant were included on the prospective and respective questionnaire forms. This data included:

- School grade
- Age
- Gender
- Household type (apartment or single-family home)
- Job description during study period
- Primary method of travel during study period

Protocols: The project protocol was developed in outline form and is shown in Exhibit C.7 The protocol outlined the tasks of the investigator and the instructions to the students in order to assure continuity in the project. A single investigator developed the project protocol and carried out the study. Therefore, the need for complete and succinct documentation and instructions was less critical than if several investigators were used. The protocols for meter wear and diary completion were verbally provided to subjects with the aid of overhead slides when the meters were deployed. The instructions were also printed on the diary cards for easy reference.

Evaluation Surveys: Upon completion of their participation, all students — those who volunteered to wear a meter as well as those who simply kept a diary — filled out a short evaluation survey to express their opinions of participation. Compilation of the survey responses provided information about the burden of participation; the clarity of the written and verbal instructions; and any confusion in carrying out the data-collection protocols. An example of the evaluation survey is attached as Exhibit C.8.

Quality Assurance: Several steps were taken throughout the pilot study to ensure the reliability of the data. For example:

- Instruments were calibrated prior to and after the project.

- Before each use, the operation of each axis of each instrument was verified.

- Forms were designed to be clear, succinct and straightforward; however due to the pilot study nature of the project, the forms were not tested prior to their use.

- During the introduction to the participants, the investigator emphasized the importance of data accuracy and explained the protocol for documenting missed events.
- The evaluation survey requested the students' opinion of the accuracy of the time-activity data.
- Upon downloading, the magnetic field data were reviewed for periods of continuous magnitude ("straight-lines") which would indicate either a meter malfunction or a period when the meter was not worn.

Data Management: The data management system was designed to combine information from multiple sources into a summary form that could be easily queried during analysis. Each participant selected a four-digit confidential code that was listed on the diaries, questionnaires, and evaluations. Upon downloading of the EMDEX data, the EMDEX files were given an eight-digit name, including the four-digit confidential code and the four-digit EMDEX serial number. Use of the confidential code on the data files and forms allowed the information on each subject to be combined in the summary files. (Note that this simple naming convention would not have been acceptable on a larger project: allowing the subjects to select their own code created a risk of duplicate codes.)

EMDEX files were reviewed for quality and backed up on floppy disks. The EMDEX files and copies of all forms were forwarded to project headquarters for data input and production of summary files. The investigator maintained copies in the event of loss or questions.

Data Analysis Procedures: Time-activity information was collected from the dairies and the questionnaires. The diary data were linked to event marks which the students entered into the EMDEX data with each change in location. The time of the event mark was assumed to be more accurate and was maintained for each location change, rather than the time reported in the diary. The cumulative time in each location was calculated for each student.

The data reported in the questionnaires were also coded for location to compare with the diary data. The cumulative time in each location was calculated for each student. The percentage misclassified for each location was defined as:

$$\%\ \mathrm{MISCLASSIFIED}_{Ln} = \sum(\mathrm{ABS}(\mathrm{TDIARY}_{Ln} - \mathrm{TQUEST}_{Ln}))/\sum(\mathrm{TDIARY}_{Ln})$$

Where TDIARY equals the total time documented in the diary for location Ln for each student, and TQUEST equals the time reported in the questionnaire for location Ln for each student.

Note that, according to this equation, any time misclassified is accounted for twice: once for the location for which it was reported in the questionnaire, and once for the location for which it should have been reported.

The total percentage misclassification was defined as follows:

$$\left(\sum_{n} \%\mathrm{MISCLASSIFIED}_{L,n}\right)/2$$

PEMs were summarized by location and by school class. Summary measures, including: number of samples, time, arithmetic mean exposure, median, maximum, geometric mean and standard deviation were computed for the total time each person spent in a given location. This information was further summarized to provide the time-weighted mean and the maximum for each class, by location.

Educational Opportunities for Students: Class participation in this pilot study afforded lessons in several areas including; how research data are collected, how physics and other sciences may interrelate in real world issues, how computers may be used for research, and the physics of EMFs. At School A, the physics teacher incorporated the pilot study into his own curriculum. He introduced electricity and magnetism to the classes prior to the study. He assigned reports on various EMF topics, in which the teams of students were requested to refer to their own PE data. The pilot study data were downloaded in a computer lab so that each student team could utilize the EMDEX software to review their data. At School B, data were downloaded and shown on overhead slides for discussion. In all classes, presentations were made by the investigator and by a representative from the local utility. After completing the studies, each student received a copy of his/her diary and a graphical printout of his/her personal magnetic field exposure data versus time.

C.1.3 Results

Time-Activity Data: Students successfully recorded information about their locations concurrently with the magnetic field exposure monitoring, using diaries. They also completed either a prospective questionnaire or retrospective questionnaire to either forecast or remember their locations during the study period in a format similar to the diaries. All students participated in the time-activity data collection, whether or not they wore a magnetic field meter.

A widespread error in the time-activity record-keeping involved accounting for sleep time. The error was readily identifiable because sleep-time is relatively predictable for high school students:

- Five students forgot to input the "sleep" activity in their diary, although they included it in the questionnaire.
- Two students omitted sleep time in the questionnaire, but included it in the diary.
- Three students, who perhaps neither listened to verbal instructions, nor read the written instructions, accounted for sleep in neither their questionnaire nor their diaries.

The errors occurred in all three classes, but were most prevalent in the students completing the prospective questionnaire.

Obviously, each of these oversights caused an approximately eight-hour error in the data. Time did not allow the investigator to confirm the error with each student, so, in each case, a correction was made as follows: 500 minutes of sleep per night (missing from either the diary, the questionnaire, or both), was added to the "Sleep" location of the diary and/or questionnaire, and a corresponding 500 minutes was deducted from the "Home" time. (An eight-hour sleep period equals 480 minutes; for those students who responded properly, the average sleep period was 513 minutes; therefore an even 500 minutes was selected for the correction.)

The results of time-activity data collection are shown in Table C.1A. The omission of sleep-time from the diaries, questionnaires, or both, caused the recording of exceptionally high amounts of time in "Home" and understated time of "Sleep". This error in the ten cases was corrected, and the results shown in Table C.1B.

Table C.2 shows the accuracy of the questionnaires in comparison with the diaries. This table reports the difference between the total minutes reported in a location by diary and by questionnaire. Once again the data have been reported as collected (Table C.2A), and as corrected for the widespread "Sleep" oversight (Table C.2B). Table C.2 shows clearly that a retrospective questionnaire will provide significantly more reliable information than a prospective study. As shown in Table C.2B, 9.8% of the time was misclassified in prospective questionnaires, and 2.6%-3.5% was misclassified in retrospective questionnaires. The relative margin of misclassification was similar for the uncorrected values of Table C.2A. Note that the retrospective questionnaires were completed immediately following the study period, which certainly assisted recall.

Magnetic Field Summaries: The results of the student exposure by school are shown in Table C.3. For each class, the average exposure was 0.7 to 0.8 milligauss. Exposures at Home were lowest for the School B class. Exposures at School B tended to be higher than at School A. However the highest exposure measured within a school was at School A in Class 2 (110.1 milligauss). Travel tended to be a location of higher overall exposure, most likely because exposures within cars are generally higher than average exposure. (Work was the location of highest exposure, though only one student was measured for work exposure.)

Information within the diaries and subject information sheets will allow further analysis by gender, age, residential type, and transportation type.

Evaluation Summaries: As participant enthusiasm and responsiveness is important for any data collection effort, all students were given the opportunity to evaluate the study process. Table C.4 shows a summary of student responses to the evaluations.

Generally, the students found the study purpose and instructions clear. They found the meter easy to use. They gave mixed responses when questioned whether wearing the meter and keeping a diary were burdensome. Making diary entries was easy, but the majority occasionally forgot to make them.

Of those who completed a retrospective questionnaire, 33 of 34 found that having kept the diary helped their recall for filling out the questionnaire. This suggests that the low percent of time misclassified in the retrospective questionnaires, as shown in Table C.2, was influenced by the assisted recall.

C.2 Pilot Study #2: Measurement of Exposure Instrument Manufacturing Employees

C.2.1 Purpose

The primary purpose of this pilot study was:

- to test the recommended guidelines in an occupational setting, with particular attention to the collection of activity-pattern data.

In keeping with this purpose, the pilot study was split into two data collection efforts that used three methods to acquire time-activity data. The activities and locations of the production workers were monitored by an observer. The professional employees completed both concurrent diaries and retrospective questionnaires.

An effort was made to assure that this study tested a different set of methods than those tested in the non-occupational study.

C.2.2 Design

Sampling Strategy - Professional Employees: Because of the limited number of participants, the data from this pilot study were not intended for inclusion in the Rapid EMF Measurements Database. Nevertheless, the sampling strategy was designed to replicate that which would be selected for a typical exposure assessment of this type. Two types of data were collected to indicate of the magnetic field exposure of the participants in selected environments: 1) magnetic field, and 2) concurrent location information for the participants.

The professional employees' activities were stratified by narrower location definitions than those used for the student pilot study. This approach addressed the differences in magnetic field levels for sub-environments within the broader environment of the entire manufacturing facility. The investigator toured the facility prior to the study date, and developed a list of sub-environments within the site. The boundaries of these sub-environments were readily understood by the participants. The following list was adopted for location-based activities in the facility.

In Administration
In Common Areas
At Participant's Desk*
In Education Area: Classroom
In Education Area: Lab
In Engineering
In Lunchroom
In Manufacturing
In Purchasing
In Test & Repair
In ETK
Using Equipment**
Out of Building
Not Wearing Meter

* Each participant's desk was located in one of the general areas of the facility: i.e., In Engineering or In Administration. In order to further delineate their locations within that area, the participant's own desk was considered a separate location.

** In order to gather information about exposure during the use of equipment, "Using Equipment" was considered a separate activity. Participants documented the type of equipment in use. It was assumed that the equipment was within the sub-environment previously indicated.

Sampling Strategy - Production Employees: The locations of the production employees were recorded by the observer only within the boundaries of the sub-environment in which they worked — either Manufacturing or Test & Repair. These two sub-environments were further divided by a grid system based on the layout of machinery and workstations. This grid system was found to be too broadly defined, and not sufficiently related to magnetic field exposure, as is further discussed in Section C.3.

Volunteer Solicitation: The selection of participants was by convenience and interest, and was not intended to be random. The firm's president was acquainted with the investigator, and he volunteered the firm's support upon request. The president then solicited professional and production employees he felt would be interested in the project.

One week prior to the study date, the investigator met individually with most of the potential volunteers. A brief review of the project purpose and design was given, and use of the meters and activity diaries was demonstrated. The volunteer nature and confidentiality of the project was emphasized. Consent forms were reviewed and handed out for signature. On the study date, some of the original volunteers were unavailable and more volunteers were required. The president identified more potential participants, who were introduced to the project and consented to participate.

Instrumentation: Personal exposure measurements were recorded using eleven EMDEX II meters manufactured by Enertech Consultants of Campbell, CA. Three orthogonal coils measure the magnitudes of vector components of the magnetic field. The instrument computes the resultant magnetic field, defined by the following formula:

$$B_{Resultant} = (B_x^2 + B_y^2 + B_z^2)^{1/2}$$

where B_x, B_y, and B_z are the magnitudes of the three components of the magnetic field. Measurements are stored in memory for later data transfer. The resultant field in the frequency range from 40 Hz to 800 Hz was measured.

The meters feature an "Event" marker, which introduces a mark in the data when a button on the outside of the instrument is pressed. This feature was used by the professional employees to mark the times of changes in location.

The EMDEX II has a liquid crystal display (LCD). The meters were set to display either the battery status or elapsed time, rather than the magnetic field reading. This was to avoid influencing the participants' activities because of their knowledge of their exposure. The calibration of each instrument was verified prior to the start of the pilot studies and again after study completion using a small magnetic field generator. The operation of each of the three coils in each meter was verified on the day prior to the study day by obtaining a reading on each coil when positioned near a known magnetic field source.

Magnetic-field Data Collection - Professional Employees: The EMDEX meters were worn by the participants in a pouch secured by a waist belt. The meters were distributed to the professional employees individually in the morning. The investigator confirmed fifteen-minute appointments with each employee late in the afternoon, at which time these meters were retrieved and downloaded. The sampling interval of three seconds was selected to optimize the capabilities of the recording meter.

Magnetic-field Data Collection - Production Employees: The production employees wore the EMDEX meter in a waist-belt for a period of approximately 1¼ to 1½ hours. Two employees in the Test and Repair area were monitored simultaneously. Then two employees in the Manufacturing area were monitored simultaneously.

Time-activity Data Collection - Professional Employees: The time-activity data collection for the professional employees was very similar to that performed in the student pilot study: employees documented their activities based on location using two methods: personal diary and questionnaire. However, the definitions of the locations/activities were much narrower for the employees than it had been for the students. Where the students had recorded locations in broad descriptions, such as home, travel and school, the employees recorded location based on sub-environments of the work environment, such as Lunchroom, Manufacturing, and Administration. In addition, the employees recorded the use of equipment.

Diaries: All professional employees completed a diary, an example of which is presented in Exhibit C.9. The diary was designed to conveniently fit in a pocket of the meter pouch. Instructions for keeping the diary were presented verbally to each participant in an individual morning meeting and were printed on the diary card for reference. The employees were instructed to enter the time and location code in the diary each time they changed from one sub-environment to another. They simultaneously pressed the "Event" button on the EMDEX meter, which marked the data with the time of the location change.

The guidelines of Section 6 recommend that time-activity categories be magnetic field-based, to the extent possible. Therefore, in addition to stratifying by location within the facility, the employees were requested to monitor their use of equipment. If a participant was using a piece of equipment, this was to be documented as the activity "Using Equipment", and the type of equipment was written on the diary. (It was determined that the personal computers of all participants remained ON for the full workday. Therefore, PC use was assumed to be included in the "At Participant's Desk" activity.)

Questionnaires: In addition to maintaining a diary, each professional employee gave an estimate of the time spent in each location in the form of a retrospective questionnaire immediately upon completion of the study period. An example of the questionnaire is shown in Exhibit C.10. This questionnaire tested two alternatives for recreating the activities of the past workday. Version #1 used a format similar to that used on the time-activity diaries, in which the participant was required to recall the time and chronology of the activities. Five of the seven professional employees found Version #1 too cumbersome. In Version #2, the participant was merely requested to estimate the percentage of time that was spent in each activity. The questionnaire also inquired about the use of equipment and time spent in other activities in which the participant suspected elevated fields. Because of the nature of the firm — production of instruments for electric utilities — the employees were relatively knowledgeable about magnetic field sources.

Time-activity Data Collection - Production Employees: The activities of the production employees were recorded by an observer. The observer monitored two sets of two employees simultaneously for 1¼ to 1½ hours per period. The stratification of activity was location-based, based on a grid of the local area. Each time the participant moved from grid-section to grid-section, the movement and new location were documented. Departure from the observed area was also recorded. The grid was arbitrarily geometric and was not associated with activities or sources. While this scheme was found to be unrelated to exposure with too broad of location definitions, implementing this data collection method did provide insight for its proper use, as described in Section C.3. The production employees were not requested to estimate their activities in a questionnaire.

Subject Information Collection: Participants were identified by job classification, which was determined during the initial interview. Participant gender was also recorded by the observer.

Protocols: The project protocol was developed in outline form and is exhibited as Exhibit C.11. The protocol outlined the tasks required of the investigator and the instructions to the participants in order to assure continuity in the project. A single investigator developed the project protocol and carried out the study. Therefore, the need for complete and succinct documentation and instructions was less critical than would be the case if several investigators were involved.

The protocols for meter wear and location recording were verbally provided upon deployment of the meters in individual meetings with the participants. The instructions were also printed on the diary cards for easy reference.

Evaluation Surveys: All participants were given the opportunity to comment on the study design in an evaluation survey. Survey questions addressed the clarity of instructions and descriptions, the burden of wearing the meters, and the use of diaries and questionnaires. The evaluations were completed at the end of the study period. Evaluation for the production employees was more brief and emphasized the burden of observation. Examples of the evaluation surveys are shown in Exhibits C.12 and C.13.

Quality Assurance: Several steps were taken throughout the pilot study to ensure the reliability of the data:

- Calibration of instruments was verified prior to and after the project.
- Before each use, the operation of each axis of each instrument was verified.
- Forms were designed to be clear, succinct and straightforward; however due to the pilot study nature of the project, the forms were not tested prior to their use.
- During the initial meeting with the participants, the investigator emphasized the importance of data accuracy — explaining the protocol for documenting missing entries.
- The evaluation survey requested the participants' opinions of the accuracy of the time-location data.
- Upon downloading of the magnetic field data, the data were reviewed for periods of continuous magnitude ("straight-lines") which would indicate either a meter malfunction or a period when the meter was not worn.

Data Management: Each participant was assigned a six-digit code that was listed on the diaries, questionnaires, and evaluations. The code consisted of two digits to identify the participant, and the four-digit serial number of the EMDEX meter worn by the participant. Upon downloading of the EMDEX data, the EMDEX files were given the six digit code as a file name. Use of the code on the data files and forms allowed the information on each subject to be combined in the summary files. (Note that this simple naming convention would not have been acceptable on a larger project: a two-digit identifier would only be appropriate for a small sample.)

EMDEX files were reviewed for quality and backed up on two floppy disks. The EMDEX files and copies of all forms were forwarded to project headquarters for data input and production of summary files. The investigator maintained copies in the event of loss or questions.

Data Analysis Procedures - Professional Employees: Time-activity information was collected from the diaries and the questionnaires. The diary data were linked to the event marks which the employees entered into the EMDEX data with each change in location. The time of the event mark was assumed to be more accurate and was maintained for each location change, rather than the time reported in the diary. The cumulative time in each location was calculated for each employee.

With such a small sample, the time-activity information from the questionnaires was not sufficient for statistical analysis.

PE measurements were summarized by location by employee. Summary measures were computed for the total time each person spent in a given location. These included: number of samples, time, arithmetic mean, median, maximum, geometric mean and standard deviation. This information was further summarized to provide the time-weighted mean and the maximum for the group of employees, by location.

Data Analysis Procedures - Production Employees: The quantity and quality of data collected for the production employees was insufficient for analysis. Nevertheless, the act of testing the protocols provided insight for study design as discussed in Section C.3.

C.2.3 Results

Magnetic Field Summaries - Professional Employees: The results of the monitoring of all professional employees are shown in Table C.5. The average exposure for all employees during the study was 0.9 milligauss. The greatest contributor to time-weighted average exposure appeared to be a building transformer outside the building where a few employees stood during smoking breaks. The highest measured exposure, 224.1 milligauss, occurred when an employee walked behind a dot-matrix printer to retrieve a report.

Table C.6 shows the exposure results for each employee. Two employees had substantially higher mean exposures than the other five employees. (1.26 mG and 2.06 mG versus .49-.74 mG). These two employees worked in the same general area and were exposed to the fields from the same printer.

Evaluation Summaries: Table C.7 shows a summary of the responses from the employee's evaluations.

The professional employees found the study instructions very clear and the purpose clear. They found the meter easy to use, and in general found that wearing the meter was no burden. Making diary entries and using the location codes were easy, though more than half occasionally forgot to make the diary entries.

As was found for the students completing a retrospective questionnaire, all professional employees found that having kept the diary helped their recall in filling out the questionnaire.

The four production employees who were observed completed abbreviated evaluations, the results of which are shown in parentheses in Table C.6. These employees found the instructions and study purpose clear and did not consider wearing a meter to be a burden. Three out of the four, however, found that being observed while they worked was somewhat distracting or "OK", while only one found it not distracting at all.

C.3 Guideline Evaluation

A draft of the recommended General EMF Exposure Assessment Guidelines was used to design and perform the pilot studies. Evaluation of the recommendations occurred throughout the pilot studies. Those methods which were successful and those with shortcomings that could affect performance of the study or the integrity of data were noted and are discussed below.

C.3.1 Study Design

Using the General EMF Exposure Assessment Guidelines: Creating the study design was facilitated by following the general exposure assessment guidelines detailed in Section 3. Building a study design worksheet helped ensure that each step of the study process was planned to achieve the project purpose and goals.

Importance of Pilot Studies: The experiences in these studies emphasized the importance of performing pilot studies. Testing prior to performance would have identified erroneous assumptions: (e.g., we assumed that students could use their social security number for a code, but none knew their number.) It also would have allowed unclear instructions to the student participants to be pointed out, such as the importance of including the "Sleep" location in the diaries, which was overlooked by 20% of the participants.

Protocols: The studies pointed out the importance of having a protocol on hand, even in this case where only a simple protocol outline was required. The time available to provide instruction and deploy meters is usually limited, and certain tasks or instructions may be overlooked without a protocol checklist. For example, in the individual meetings with several professional employees, the procedure for correcting a "missed" event was not explained, compromising the accuracy of the time-activity data.

C.3.2 Instrumentation

Field meters and other instrumentation should be thoroughly tested and their operation understood prior to use in the field. The measurement technician should not presume that all similar meters are identical: in some models the default settings, memory, etc. may differ between meters. For example, we assumed that a clock could be displayed on each meter during data collection, but this option was not available on several meters. The battery life and memory capacity should be confirmed for each meter in order to ensure performance for the full sample period.

The designers of the study should not make assumptions about what the participants might have available for the study. For example, we assumed that each high school student could record activity times in their diary based on the time on their watch, but learned that few students wore watches. We also learned, when deploying one meter pouch without its own belt, that students today do not wear belts. There was no way for a student to wear the meter pouch without supplying a belt.

C.3.3 Activity-Pattern Data Collection

Stratification: Very broad definitions of location were used in the high-school student study, and somewhat less broad definitions were used in the workplace study. Neither set of locations had a substantial relationship to magnetic field exposure. Optimally, the activities or locations chosen in both pilot studies could have been more relevant to magnetic field exposure. However, this may have required much more detailed definitions for location or activity. Record-keeping for detailed activities can be burdensome for subjects, particularly in 24-hour studies. Conversely, if a study purpose were confined to focusing on a few specific activities of interest, the study could be designed to allow greater collection detail for fewer activities.

Worn-Not Worn Status: The design of the diaries allowed magnetic field data to be collected and stratified during all periods when the participant wore the meter. However, in our case, the activity of "Not Worn" did not identify the location of the participant during the "Not Worn" period. Such a distinction is important to fully understand the time-activity patterns of the participants.

Observation: The observation process was unsuccessful in this pilot study because no definitive sub-environments or micro-environments had been identified. The geometric grid system bore no relation to magnetic field exposure. For the observer method to succeed, objective, predetermined zones, preferably related to exposure, must be identified in the study design and clearly understood by the observers. Developing such a system requires prior knowledge of the magnetic field environment. The use of observers can be expensive and is most appropriate when the complexity and volatility of the activities or locations is beyond the ability of the participant to record in a diary or other format.

We found that one observer could efficiently monitor and record activities in an open interior 50' x 50' space. Observing two participants simultaneously was realistic. Observation of greater numbers would depend on the extent of the subjects' activities. If several people are to be observed it would be helpful to have each person clearly marked, for example with a color-coded armband. In this study, most people in the study area were male with dark hair and a white lab coat. More than two simultaneous participants would have been confusing for the observer.

We also found that even though observation required continuous concentration, it became difficult for the observers to remain alert.

Diaries: Very objective categories with clear descriptions must be defined for the participants to successfully complete the time-activity diaries. Use of diaries has proven a very efficient method of recording activities. However, activities must be defined so that movement from one activity to the next does not become so frequent as to make record-keeping burdensome. In these pilot studies, the location definitions were sufficiently clear and broad that the participants felt comfortable and confident in their data entry.

Our diary instructions did not specify the inclusion of "am" and "pm", or the use of 24-hour clock time. This made data entry by the investigators arduous: requiring that each entered time be carefully translated into the 24-hour format before transferring the information from the diaries to the database.

In these studies any time difference between watches (or other source of time) for diary entry and the computer time assigned to the data was not important. The event-mark capability of the meter and the relatively infrequent changes in location status allowed the event marker times to be used. In many studies however, it will be important to ensure synchronizing of all equipment.

Retrospective Questionnaires. The pilot studies showed that retrospective questionnaires executed immediately upon completion of the study period could prove successful. However, they are best adapted for people with highly scheduled activities: e.g., students with a class schedule or assembly employees with specific workspaces and scheduled breaks. Such individuals were able to recreate their daily activities reasonably well, provided the activities or locations were somewhat broad. However, people who frequently or sporadically change activities seemed to have difficulty in recreating their activities in chronological order. At best they provide estimates of the total time in each activity. For example, the professional employees were requested to attempt a chronological recall of events, (Exhibit C.10, page 2), and only two of seven completed it.

Prospective Questionnaires: The prospective questionnaires proved more burdensome to complete than the retrospective questionnaire. It appeared that prospective questioning might prove successful with strictly scheduled people. A comparison of the misclassification showed that the data provided in a prospective questionnaire would be significantly less accurate than that of an immediate retrospective questionnaire.

Our design of the prospective questionnaire requested activity time as follows:

LOCATION TIME
____________________ from: _____ to: ______
____________________ from: _____ to: ______
____________________ from: _____ to: ______

This proved redundant, in that the "to" time of one event equaled the "from" time for the next event. This required that the subject duplicate their time entry in an already lengthy questionnaire. Also, the possibility of duplicated time or time unaccounted for was entered into this design if the "to" time entered by the subject differed from the "from" time of the previous event.

We tested two methods of accounting for time in the prospective questionnaires; the chronological descriptive format shown above, and a time-line format (Exhibit C.6, page 4). We gave the students in School A Class #2 their choice of formats. Interestingly, all but one boy and no girls choose the time-line format over the descriptive format. This would suggest different questionnaire designs will prove most efficient with different groups of people, and pilot studies should be performed to determine the optimal design.

C.3.4 Magnetic-Field Data Collection

Meter display: The pilot studies were planned such that the participants were unaware of their exposure levels while data was being collected. However, in two cases subjects inadvertently reset the meters to display concurrent magnetic field readings. Both students admitted that seeing magnetic field levels influenced their activities. This suggests that in most cases, field exposure readings should not be displayed to subjects.

C.3.5 *Quality Assurance*

Time was not scheduled into the study designs to allow the investigator to query the participants after the investigator reviewed the collected data. The investigator should have manually examined the data to compare the diaries with event marks and to ensure that the EMDEX data "made sense", and then immediately returned to the sites to question the participants about any ambiguities. Such an addition to the schedule would have allowed that the "Sleep" time error, and perhaps others, be immediately rectified.

C.3.6 *Summary*

The recommended guidelines were of benefit in developing and performing the pilot studies as follows:

- Section 5 of the guidelines provides an excellent template for preparing a study plan based on the project purpose, resources, and parameters.
- A written study plan and protocol are emphasized throughout the guidelines. Their importance was seen in the pilot studies. A study purpose and plan was accepted by the sponsor and investigator prior to the project. The written protocol outline guided the details of implementation, and in the one event where the outline was not at hand, instruction details were missed.
- Section 6.4 emphasizes relating the set of activities or locations selected for activity pattern data collection to magnetic field exposure. This was found to be difficult in practice. Fully implementing such a strategy would require a) knowledge of the expected sources and magnitudes of exposure, and b) such a detailed stratification of the activities or locations that collecting the data would prove too burdensome. Nevertheless, the researcher should at minimum consider exposure when selecting the set of activities, and perhaps limited the extent of the study in order to focus on certain activities or exposures, if the study permits.
- Section 6.4 presented activity pattern data collection methodologies based on three time periods: prospective, concurrent (diaries or observation), and retrospective. The pilot studies confirmed that concurrent information is the most reliable information, and the retrospective questionnaires provide more reliable information than prospective questionnaires. In order to further enhance the quality of data, the retrospective or prospective questionnaires should immediately follow or proceed the study period.
- Section 6 discusses the importance of performing pilot studies. This provides the opportunity to test the instrumentation and protocol design, which will minimize equipment issues in the fields and will ferret out erroneous assumptions made in the study plans.

TABLE C.1A: SUMMARY OF TIME-ACTIVITY DATA OF HIGH SCHOOL STUDENTS AS RECORDED BY STUDENTS (in MINUTES)

SCHOOL	DAYS	ENVIRONMENT					
		SCHOOL	HOME	TRAVEL	WORK	OTHER	SLEEP
FROM DIARY							
A1	1	504.6	327.7	88.9	10.8	43.1	464.8
A2	2	387.9	485	100.8	13.6	72.3	380.4
B	1	397.4	389.5	83.6	25.6	71.5	472.3
FROM PROSPECTIVE QUESTIONNAIRE							
A2	2	380.4	444.4	117.6	19.6	63.1	413.3
FROM RETROSPECTIVE QUESTIONNAIRE							
A1	1	495.9	296.1	108.9	10.2	38.8	488.7
B	1	376.4	368.5	77.8	25.3	74.1	505.2

TABLE C.1B: SUMMARY OF TIME-ACTIVITY DATA OF HIGH SCHOOL STUDENTS CORRECTED FOR "SLEEP" TIME ERRORS (in MINUTES)

SCHOOL	DAYS	ENVIRONMENT					
		SCHOOL	HOME	TRAVEL	WORK	OTHER	SLEEP
FROM DIARY							
A1	1	504.6	272.2	88.9	10.8	43.1	520.4
A2	2	387.9	344.4	100.8	13.6	72.3	521.1
B	1	397.4	360.1	83.6	25.6	71.5	501.7
FROM PROSPECTIVE QUESTIONNAIRE							
A2	2	380.4	335	117.6	19.6	63.1	522.7
FROM RETROSPECTIVE QUESTIONNAIRE							
A1	1	495.9	286.9	90.3	10.2	38.8	516.5
B	1	376.4	368.5	77.8	25.3	74.1	505.2

TABLE C.2A: MISCLASSIFICATION OF QUESTIONNAIRE DATA IN COMPARISON WITH DIARY DATA (AS REPORTED BY HIGH SCHOOL STUDENTS)

SCHOOL	DAYS	PERCENTAGE MISCLASSIFICATION OF ENVIRONMENTS						
		ALL	SCHOOL	HOME	TRAVEL	WORK	OTHER	SLEEP
PROSPECTIVE QUESTIONNAIRE								
A2	2	18.2%	17.1%	42.0%	58.0%	45.8%	98.4%	46.6%
RETROSPECTIVE QUESTIONNAIRE								
A1	1	4.1%	2.7%	16.9%	42.6%	0.0%	39.9%	7.1%
B	1	5.4%	8.2%	17.8%	20.0%	1.1%	9.9%	10.0%

TABLE C.2B: MISCLASSIFICATION OF QUESTIONNAIRE DATA IN COMPARISON WITH DIARY DATA (CORRECTED FOR "SLEEP" TIME OVERSIGHT)

SCHOOL	DAYS	PERCENTAGE MISCLASSIFICATION OF ENVIRONMENTS						
		ALL	SCHOOL	HOME	TRAVEL	WORK	OTHER	SLEEP
PROSPECTIVE QUESTIONNAIRE								
A2	2	9.8%	17.1%	23.9%	58.0%	45.8%	98.4%	10.6%
RETROSPECTIVE QUESTIONNAIRE								
A1	1	2.6%	2.7%	9.8%	22.9%	0.0%	39.9%	3.3%
B	1	3.5%	8.2%	11.5%	20.0%	1.1%	9.9%	4.0%

TABLE C.3: SUMMARY OF HIGH SCHOOL STUDENTS' MAGNETIC FIELD EXPOSURE BY LOCATION, BY CLASS (in MILLIGAUSS)

	SCHOOL A CLASS #1		SCHOOL A CLASS #2		SCHOOL B	
	MEAN	MAXIMUM	MEAN	MAXIMUM	MEAN	MAXIMUM
SCHOOL IN CLASSROOM	0.3	10.1	0.5	110.1	0.9	45.3
SCHOOL NOT IN CLASS	0.2	7.6	0.2	3.5	0.8	18.1
SCHOOL*	-	-	0.4	52.9	-	-
HOME	1.1	8.4	0.9	188.5	0.6	198.9
TRAVEL	0.8	10.8	1.2	38.9	1.0	39.3
WORK	-	-	4.0	7.5	-	-
OTHER	0.3	8.4	1.3	17.5	0.9	187.1
SLEEP	1.0	5.9	0.5	9.1	0.8	12.9
TOTAL	**0.7**	**10.8**	**0.7**	**188.5**	**0.8**	**198.9**

* The School A, Class #2 students were not required to differentiate between the locations "School In Classroom" and "School Not In Class" on the second day of their 48-hour study period.

TABLE C.4: HIGH SCHOOL STUDENT RESPONSES TO EVALUATION SURVEYS (in NUMBER OF STUDENTS RESPONDING)

QUESTION	RESPONSE				
INSTRUCTIONS AND PROJECT DESCRIPTIONS					
Were verbal instructions clear?	Very Unclear 0	Unclear 0	OK 1	Clear 23	Very Clear 27
Did you read instructions?	No 11	Yes 40			
Were written instructions clear?	Very Unclear 1	Unclear 0	OK 3	Clear 19	Very Clear 17
Was purpose description clear?	Very Unclear 0	Unclear 3	OK 8	Clear 22	Very Clear 16
WEARING THE METER					
Was meter easy to use?	Very Tough 0	Tough 0	OK 4	Easy 9	Very Easy 18
Did you ever forget to wear meter?	No 22	Yes 9			
Was meter easy to wear for 24 hours?	Never Again 3	Never-OK 4	OK 14	OK-Didn't Mind 5	Didn't Mind 4
KEEPING THE DIARY					
Was it easy to make entries?	Very Difficult 0	Difficult 1	OK 23	Easy 15	Very Easy 12
Were you unsure of code to use at any time?	No 46	Yes 5			
Were location codes easy to use?	No 3	Yes 48			
Did you remember to record location changes?	Always Forgot 0	Frequently Forgot 2	Sometimes Forgot 8	Occasionally Forgot 31	Never Forgot 7
Did wearing meter or keeping diary influence how you spent your time?	No 45	Yes 3			
Did you ever"cheat" after forgetting an entry?	No 44	Yes 3			
How much of a chore was keeping a diary?	Never Again 2	Never-OK 7	OK 25	OK-Didn't Mind 10	Didn't Mind 7
FILLING OUT THE QUESTIONNAIRE					
Did diary help your recall for questionnaire?	No 1	Yes 33			
Were any questions confusing?	No 43	Yes 5			
How much of a chore was questionnaire?	Never Again 1	Never-OK 5	OK 19	OK-Didn't Mind 11	Didn't Mind 14

TABLE C.5: SUMMARY OF PROFESSIONAL EMPLOYEES MAGNETIC FIELD EXPOSURE BY LOCATION

	INSTRUMENT MANUFACTURING FIRM		
	AVERAGE TIME, MINUTES	MEAN FIELD, mG	MAXIMUM FIELD, mG
ADMINISTRATION	26.6	0.8	6.0
COMMON AREAS	40.3	1.1	224.1
CUSTOMER SERVICE	<1.0	0.4	1.1
DESK	191.1	0.8	182.3
EDUCATION CLASSROOM	0.0	--	--
EDUCATION LAB	18.0	0.4	2.8
ELECTROTEK WING	12.9	0.5	1.2
ENGINEERING	3.4	0.7	4.6
LUNCHROOM	1.0	1.1	11.0
MANUFACTURING	7.7	1.5	97.3
OUT OF BUILDING	65.1	1.5	66.5
PURCHASING	12.0	0.3	2.8
TEST & REPAIR	0.9	0.4	0.7
USING EQUIPMENT	<1	10.3	56.9
TOTALS	378.1	0.9	224.1

TABLE C.6: SUMMARY OF MAGNETIC FIELD EXPOSURE BY EMPLOYEE (ALL LOCATIONS) (in MILLIGAUSS)

SUBJECT	N samples	HOURS	MEAN	MEDIAN	MAX	StDEV	GEOMEAN
1	7604	6.3	2.09	0.81	182.3	5.88	0.96
2	7210	6	1.26	0.74	224.1	6.17	0.64
3	8065	6.7	0.64	0.54	14.5	0.92	0.47
6	8844	7.4	0.84	0.67	19.7	1.03	0.62
7	6656	5.5	0.55	0.47	17.43	0.68	0.42
8	8545	7.1	0.51	0.49	8.17	0.27	0.49
9	6113	5.1	0.62	0.66	4.74	0.28	0.52

TABLE C.7: EMPLOYEE RESPONSES TO EVALUATION SURVEYS (PRODUCTION EMPLOYEE RESPONSES IN PARENTHESES)

QUESTION	NUMBER OF RESPONSES				
INSTRUCTIONS AND PROJECT DESCRIPTIONS					
Were verbal instructions clear?	Very Unclear 0	Unclear 0	OK 0	Clear 0 (2)	Very Clear 7 (2)
Did you read instructions?	No 4	Yes 3			
Were written instructions clear?	Very Unclear 0	Unclear 0	OK 0	Clear 2	Very Clear 1
Was purpose description clear?	Very Unclear 0	Unclear 0	OK 0 (1)	Clear 6 (2)	Very Clear 1 (1)
WEARING THE METER					
Was it easy to use meter functions?	Very Tough 0	Tough 0	OK 0	Easy 2	Very Easy 5
Did you ever take off the meter?	No 6 (3)	Yes 1 (1)			
Was meter easy to wear for 24 hours?	Never Again 0	Never-OK 0	OK 1 (1)	OK-Didn't Mind 0	Didn't Mind 6 (3)
Was being observed distracting?	Very Distracting		Somewhat distract (3)		Not Distracting (1)
KEEPING THE DIARY					
Was it easy to make entries?	Very Difficult 0	Difficult 0	OK 1	Easy 4	Very Easy 2
Were you unsure of code to use at any time?	No 6	Yes 1			
Were location codes easy to use?	No 0	Yes 7			
Did you remember to record location changes?	Always Forgot 0	Frequently Forgot 0	Sometimes Forgot 2	Occasionally Forgot 2	Never Forgot 3
Did wearing meter/keeping diary influence how you spent your time?	No 5 (4)	Yes 2			
Did you ever"cheat" after forgetting an entry?	No 5	Yes 1			
Was keeping the diary much of a chore?	Never Again 0	Never-OK 0	OK 2	OK-Didn't Mind 3	Didn't Mind 2
FILLING OUT THE QUESTIONNAIRE					
Did diary help your recall for questionnaire?	No 0	Yes 7			
Were any questions confusing?	No 7	Yes 0			
Was questionnaire much of a chore?	Never Again 0	Never-OK 0	OK 0	OK-Didn't Mind 4	Didn't Mind 3

EXHIBIT C-1 (Page 1 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #1
MEASUREMENT OF EXPOSURE OF HIGH SCHOOL PHYSICS STUDENTS

STATEMENT OF PURPOSE	CONFIRMED WITH PRINCIPAL INVESTIGATOR ON 8/27/96 **1. To test the recommendations for guidelines in a non-occupational setting, with particular attention to the collection of activity pattern data.** **2. To gather a set of quality data on the group, appropriate for inclusion in the EMF Program Database** **3. To provide an educational opportunity for the students** TYPE OF STUDY: EXPOSURE CHARACTERIZATION
What question(s) will the data be called upon to answer?	• What activity pattern collection methods are most successful with this group? • How does the A.P. prospective data and retrospective data compare with the data collected in the diaries? • What did the students find confusing? • Was the burden on the students reasonable? • How can the exposure of the subject group be characterized? • For the subject group, how does exposure in the school environment compare to the home or other environments? • What is the variation between/among students? • How can the students use the data and the data collection process to learn about physics and/or data collection?
AVAILABLE RESOURCES/ CONSTRAINTS	Instrumentation: 13 EMDEX II meters, available for approximately two weeks Manpower: Pam Bittner: well-trained with strong experience in PEM No secondary technician available Some support available from the teachers Approximately 40 manhours available over two weeks Time: Time for distribution and retrieval is only during class hours Length of study periods limited by student attention span Two-week window available for assessing four groups of students Financial: No other major costs anticipated beyond manpower
THE EXPOSURE MODEL	Measured parameters limited by the Instrumentation, the EMDEX II to Broadband and Harmonic Magnetic Flux Density (as a function of time) Exposure metrics could include: TWA Harmonic content Peak 95th percentile
STUDY DESIGN OUTLINE	

EXHIBIT C-1 (Page 2 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #1 MEASUREMENT OF EXPOSURE OF HIGH SCHOOL PHYSICS STUDENTS

SAMPLING STRATEGY	Subjects:	Volunteering physics students (and teachers, if meters available). All in each of three classes will be requested to volunteer. Up to 13 in each class as limited by meter availability. *Notes: 1) because this study's primary focus is to test the activity patterns collection methods, because 2) the number of subjects is small, and 3) because the funds are not available, we don't consider it necessary to select the participants randomly.*
	Time:	24 hours (2 groups) and 48 hours (1 group) *Notes: The 24 hour period is in response to two factors: the availability of the subjects (they disperse in all directions at the end of class), and that the output would be interesting for Purpose #3, allowing the students to compare their home exposure to school, etc. Since one class does not meet the day after we hand out meters, we will to test their attention span for the 48 hours.*
	Sample rate:	60 seconds in classes using the data for class assignment, so that the data quantity is such that students can examine it in a spreadsheet. 1.5 or 3 seconds for others, to maximize data collected.
SELECTION OF PARAMETERS	Magnetic flux density, harmonic and/or broadband, as a function of time, as limited by EMDEX II	
INSTRUMENTATION	EMDEX II. (available at no cost)	
DATA COLLECTION PROTOCOLS	Wear meter in waist pouch for 24+ (or 48+) hours, taking off only for bed and wet activities, using event markers and diaries to track changes in six major locations: home, school classroom, school other, travel, work, other, not wearing - sleeping, and not wearing other. A written protocol in outline form will be sufficient because only one investigator involved in project.	
ACTIVITY PATTERN DATA COLLECTION	All will use diary, including those without meters. All in two classes will fill out retrospective questionnaire in diary format. All in one class will fill out prospective questionnaire in timeline format. All will fill out subject information sheets.	
DATA MANAGEMENT PROCEDURES	The data set of each student will be coded as follows: *AAAAXXXX* where *AAAA* equals the first four digits of the subject's social security number, and the *XXXX* is the serial number of the EMDEX they are wearing. The EMDEXes will have the serial number visible. The number will be listed on the data files, questionnaires, diaries, and any other forms. Downloading will occur in classroom as part of educational goal. Data will be shipped to project headquarters for database entry and project analysis.	

EXHIBIT C-1 (Page 3 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #1 MEASUREMENT OF EXPOSURE OF HIGH SCHOOL PHYSICS STUDENTS

DATA ANALYSIS STRATEGIES	POSSIBILITIES: Exposure Data: Comparison among students, females, male Stratification by home, school, travel, other, etc. Comparison between students by class Comparison between teachers and students AP Data: Compare questionnaire data with diaries Compare prospective and retrospective questionnaires Determine how was instrument use for subjects? Determine what was confusing, unclear Determine how great the burden was on the subject Should either 1) ask the kids to give their thoughts about the instruments in an open discussion, or 2) provide a questionnaire requesting this information.
QUALITY ASSURANCE PLAN	**Instrument calibration verification:** Verify before start of pilots, and after completion. Also, ask subjects after each measurement session if any meter was dropped or otherwise abused **Instrument performance verification:** Before every issuance, verify operation of all axes coils **Data transfer:** Verify successful download by viewing the data graph, prior to turning off meter. **Data Collection: Meter operation:** Verify by reviewing data graph for "straight lines" to be sure meter was operating successfully **Data Collection: Diaries, Event Markers, and Wearing of Meters:** Verify quality of data by a confidential questionnaire to students that they wore the meter according to protocol, and marked any estimated events. **Data Management:** Backup data on two sets of disks. Use file naming conventions.
ESTIMATE UNCERTAINTIES	Quantitative estimate is beyond the scope. Variability anticipated includes: **Instrumentation accuracy:** should be <5%, based on manufacturer **Location of meter:** does it stay at waist while wearing? Where is it while off? Is it worn during all of the time that the student says it is? **Sample rate:** Assumption that every 3 seconds or 60 seconds represents a continuum. Did we miss the peaks? **Accuracy of activity pattern data:** How reliable are the student's diary times? Did they miss location changes? **Limitations of the procedures:** Limited number of subjects and limited time period of 24 (or 48) hours.

EXHIBIT C-1 (Page 4 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #1
MEASUREMENT OF EXPOSURE OF HIGH SCHOOL PHYSICS STUDENTS

DEVELOP ARCHIVAL PLAN	Methods: the study design and protocol documentation will be maintained for future review. A brief description will be included in all reports. Forms with descriptive information will be identified by the subject code and maintained. The non-anecdotal information will be input to a database for comparison with the exposure data Diary information will be coded and input to a database with the exposure data Raw data files will be maintained at project headquarters Summary files will be developed at project headquarters and submited to the investigator.
DEVELOP PLAN FOR SUBJECT-RELATED ISSUES	Introduction: Bittner will meet with class to present and hand out consent forms, show basic use of meter and holster. This will allow time for preliminary questions. Bittner phone number is given out for questions from subjects or parents. Consent forms: Use consent forms approved by human subjects committee Analysis timing: Data will be downloaded, and graphs printed, immediately upon return of meters. Diaries will be copied for students. Within 24-hours, students will be given a copy of their ASCII file, if requested, so that they may personally analyze their data for purposes of their class reports. The importance of not sharing information w/next class will be accentuated Anonymity: All data will be coded so that each subject can recognize his/her code. Students will be informed that all information is confidential, but they may *voluntarily* discuss their own data in their class discussion or reports. Education: Bittner will be prepared to introduce some basics about magnetic fields, and talk about research and data collection to the students. A PG&E representative will also visit two of the classes, as requested by the teacher, to provide further information. Bittner will assist the teacher in developing a series of short paper topics for the students, and will attend a question and answer session to assist the students with paper research and production.
REQUIRED DOCUMENT DEVELOPMENT	Consent forms Protocol outline Subject Information Sheets Diaries Instructions for Diaries and Wearing Meters Prospective questionnaire Retrospective questionnaire Evaluation survey, about study burden and clarity

EXHIBIT C-2 (Page 1 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #2: MEASUREMENT OF EXPOSURE OF INSTRUMENT MANUFACTURER EMPLOYEES

STATEMENT OF PURPOSE	CONFIRMED WITH PRINCIPAL INVESTIGATOR ON 8/27/96 1. To test the recommendations for guidelines in an occupational setting, with particular attention to the collection of activity pattern data. to the extent possible, those methods not tested in Pilot Study #1 should be tested here. Also test the same methods as Pilot Study #1, but with a different people type. TYPE OF STUDY: EXPOSURE CHARACTERIZATION
What question(s) will the data be called upon to answer?	• What activity pattern collection methods are most successful with this group? • How does the A.P. prospective data and retrospective data compare with the data collected in the diaries? *(Note: prospective questionnaires were not used in study.)* • What is most acceptable method of collecting prospective or retrospective data? • What level of effort is appropriate to expect from professional employees? • How many locations can be included, and not be considered too burdensome? • Observations: How many stationary people can one observer readily observe? • What are the parameters for selecting locations for the observed activity patterns?
AVAILABLE RESOURCES/ CONSTRAINTS	Instrumentation: 13 EMDEX II meters Manpower: Pam Bittner: well-trained with strong experience in PEM No secondary technician available Approximately 12 manhours available, plus six hours for planning Time: Time for distribution and retrieval is limited to work hours, as the professional schedules allow. Two-week window available. Financial: No other major costs anticipated beyond manpower Volunteers: Professional employees: must acknowledge busy schedules Production employees: some do not speak English The task will be to educate the volunteers sufficiently without impacting their productivity.

EXHIBIT C-2 (Page 2 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #2: MEASUREMENT OF EXPOSURE OF INSTRUMENT MANUFACTURER EMPLOYEES

THE EXPOSURE MODEL	Measured parameters limited by the instrumentation, the EMDEX II to Broadband and Harmonic Magnetic Flux Density (as a function of time) Exposure metrics could include: TWA Harmonic content Peak 95th percentile
STUDY DESIGN OUTLINE	
Sampling strategy	Subjects: Eight professionals in a variety of positions within the company (engineers, sales, accounting, president) At least four hourly production people on the manufacturing floor for observation. None will be selected randomly. Professionals will be requested by the president to volunteer, based on assumed interest and availability. Hourly will be recruited by their supervisor, based on their English comprehension and expected response. Time: Professionals will be set up individually in the morning. A 15-min appointment will be scheduled with each at the end of the day to download, debrief and evaluate. Therefore actual monitored time will be somewhat less than the workday.24 hours Production people will be observed for approximately one hour each. Observation of two simultaneously will be attempted. Sample rate: Fully utilize equipment: three-second intervals for broadband and harmonic measurements.
Selection of parameters	Magnetic flux density, harmonic and broadband, as a function of time, as limited by EMDEX II
Instrumentation	EMDEX II. (available at no cost)
Data Collection Protocols	Wear meter in waist pouch for selected period, taking off only for safety to person or instrument. Use event markers and diaries to track changes in locations. Exposure will not be displayed. A written protocol in outline form will be sufficient because only one investigator involved in project. Observed: Wear meter in waist pouch for selected period. Do not keep diary.
Activity Pattern Data Collection	Professional employees will use diary. Hourly employees will be observed by investigator. All participants will complete a retrospective questionnaire. Due to limited numbers no prospective questionnaire will be tested. Very basic subject information will be collected by investigator during meetings.

EXHIBIT C-2 (Page 3 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #2: MEASUREMENT OF EXPOSURE OF INSTRUMENT MANUFACTURER EMPLOYEES

Data Management Procedures	The data set of each employee will be coded as follows: *AAXXXX* where *AA* equals an assigned number, and the *XXXX* is the serial number of the EMDEX they are wearing. The EMDEX will have the serial number visible. The number will be listed on the data files, questionnaires, diaries, and any other forms. Downloading will occur at meter collection on a portable PC so that the participants can see and discuss their exposures. Data will be shipped to project headquarters for database entry and project analysis.
Data Analysis Strategies	POSSIBILITIES: Exposure Data: Comparison among students, females, male Stratification by home, school, travel, other, etc. Comparison between students by class Comparison between teachers and students AP Data: Comparison of questionnaire data with diaries will only be anecdotal because of limited numbers. Determine how was instrument use for subjects? Determine what was confusing, unclear. Determine how great the burden was on the subject
QUALITY ASSURANCE PLAN	Instrument calibration verification: Verify before start of pilots, and after completion. Also, ask subjects after each measurement session if any meter was dropped or otherwise abused **Instrument performance verification:** Before every issuance, verify operation of all axes coils **Data transfer:** Verify successful download by viewing the data graph, prior to turning off meter. **Data Collection: Meter operation:** Verify by reviewing data graph with user for "straight lines" to be sure meter was operating successfully **Data Collection: Diaries, Event Markers, and Wearing of Meters:** Review data with subject. Ask about errors in data or forgotten events. Ask about use of equipment and estimates of location during highest readings. **Data Management:** Backup data on two sets of disks. Use file naming conventions.
ESTIMATE UNCERTAINTIES	Quantitative estimate is beyond the scope. Variability anticipated includes: **Instrumentation accuracy:** should be <5%, based on manufacturer **Location of meter:** does it stay at waist while wearing? Where is it while off? **Sample rate:** Assumption that every 3 seconds represents a continuum. Did we miss the peaks? **Accuracy of activity pattern data:** Can we have this "rated" in the questionnaire? **Limitations of the procedures:** Limited number of subjects, limited time period, and limited stratification of environment.

EXHIBIT C-2 (Page 4 of 4)

STUDY PLAN NOTES FOR PILOT STUDY #2: MEASUREMENT OF EXPOSURE OF INSTRUMENT MANUFACTURER EMPLOYEES

DEVELOP ARCHIVAL PLAN	Methods: the study design and protocol documentation will be maintained for future review. A brief description will be included in all reports. Forms with descriptive information will be identified by the subject code and maintained. The non-anecdotal information will be input to a database for comparison with the exposure data Diary information will be coded and input to a database with the exposure data Raw data files will be maintained at project headquarters Summary files will be developed at project headquarters and submitted to the Investigator.
DEVELOP PLAN FOR SUBJECT-RELATED ISSUES	Introduction: Bittner met with volunteer professional employees during the week before the study. The pouch, meter, diary and output will be explained and exhibited. Bittner met with the supervisor of the production employees, to explain the project and supply consent forms. He will solicit participation. On study day, prior to monitoring, Bittner will explain: voluntary nature; confidentiality, purpose of observations. Consent forms: During initial meeting, hand out consent forms approved by human subjects committee. Collect on morning of study. Analysis timing: Data will be downloaded, and graphs of exposure vs. time will be shown immediately on a portable PC. Hard copies of graphs and diaries will be copied for employees and mailed with a thank you letter. A summary will be submitted to the president. Anonymity: All data will be coded so that each subject can recognize his/her code. Employees will be informed that all information is confidential.
REQUIRED DOCUMENT DEVELOPMENT	Consent forms Protocol outline Diaries Instructions for Diaries and Wearing Meters Retrospective questionnaire Evaluation survey, about study burden and clarity

EXHIBIT C-3

T. DAN BRACKEN, Inc.

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CONSENT FORM

Project: Pilot Study for Development of Recommendations for Personal EMF Exposure Measurement Guidelines

Principal Investigator:	T. Dan Bracken T. Dan Bracken, Inc. Portland, Oregon Phone (503) 233-2181
Co-Principal Investigator:	Paul C. Gailey Oak Ridge National Laboratory Oak Ridge, Tennessee Phone (615) 574-0419
Pilot Studies Coordinator:	Pamela Long Bittner Magnetic Measurements Kentfield, California Phone (415) 458-8893

Sponsor: U.S. Department of Energy, Oak Ridge National Laboratory

PURPOSE

The purpose of this pilot study is to test and evaluate guidelines developed for measurement of personal exposure to electric and magnetic fields (EMF). Currently, researchers follow different exposure measurement methods making it difficult to compare various data sets. These guidelines will assist researchers in gaining greater comparability of exposure data from different studies.

PROCEDURES

As a participant in this study, you will be asked to wear an EMF meter on your body. The meter is similar in size and weight to a portable "walkman" tape player. The meter collects and stores magnetic field measurements. You will be asked to keep a simple time card indicating daily activities such as waking up, commuting to work, going to bed, etc. You will be asked to complete a questionnaire regarding the use of particular electrical appliances at home and the use of particular equipment in the work place.

RISKS AND BENEFITS

At present no health effects can be linked to exposure to EMF at the levels we will be measuring. Although epidemiological studies have suggested an association between possible EMF sources and a risk of disease (e.g. living near power lines and leukemia risk in children), similar studies based on measurements of EMF have found no increase in the risk of disease in adults or children.

You will not be exposed to any additional EMF beyond what currently exists in your home or office. There are no known physical risks associated with wearing the EMF meter or participating in this study. The meter only measures magnetic fields and does not emit any magnetic energy while operating. The meter is fairly lightweight and can be worn comfortably in a pouch.

Exhibit C-3 continued

The benefit of participating in this study is to assist in developing guidelines for personal exposure measurement. At your request, you will receive a summary of your personal EMF exposure measurements as recorded by the meter you wore.

CONFIDENTIALITY

Your identity will remain confidential. Strict confidentiality will be maintained on all the measurement data, time cards, questionnaires, and individual records obtained from this study. All individual identifiers on the data collection forms will be replaced with a unique study code after the data is collected. We will retain a copy of the master code key until after the analysis is completed. This way we can provide a summary of the readings to you at your request. Once the analysis is completed, we will destroy the master key so the data can no longer be linked to specific individuals. You will never be publicly identified.

OTHER INFORMATION

If this study is being conducted at your work site, your employer knows about this study and has granted us permission to conduct it on these premises. You should understand that your decision to participate or not to participate in this study is voluntary and will not affect your employment status in any way.

PARTICIPANT'S STATEMENT

I ______________________________ (participant's name) have read the information provided above. The purpose, procedures, risks, and benefits of the study have been explained to me by ______________________________. I voluntarily agree to participate in this activity. I have had an opportunity to ask questions. I understand that further questions I may have about the research or about my rights as a subject will be answered by ______________________________ (name) ________________ (phone number). I understand that there are no known physical or health risks associated with my participation in this study. I may decide at any time to withdraw my consent and stop participating without any penalty or loss of benefits to which I am otherwise entitled.

Participant's Signature ______________________________ Date ____________
or Parent's/Guardian's Signature

Witness's Signature ______________________________ Date ____________

I ______________________________ (name of person obtaining consent) have discussed the above information with ______________________________ (participant's name) and have addressed questions to his/her satisfaction.

Signature of Person Obtaining Consent ______________________________

Date ____________

Consent Form approved by the ORAU/ORNL Committee on Human Studies (IRB #M1394) on 08/03/95.

August 9, 1995

EXHIBIT C-4
VOLUNTEER'S DIARY

INSTRUCTIONS FOR VOLUNTEERS

KEEPING YOUR DIARY:

We need to know where you are while you are wearing the EMDEX. Make an entry in the diary whenever you change locations as follows:

1. Remove the diary and pen from the pouch.
2. Enter the time displayed in the pouch window in the diary.
3. Push the "EVENT" button on the EMDEX by pressing the circle on the outside of the pouch.
4. Enter the Event number shown on the LCD.
5. Enter the new location.
6. Enter any comments you have

If you forget to make an entry when changing locations, then make the appropriate entry of the new location, and estimate and enter the time you moved to that location. You should not push the "EVENT" button. Instead, write "est" (estimate) in the "Event Number" column.

The locations to record include:

SC - School-Classroom
SN - School- Not in classroom
H - Home
T - Travel (including, walking, biking, riding)
W - Work
O - Other
Zz - Sleeping
XX - Not wearing meter (other than sleeping)

See other side for meter wearing instructions

VOLUNTEER'S DIARY

EMDEX Serial # __________

Subject Code ___________

Engineer: Pam Bitner Phone: 458-8893

Date Started: _______

Date to be Returned: ________

Time	Event Number	Location	Comments
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
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EXHIBIT C-4
VOLUNTEER'S DIARY continued

INSTRUCTIONS FOR VOLUNTEERS

WEARING YOUR EMDEX:

Wear the EMDEX for a minimum of 24 hours beginning when you receive the meter.

Do not wear the EMDEX if it is likely to damage the instrument (i.e. vigorous exercise, showering, etc.), or adversely effect your safety. If you have to remove the EMDEX, place it in a safe place and make an "XX" entry in the diary.

While sleeping, place the EMDEX next to your bedside, but away from an electrical appliances, such as a clock or radio. Make a "ZZ" entry in your diary.

If you don't understand any of these instructions, you may call the engineer listed on the diary.

See other side for instructions on keeping your diary

VOLUNTEER'S DIARY

CONTINUED FROM OTHER SIDE

EMDEX Serial # __________

Subject Code __________

Date: __________________

Time	Event Number	Location	Comments
:			
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EXHIBIT C-5

EMF PERSONAL EXPOSURE MONITORING
RETROSPECTIVE ACTIVITY QUESTIONNAIRE

1. Subject's Code _ _ _ _ Sex F / M Age ___ Grade ___

2. Do you live in a: House or Apartment? (Circle One).

3. What methods of travel did you use in the past 24 hours? (Circle all that apply.)
Walking Bike Car Other

4. If you went to a job, yesterday, describe the job and location. ____________________

5. In the same format that you kept the diary, write down the list of locations where you spent your last 24 hours, and the approximate time you entered each location. The locations to record include:

SC - School-Classroom
SN - School- Not in classroom
H - Home
T - Travel (including walking, biking, riding)
W - Work
O - Other
Zz - Sleeping
XX - Not wearing meter

Time	Location	Comments
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________

Diary continued:

Time	Location	Comments
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________
__:__	______	________________

6. Review the entries in question #5, above:
Next to any times and/or locations for which you are *unsure* place a **question mark ("?")**.

Circle those times for which you are *<u>very</u> confident* (i.e. leaving class at 8:52).

EMF RETROSPECTIVE ACTIVITY QUESTIONNAIRE
Page 2

7. While at home, how many hours were you awake? (Add last evening and this morning) ________ hours.

How much of that time did you spend in each of the following areas? Next to each entry specify whether your estimate is in hours or minutes.

Your bedroom __________ (hr or min)
Kitchen __________ (hr or min)
Bathroom __________ (hr or min)
Room most used as a "family" room __________ (hr or min)
(could be living room or den)
Outside __________ (hr or min)
Other __________ (hr or min)
TOTAL =

8. Of the following list of activities, which ones did you do in the past 24 hours? Indicate the approximate time frame(s), and the locations in which they were performed:

ACTIVITY	(Y)ES /(N)O (U)NSURE	LOCATION CODE(S)	APPROX TIME(S)
Used Electric Tools			from ___ to ____ and ___ to ____
Used Power Saw			from ___ to ____ and ___ to ____
Used Hair Dryer			from ___ to ____ and ___ to ____
Used Sewing Machine			from ___ to ____ and ___ to ____
Used Microwave			from ___ to ____ and ___ to ____
Cooked at an Electric Stove			from ___ to ____ and ___ to ____
Rode BART			from ___ to ____ and ___ to ____
Used the Computer			from ___ to ____ and ___ to ____
Played Video Arcade Games			from ___ to ____ and ___ to ____
Used Electric Blanket			from ___ to ____ and ___ to ____
Watched Television			from ___ to ____ and ___ to ____
Did Laundry			from ___ to ____ and ___ to ____
Used Copy Machine			from ___ to ____ and ___ to ____
Used Overhead Projector			from ___ to ____ and ___ to ____

Location codes:
SC - School-Classroom
SN - School- Not in classroom
H - Home
T - Travel (including walking, biking, riding)
W - Work
O - Other
Zz - Sleeping
XX - Not wearing meter

9. Based on what you know about EMF's, in what other activities were you involved or places were you in where you might have been exposed to elevated field levels? List only those that were not mentioned in Question 8.

ACTIVITY and/or PLACE	LOCATION CODE(S)	APPROX TIME(S)
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___

Location codes:

SC - School-Classroom
SN - School- Not in classroom
H - Home
T - Travel (including walking, biking, riding)
W - Work
O - Other
Zz - Sleeping
XX - Not wearing meter

EXHIBIT 6

EMF PERSONAL EXPOSURE MONITORING
PROSPECTIVE ACTIVITY QUESTIONNAIRE

1. Volunteer's I.D. _ _ _ _ Sex F / M Age ___ Grade ___ Physics Period 1 / 2

2. Do you live in a: House or Apartment? (Circle One).

3. What methods of travel did you use in the past 24 hours? (Circle all that apply.)
Walking Bike Car Other

4. If you have a job, describe the job and location. ______________________________

---

5. We need you to guess where you will spend your time over the next 48 hours. Using the location codes which Ms. Bittner discussed (listed below), develop a time line, including each location to which you expect to go, starting with School ("S"), right now. Provide any additional information you think would be helpful in the "comments" column.

Alternatively, you may use the timeline format on Page 4 to document this data.

	Location	Time	Comments
	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________
then	_______	from __:__ to __:__	____________________

Location codes:

S - School
H - Home
T - Travel (including walking, biking, riding)
W - Work
O - Other
ZZ - Sleeping
XX - Not wearing

EMF PROSPECTIVE ACTIVITY QUESTIONNAIRE
Page 2

6. Review your entries to question #5. **Circle** those times and places which you feel *very confident* about. Place a **question mark ("?)** next to any place or time for which you are *unsure.*

7. Of the following list of activities, which ones do you expect to do in the next 48 hours? Indicate the approximate time frame(s), and the locations in which they will be performed:

ACTIVITY	**(Y)ES /(N)O (U)NSURE**	**LOCATION CODE(S)**	**APPROX TIME(S) and DAY (if you can't predict, enter "?")**
Use Electric Tools			
Use Power Saw			
Use Hair Dryer			
Use Sewing Machine			
Use Microwave			
Cook at an Electric Stove			
Ride BART			
Use the Computer			
Play Video Arcade Games			
Use Electric Blanket			
Watch Television			
Do Laundry			
Use Copy Machine			
Use Overhead Projector			

Location codes:

SC - School-Classroom
SN - School- Not in classroom
H - Home
T - Travel (including walking, biking, riding)
W - Work
O - Other
Zz - Sleeping
XX - Not wearing meter

EMF PROSPECTIVE ACTIVITY QUESTIONNAIRE
Page 3

8. Based on what you know about EMF's, in what other activities do you expect to be involved or places do you expect to be, where you might be exposed to elevated field levels?

ACTIVITY and/or PLACE	LOCATION CODE(S)	EXPECTED EMF SOURCE

Location codes:

SC - School-Classroom	W - Work
SN - School- Not in classroom	O - Other
H - Home	Zz - Sleeping
T - Travel (including walking, biking, riding)	XX - Not wearing meter

9. While at home, how much of your waking hours will you spend in the following areas on a typical weekday? (Note whether each entry is in hours, minutes, or both).

Your bedroom ________ (hours or minutes)
Kitchen ________
Bathroom ________
Room most used as a "family" room ________
(could be living room or den)
Outside ________
Other ________
TOTAL = ________ hours

EMF PROSPECTIVE ACTIVITY QUESTIONNAIRE
Page 4

Timeline Day 1

8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00

Timeline Day 2

8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00

EXHIBIT C-7
Pilot Study #1: High School Students
INVESTIGATOR'S PROTOCOL CHECKLIST

ONE WEEK BEFORE MEASUREMENT

Introduction to participants: attend classes to introduce project

_____ 1. Introduce self
_____ 2. Describe project purpose
_____ 3. Illustrate use of meter and holster
_____ 4. Illustrate use of diary
_____ 5. Hand out and discuss consent forms
_____ 6. Discuss confidentiality issues
_____ 7. Discuss how project will fit into class lessons
_____ 8. Answer questions

NIGHT BEFORE MEASUREMENTS

Measurement session preparation

_____ 1. Check and resupply field kit
_____ 2. Put together EMDEX packages: diary, pencil, EMDEX
_____ 3. Install fresh battery and perform EMDEX functional check
_____ 4. Identify EMDEX serial numbers on diary cards and questionnaires

MORNING OF MEASUREMENTS

Measurement session preparation

_____ 1. Initialize EMDEXes

DEPLOYMENT PERIOD

Project Introduction and Setup

_____ 1. Verify voluntary status: collect consent forms
_____ 2. Hand out meters and questionnaires

DEPLOYMENT PERIOD (CONTINUED)

_____ 3. Demonstrate the placement of the holster on the body
_____ 4 Start meters (must get going quickly in order to gather 24-hour data by beginning of next class)
_____ 5. Request that each participant make up a four-digit code and mark it on the diary and questionnaires
_____ 6. Describe the purpose of the questionnaires and diaries with respect to the study purpose.
_____ 7. Answer any questions

Prospective Questionnaires

_____ 1. For one group hand out prospective questionnaires and ask for their completion.

Describe Use of Meters

_____ 1. Wear on waist for 24-hour period
_____ 2. Meter is measuring every 60 seconds
_____ 3. Only take off for sleep, showers, sporting events etc, or other times when might effect the safety of the wearer
_____ 4. During sleep: lie at bedside, away from electric clock, etc.
_____ 5. Very expensive instruments: need to take care.
_____ 6. Illustrate event marking: have all students try it.

Explain Diaries: Each time the student changes environments the new environment should be recorded as follows

_____ 1. Time registered should be that time on the EMDEX LCD
_____ 2. The EMDEX "event" button should be pushed, and the Event number shown on the LCD recorded in space provided.

CONTINUED

EXHIBIT C.7 (CONTINUED)
Pilot Study #1: High School Students
INVESTIGATOR'S PROTOCOL CHECKLIST

DEPLOYMENT PERIOD (CONTINUED)

_____ 3. The appropriate environment code should be recorded:
  - a. **SC- School Classroom:** inside the walls of a classroom
  - b. **SO** - School Other: on school property, but not inside the walls of a classroom
  - c. **H** - Home: inside the individual's home, or the yard of that home
  - d. **T - Travel:** in any environment where traveling from location to another, by foot, bike, or vehicle
  - e. **W - Work:** on work premises
  - f. **O - Other:** In any environment other than those listed
  - g. **ZZ - Sleeping:** while sleeping, meter will not be worn, but will be in proximity to the bed.
  - h. **XX - Not wearing:** other than sleeping, any time during which the meter is not worn

_____ 4. If the student forgets an entry, he should record the new environment, enter the estimated time of the event, and write "est" Ion the "event number" column. The event marker need not be pushed

_____ 5. The comment column is for anything the student wishes to clarify or record.

RETRIEVAL

Retrieval:

_____ 1. Confirm that 24-hours have past since each meters deployment by checking the time on the LCD.

_____ 2. Collect the meters, holsters and diaries

_____ 3. Confirm that the codes on all forms match.

RETRIEVAL (CONTINUED)

_____ 4. Log in all consent forms, questionnaires, diaries, evaluations, and EMDEX data.

Downloading Data (Steps 1-3 on site at School A)

_____ 1. Download each meter, naming the eight-digit number selected for the student.

_____ 2. Print graphs for each student

_____ 3. Request that each student compare their diary to their graph and note what they think are sources of the peak exposures.

ACTIVITY PATTERN REVIEW

Retrospective questionnaires

_____ 1. For two of the groups, hand out retrospective questionnaires and ask for their completion.

QUALITY ASSURANCE AND DATA MANAGEMENT

_____ 1. Perform quality assurance on the EMDEX Data
  - a. Confirm that there are no flat lines in the graph, indicating a possible meter disorder.
  - b. (Further assurance will be included on a questionnaire, asking if the meter was dropped or otherwise abused, or if the students wore the meter as stated.)

_____ 2. Save the data on floppy disks, as the eight-digit file name.

_____ 3. Make copies of all data and forward to project headquarters.

EXHIBIT C.8

EMF PERSONAL EXPOSURE MONITORING
EVALUATION of PARTICIPATING IN THE STUDY

These questions are to help us evaluate our success in designing a study protocol which is easy to implement, and very clear to the volunteers.

INSTRUCTIONS AND PROJECT DESCRIPTIONS		
1.	How clear were the verbal instructions presented?	Very Unclear Unclear OK Clear Very Clear ☐ ☐ ☐ ☐ ☐
2.	Did you read the instructions on the diaries?	Yes / No
	2a. If yes, how clear were the written instructions?	Very Unclear Unclear OK Clear Very Clear ☐ ☐ ☐ ☐ ☐
3.	How clear was the description of the purpose of this study?	Very Unclear Unclear OK Clear Very Clear ☐ ☐ ☐ ☐ ☐
WEARING THE METER		
4.	How easy was it to use the meter's functions?	Very Tough Tough OK Easy Very Easy ☐ ☐ ☐ ☐ ☐
5.	Did you ever take the meter off for sports, safety, or other reasons?	Yes / No
6.	Overall, how much of a burden was it to wear the meter during your work day?	UGH! Never Again! OK Didn't mind at all ☐ ☐ ☐ ☐ ☐
KEEPING THE DIARY		
7.	How easy was it to make entries into the dairy?	Very Difficult Difficult OK Easy Very Easy ☐ ☐ ☐ ☐ ☐
8.	Was there any time(s) that you were unsure of which location code to choose?	Yes/No
	8a. If yes, what were the circumstances?____________________ ______________________________	
9.	Were the *codes* for the locations ("D" for desk, etc.) easy to use?	Yes/No

EMF PERSONAL EXPOSURE MONITORING
EVALUATION of PARTICIPATING IN THE STUDY
PAGE 2

10. How successful were you in remembering to record changes in location?

Always Forgot	Frequently Forgot	Sometimes Forgot	Occasionally Forgot	Never Forgot
☐	☐	☐	☐	☐

10a. If no, which codes were confusing?______________________________

11. Did wearing the meter and/or keeping the diary have an influence on where and how you spent your time? Yes / No

11a. How? ______________________________

12. Did you ever "cheat" when you forgot to make an entry at a location change, and push the event market rather than writing in an estimate, as was explained? Yes / No

13. Overall, how much of a chore was at to keep a diary?

UGH! Never Again!		OK		Didn't mind at all
☐	☐	☐	☐	☐

FILLING OUT THE QUESTIONNAIRE

14. Think about the time/location questionnaire that you filled out. If you just completed a *retrospective* questionnaire, did having filled out the diary help you to more easily recall the information to fill out the questionnaire? If you completed your questionnaire this morning, skip to #15. Yes / No

15. Were any questions or parts of the questionnaire confusing? Yes / No

15a. If yes, which questions?______________________________

____

16. Overall, how much of a chore was it to complete the questionnaire?

UGH! Never Again!		OK		Didn't mind at all
☐	☐	☐	☐	☐

EXHIBIT C-9

INSTRUCTIONS FOR VOLUNTEERS

KEEPING YOUR DIARY:

We need to know where you are while you are wearing the EMDEX. Make an entry in the diary whenever you change locations as follows:

1. Remove the diary from the pouch.
2. Enter the time on your watch.
3. Push the "EVENT" button on the EMDEX by pressing the circle on the outside of the pouch.
4. Enter the Event number shown on the LCD.
5. Enter the new location.
6. Enter any comments you have

If you forget to make an entry when changing locations, then make the appropriate entry of the new location, and estimate and enter the time you moved to that location. You should not push the "EVENT" button. Instead, write "est" (estimate) in the "Event Number" column.

The locations to record include:

A-Administration
C-Common Areas
D-Desk
EC-Education: Classroom
EL-Education: Lab
Elect-Electrotec
Eng-Engineering
L-Lunchroom
M-Manufacturing
O-Out of Building
P-Purchasing
T-Test & Repair
U-Using Equipment
XX - Not wearing meter

VOLUNTEER'S DIARY

EMDEX Serial # __________

Subject Code ____________

Engineer: Pam Bittner Phone: 458-6893

Date Started: _______

Date to be Returned: ________

Time	Event Number	Location	Comments/ Equipment
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			
__:__			

EXHIBIT C-9
VOLUNTEER'S DIARY continued

INSTRUCTIONS FOR VOLUNTEERS

WEARING YOUR EMDEX:

Wear the EMDEX in the waist pouch until the agreed upon time for meter retrieval this afternoon.

Do not wear the EMDEX if it is likely to damage the instrument (i.e. vigorous exercise, showering, etc.), or adversely effect your safety. If you have to remove the EMDEX, place it in a safe place and make an "XX" entry in the diary.

If you do not understand any of the wearing instructions or diary instructions, see Pam Bittner at the site.

See other side for instructions on keeping your diary

VOLUNTEER'S DIARY

CONTINUED FROM OTHER SIDE

EMDEX Serial # ____________

Subject Code ____________

Date: ____________________

Time	Event Number	Location	Comments/ Equipment
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			
:			

EXHIBIT C.10

There are several ways to request information about your activity pattern, or location data. Here we suggest and test two.

Page 1-version A asks for very specific information about when you spent time in the various locations.

Page 2-version B only asks for estimates of total time.

Version A provides us with more relevant information, but if you change locations frequently, such a recollection may not be possible or practical.

Please review Page 1 version A, and if you think you can fill it out with some confidence, do so. Then skip to Page 2.

If you think it would be impractical to recreate your movements, as requested in Version A, please move to Version B on the next page.

EXHIBIT C.10

EMF PERSONAL EXPOSURE MONITORING
RETROSPECTIVE ACTIVITY QUESTIONNAIRE

Subject's Code ________ **Page 1 version A**

In the same format that you kept the diary, write down the list of locations where you spent your work day, and the approximate time you entered each location. The locations to record include:

A-Administration
C-Common Areas
D-Desk
EC-Education: Classroom
EL-Education: Lab
Elect-Electrotec
Eng-Engineering
L-Lunchroom
M-Manufacturing
O-Out of Building
P-Purchasing
T-Test & Repair
U-Using Equipment
XX - Not wearing meter

Time	Location	Equipment/Comments
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________

Diary continued:

Time	Location	Equipment/Comments
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________
__:__	____	____________

Review the entries above:

Next to any times and/or locations for which you are *unsure* place a **question mark ("?")**.

Circle those times for which you are *very confident.*

When you are at your desk is your computer:
Almost Always On ____ Sometimes On___ Don't use a Computer____.

EXHIBIT C.10

EMF PERSONAL EXPOSURE MONITORING RETROSPECTIVE ACTIVITY QUESTIONNAIRE

Subject's Code _ _ _ _ _ _ _ _ _ **Page 1: version B**

For each of the locations listed on the diary, estimate how much time you spent there during the time you wore a magnetic field meter. If any locations were not included in the code list where you spent significant time, please identify them in the final few rows.

LOCATION	TIME (designate minutes and/or hours	% of TOTAL (optional: to help you calculate time)
A-Administration		
C-Common Areas		
D-Desk		
EC-Education: Classroom		
EL-Education: Lab		
Elect-Electrotec		
Eng-Engineering		
L-Lunchroom		
M-Manufacturing		
O-Out of Building		
P-Purchasing		
T-Test & Repair		
U-Using Equipment		
XX - Not wearing meter		

Review the entries above:

Next to any times for which you are *unsure* place a **question mark ("?")**.

Circle those times for which you are *very confident*.

When you are at your desk is your computer?:

Almost Always On ____ Sometimes On___ Don't use a Computer _____.

EMF RETROSPECTIVE ACTIVITY QUESTIONNAIRE
Page 2

What electrical appliances and equipment did you use during the study period? Indicate the approximate time frame(s), and the locations in which they were used. For your reference, a list of typical office equipment has been attached to this survey.:

EQUIPMENT	LOCATION CODE(S)	APPROX TIME(S)
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___

Location codes:

A-Administration
C-Common Areas
D-Desk
EC-Education: Classroom
EL-Education: Lab
Elect-Electrotec
Eng-Engineering
L-Lunchroom
M-Manufacturing
O-Out of Building
P-Purchasing
T-Test & Repair
U-Using Equipment
XX - Not wearing meter

Based on what you know about EMF's, in what activities were you involved or places were you in where you might have been exposed to elevated field levels *in addition to uses of equipment listed in the above section?*

ACTIVITY and/or PLACE	LOCATION CODE(S)	APPROX TIME(S)
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___
		from ___ to ___ and ___ to ___

EXHIBIT C.11

Pilot Study #2: Employees of Instrument Manufacturer
INVESTIGATOR'S PROTOCOL CHECKLIST

ONE WEEK BEFORE MEASUREMENT

Introduction to participants: attend classes to introduce project

____ 1. Introduce self
____ 2. Describe project purpose
____ 3. Illustrate use of meter and holster
____ 4. Illustrate use of diary
____ 5. Hand out and discuss consent forms
____ 6. Discuss confidentiality issues
____ 7. Answer questions

NIGHT BEFORE MEASUREMENTS

Measurement session preparation

____ 1. Check and resupply field kit
____ 2. Put together EMDEX packages: diary, pencil, EMDEX
____ 3. Install fresh battery and perform EMDEX functional check
____ 4. Identify EMDEX serial numbers on diary cards and questionnaires
____ 5. Assign two-digit codes and mark them on diaries and questionnaires

MORNING OF MEASUREMENTS

Measurement session preparation

____1. Initialize EMDEXes

DEPLOYMENT PERIOD

Project Introduction and Setup: Meet with each employee individually to:

____ 1. Verify voluntary status: collect consent forms

DEPLOYMENT PERIOD (CONTINUED)

____ 2. Hand out meter
____ 3. Demonstrate the placement of the holster on the body
____ 4. Start meter data collection
____ 5. Log in employee by the two digit code and document EMDEX serial number
____ 6. Describe the purpose of the questionnaires and diaries with respect to the study purpose. (Diaries used by professional employees only)
____ 7. Explain to production employees that observer will only be documenting their activities and/or locations with respect to magnetic fields - not productivity.
____ 8. Answer any questions

Describe Use of Meters

____ 1. Wear on waist for period of: workday for professional employees, 1.5 hours for production employees.
____ 2. Meter is measuring every 3 seconds
____ 3. Only take off when safety of wearer or meter might be compromised.
____ 4. Very expensive instruments: need to take care.
____ 5. Professional Employees: Illustrate event marking.

Explain Diaries - Professional Employees: Each time the employee changes environments the new environment should be recorded as follows

____ 1. Time registered should be that on employee's watch.
____ 2. The EMDEX "event" button should be pushed, and the Event number shown on the LCD recorded in space provided.

CONTI. D

EXHIBIT C.11 (CONTINUED)
Pilot Study #2:
Employees of Instrument Manufacturer
INVESTIGATOR'S PROTOCOL

DEPLOYMENT PERIOD (CONTINUED)

_____ 3. The appropriate environment code should be recorded, according to the list printed on the diary. Review list w/ employee and confirm that they understand the locations. Explain:

D-Desk Is the employees own desk
U-Using Equipment should be used when equipment is used in any area. However, the employee's use of the their own PC is assumed at their desk, and should not be recorded.
XX-Not wearing meter should be used if the client must take off the meter for sport or other.

_____ 4. If the employee forgets an entry, he should record the new environment, enter the estimated time of the event, and write "est" ion the "event number" column. The event marker need not be pushed.

_____ 5. The comment column is for anything the employee wishes to clarify or record, and to describe any equipment used.

OBSERVATION: PRODUCTION EMPLOYEES

_____ 1. Prior to commencement of study determine method of stratifying the work area of the production employees:

_____ 2. For a two periods of one-to 1.5 hours, document the time and changes in employee activity or location within the work area.

RETRIEVAL

Retrieval: In the individual afternoon meetings:

RETRIEVAL (CONTINUED)

_____ 1. Collect the meter, pouch and diary
_____ 2. Confirm that the codes on all forms match.
_____ 3. Log in the consent form, diary, and EMDEX data.

Downloading Data

_____ 1. Download the meter, naming the EMDEX file with the six number selected for the student.

_____ 2. Create the graph of personal exposure vs. time and show to the employee on the portable PC.

_____ 3. Request that the employee compare his/her diary to the graph and describe what might be the sources of the peak exposures.

ACTIVITY PATTERN REVIEW

Retrospective questionnaires: While downloading:

_____ 1. Provide the retrospective questionnaires and ask for its completion.

QUALITY ASSURANCE AND DATA MANAGEMENT

_____ 1. Perform quality assurance on the EMDEX Data
   a. Confirm that there are no flat lines in the graph, indicating a possible meter disorder.
   b. (Further assurance will be included on a questionnaire, asking if the meter was dropped or otherwise abused.)

_____ 2. Save the data on floppy disks, as the eight-digit file name.
_____ 3. Make copies of all data and forward to project headquarters.

EXHIBIT C.12

Date ________ **Subject Code:** ________

EMF PERSONAL EXPOSURE MONITORING
EVALUATION of PARTICIPATING IN THE STUDY

These questions are to help us evaluate ***our*** *success in designing a study protocol which is easy to implement, and very clear to the volunteers.*

INSTRUCTIONS AND PROJECT DESCRIPTIONS

1.	How clear were the verbal instructions presented?	Very Unclear ☐	Unclear ☐	OK ☐	Clear ☐	Very Clear ☐
2.	Did you read the instructions on the diaries?	Yes / No				
	2a. If yes, how clear were the written instructions?	Very Unclear ☐	Unclear ☐	OK ☐	Clear ☐	Very Clear ☐
3.	How clear was the description of the purpose of this study?	Very Unclear ☐	Unclear ☐	OK ☐	Clear ☐	Very Clear ☐

WEARING THE METER

4.	How easy was it to use the meter's functions?	Very Tough ☐	Tough ☐	OK ☐	Easy ☐	Very Easy ☐
5.	Did you ever take the meter off for sports, safety, or other reasons?	Yes / No				
6.	Overall, how much of a burden was it to wear the meter during your work day?	UGH! Never Again! ☐	☐	OK ☐	☐	Didn't mind at all ☐

KEEPING THE DIARY

7.	How easy was it to make entries into the dairy?	Very Difficult ☐	Difficult ☐	OK ☐	Easy ☐	Very Easy ☐
8.	Was there any time(s) that you were unsure of which location code to choose?	Yes/No				

8a. If yes, what were the circumstances?________________________

____

9.	Were the *codes* for the locations ("D" for desk, etc.) easy to use?	Yes/No				
10.	How successful were you in remembering to record changes in location?	Always Forgot ☐	Frequently Forgot ☐	Sometimes Never Forgot ☐	Occasionally Forgot ☐	Forgot ☐

EMF PERSONAL EXPOSURE MONITORING
EVALUATION of PARTICIPATING IN THE STUDY
PAGE 2

	10a. If no, which codes were confusing?________________________	
11.	Did wearing the meter and/or keeping the diary have an influence on where and how you spent your time?	Yes / No
	11a. How? ____________________________________	
12.	Did you ever "cheat" when you forgot to make an entry at a location change, and push the event market rather than writing in an estimate, as was explained?	Yes / No
13.	Overall, how much of a chore was at to keep a diary?	UGH! Never Again! OK Didn't mind at all ☐ ☐ ☐ ☐ ☐

FILLING OUT THE QUESTIONNAIRE

14.	Think about the time/location questionnaire that you filled out. If you just completed a *retrospective* questionnaire, did having filled out the diary help you to more easily recall the information to fill out the questionnaire? If you completed your questionnaire this morning, skip to #15.	Yes / No
15.	Were any questions or parts of the questionnaire confusing?	Yes / No
	15a. If yes, which questions?____________________________ ____	
16.	Overall, how much of a chore was it to complete the questionnaire?	UGH! Never Again! OK Didn't mind at all ☐ ☐ ☐ ☐ ☐

EXHIBIT C.13
Date ________

Subject Code: ________

EMF PERSONAL EXPOSURE MONITORING
EVALUATION of PARTICIPATING IN THE STUDY

These questions are to help us evaluate our success in designing a study protocol which is easy to implement, and very clear to the volunteers.

INSTRUCTIONS AND PROJECT DESCRIPTIONS

		Very Unclear	Unclear	OK	Clear	Very Clear
1.	How clear were the verbal instructions presented?	☐	☐	☐	☐	☐
		Very Unclear	Unclear	OK	Clear	Very Clear
2.	How clear was the description of the purpose of this study?	☐	☐	☐	☐	☐

WEARING THE METER

3. Did you ever take the meter off for sports, safety, or other reasons? Yes / No

		UGH! Never Again!		OK		Didn't mind at all
4.	Overall, how much of a burden was it to wear the meter during your work day?	☐	☐	☐	☐	☐

OBSERVATION

		Very Distracting		OK		Not Distracting
5.	How distracting was being observed during your work?	☐	☐	☐	☐	☐

6. Did wearing the meter have an influence on where and how you spent your time? Yes / No

6a. How? ________________________________