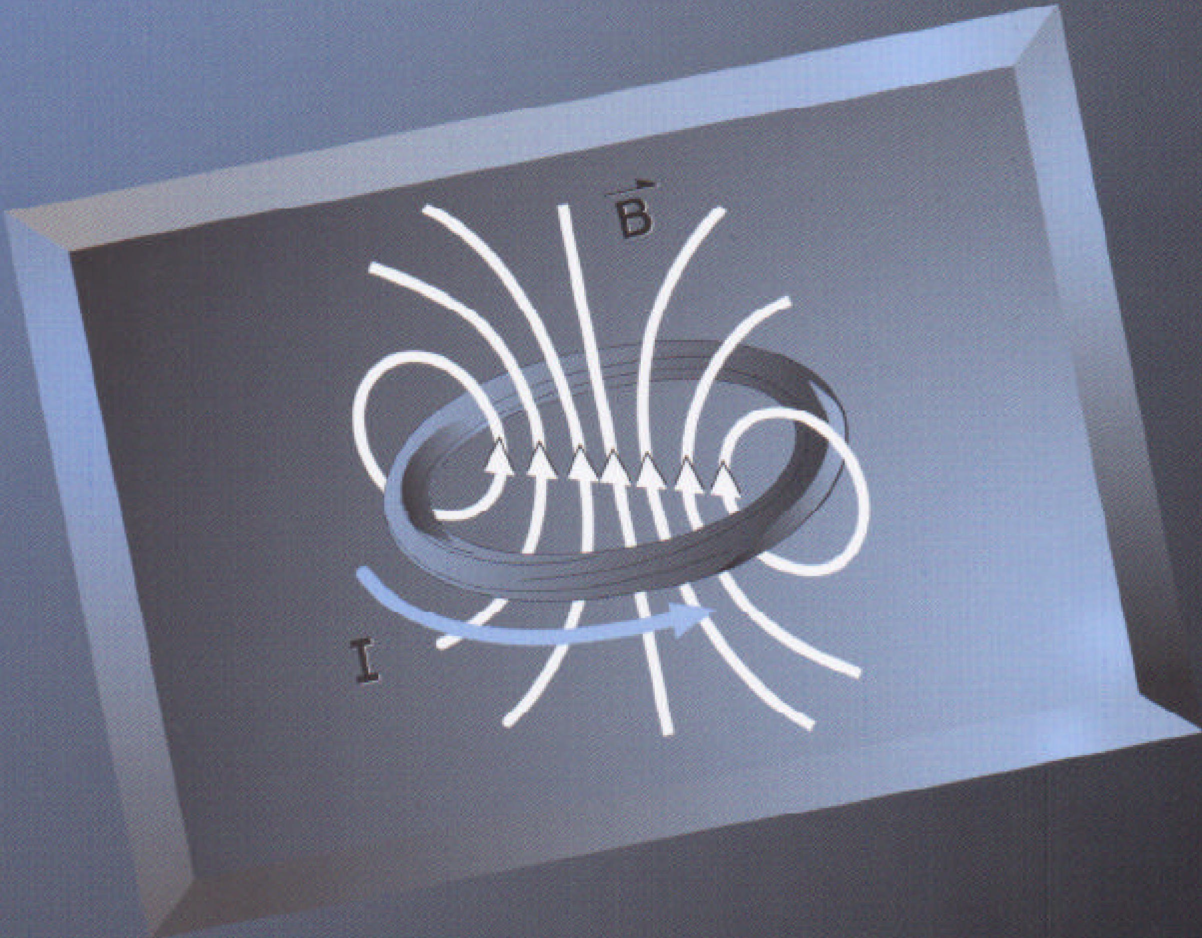
NIOSH

MANUAL FOR MEASURING OCCUPATIONAL ELECTRIC AND MAGNETIC FIELD EXPOSURES



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

MANUAL FOR MEASURING OCCUPATIONAL ELECTRIC AND MAGNETIC FIELD EXPOSURES

Joseph D. Bowman*
Michael A. Kelsh**
William T. Kaune***

* National Institute for Occupational Safety and Health
** EcoAnalysis, Inc., Ojai, CA
*** EM Factors, Inc., Richland, WA

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Biomedical and Behavioral Sciences

October 1998

DISCLAIMER

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Copies of this and other NIOSH documents are available from

Publications Dissemination, EID
National Institute for Occupational Safety and Health
4676 Columbia Parkway
Cincinnati, OH 45226

Fax number: (513) 533-8536

To order NIOSH publications or to receive information about occupational safety and health problems, call 1-800-35-NIOSH (1-800-356-4674)

DHHS (NIOSH) Publication No. 98-154

PREFACE

The National Institute for Occupational Safety and Health (NIOSH) has been studying whether electric and magnetic fields (EMF) from electrical equipment could cause cancer and other diseases since its Scientific Workshop on the Health Effects of EMF on Workers in 1991. The workshop's conclusions emphasized the need for better exposure assessments, and called for the development of standardized EMF measurement protocols. This undertaking is natural for NIOSH which throughout its 25-year history has developed and evaluated methods for measuring worker exposures to hazardous gases, vapors, and aerosols. These methods are published in a standardized format in the *NIOSH Manual of Analytical Methods*. Even though the health risks of EMF are research questions, exposure assessment protocols are still needed for epidemiologic studies, surveillance, and Health Hazard Evaluations. Therefore, the first edition of this document was prepared in 1992 for use by NIOSH investigators.

NIOSH has also been conducting exposure assessment research to develop new measurement methods based on biological mechanisms of interaction with EMF. To review this question, NIOSH and the Department of Energy sponsored a workshop on EMF Exposure Assessment and Epidemiology: Hypotheses, Metrics, and Measurements in 1994. The workshop's starting point was that the exposure assessment methods in previous epidemiologic studies did not measure all the EMF characteristics needed to predict the outcome of the most plausible biologic mechanisms. Although exposure assessments for health studies should clearly be guided by biology, there was no consensus on which EMF mechanisms were the most credible. The workshop concluded with many good ideas but no recommendations for the best way to do future EMF studies.

This uncertainty over which EMF features to measure clearly raises difficulties for developing standardized measurement protocols. On one hand, refining and testing a standard exposure assessment protocol is a questionable undertaking if the biologic assumptions underlying the method could be wrong. On the other hand, EMF epidemiologic studies and other health hazard evaluations are still taking place, and the scientific enterprise would be more productive if the investigators have some guidance on how to take measurements.

To address these contradictory concerns, this *Manual for Measuring Occupational EMF Exposures* has collected important assessment protocols from previous studies and printed them in a standard format, each with a summary of its important features and a critique of its strengths and limitations. Important parts of the manual are its system for summarizing the methods and its definitions of EMF measurement terminology.

The manual's philosophy is that providing investigators with successful methods from past studies will assist them in synthesizing protocols for their own applications. Exposure assessments serve many purposes: epidemiology, source assessment, compliance with guidelines, etc. Protocols written for one purpose can be of great value for other studies with minor modifications. As EMF biology evolves, these existing protocols can be the basis for improved methods.

By providing this service to exposure assessors, this manual can assist in research to determine whether EMF is a health hazard. Where disease risks are established, these methods can be used to measure workers' exposures and assess sources so that any EMF hazard can be reduced.

ABSTRACT

The purpose of this manual is to assist investigators in developing methods for occupational exposure assessments for electric and magnetic fields (EMF). Scientific reports that associate EMF with increased risks of various diseases have led to exposure assessments for the purposes of research, source assessment, and the surveillance of worker exposures. To provide guidance for these studies, methods that have been used successfully to measure EMF are summarized and presented in a standard format. The scope of the manual is methods for measuring occupational EMF with frequencies below 30 kHz. This covers most fields resulting directly from DC or 50/60 Hz AC electricity, as well as common electric and electronic equipment such as Video Display Terminals (VDT).

In this manual, exposure assessment protocols are classified either as complete methods or partial methods. Complete methods are sets of instructions for the sampling strategy, calibration, measurement, data management and calculation of EMF exposure metrics. The exposure metric and other information about the method are contained in a summary table accompanied by a critique of the method's strengths and weaknesses. Partial methods are essentially parts of a full method that emphasize important aspects of EMF exposure assessments: sampling strategies, spot measurement surveys, personal monitoring, area monitoring, measuring EMF characteristics, measuring EMFs from sources, walkthrough monitoring, quality control, calibration, data management, and calculating exposure metrics. By combining aspects of these complete and partial methods, industrial hygienists and other investigators can assemble protocols specifically tailored to assess EMF exposures for different purposes, applications, and work environments.

CONTENTS

I. INTRODUCTION

Purpose and Scope

This manual is a collection of procedures for measuring occupational exposures to electric and magnetic fields (EMF). Some epidemiological studies in occupational as well as non-occupational settings have found positive associations between EMF exposures and diseases such as cancer, and reproductive and neurobehavioral disorders.[1] Assessment of the reported health effects has been impeded by limited data on EMF exposures as well as an inadequate understanding of why humans and other living systems may be sensitive to such exposures. Therefore, NIOSH has undertaken the measurement of workers' exposures to these fields as part of an effort to assess the possibility that EMFs pose some health risk.[2]

The purpose of this manual is to assist investigators in developing methods for exposure assessments of EMF in workplaces. NIOSH undertook this project because of its historic commitment to developing methods for measuring occupational exposures to hazardous gases, vapors and aerosols, and disseminating this information through the *NIOSH Manual of Analytical Methods.*[3] To provide this service for exposure assessments investigating EMF's potential risks, state-of-the-art measurement procedures that have been used successfully in health-related studies are collected, summarized, and presented in a standard format. Industrial hygienists, epidemiologists, engineers, and other investigators with a knowledge of EMF can use the manual to define the exposure characteristics that should be measured, to assemble measurement methods tailored to fit their study's requirements, to develop sampling strategies, and to plan data summarizations and exposure data analysis. This manual contains procedures for measurements appropriate in preliminary surveys, Health Hazard Evaluations, hazard surveillance, epidemiological studies, and control technology assessments.

It is not the purpose of this manual to present a definitive measurement or exposure assessment protocol that will be applicable to all research needs. Electric and magnetic fields are complex physical agents whose potential health effects are the subject of much research. Particularly controversial are the biophysical mechanisms by which these extremely low-energy fields may affect biological systems.[4] Knowledge of biological mechanisms has historically been the source from which the occupational and environmental sciences have developed quantities for summarizing exposures to complex agents in health-effect studies. The resulting "exposure metrics" such as the Time-Weighted Average (TWA), respirable dust, and the A-weighting for noise are fundamental to industrial hygiene and occupational health.

With EMF, the uncertainty about the underlying biophysical mechanisms has meant uncertainty as to how exposure should be measured. Despite research on which exposure metrics to use in health-effect studies,[5] we still do not know which metrics are important. Given the rapidly evolving understanding of EMF health risks and new developments in instrumentation, this flexible and expandable manual is the appropriate format for guiding EMF exposure assessment efforts. This flexibility allows for the selection of new exposure metrics specifically tailored to the unusual EMF environment that may be found in many workplaces. The format of this manual facilitates the creation of new methods that may be useful in future research.

Determining disease risks from these measurements is a complex undertaking that is beyond the scope of this manual. Although exposure metrics such as the TWA magnitude of the ELF magnetic field have been associated with increased disease risks in some epidemiologic studies, a cause-and-effect relationship has not been established. For other metrics, no associations with disease have been reported. Overall, NIOSH has concluded:[6]

> NIOSH and other government agencies do not consider EMFs a proven health hazard. Because some studies have associated high magnetic field exposures with increased cancer risks, the government will continue studying EMFs. While research continues, concerned workers and employers might consider simple, inexpensive measures for reducing EMF exposures.

With the uncertainty surrounding EMF's health effects, assessment of disease risks from EMF measurements requires a case-by-case review of the applicable research. Furthermore, the methods described in this manual have not been designed to evaluate the compliance of EMF environments with exposure limits from government regulatory agencies or guidelines from independent groups.[7]

The manual's scope is primarily measurement procedures for electric and magnetic fields with extremely low frequencies (ELF = 3-3000 Hz). Also included are occupational EMF below the radio frequency range (<30 kHz). This scope covers most EMF resulting directly from DC or 50/60 Hz AC electricity, as well as from common electric and electronic equipment such as Video Display Terminals (VDT).

The manual contains methods and procedures that can be used to measure and summarize occupational exposures. Both occupational and residential studies are included. Many methods are unpublished protocols which were obtained from the authors. Published protocols have not been re-printed. A few partial methods have been written for this manual, based on unpublished procedures in successful studies. For the most part, the protocols have not been edited.

These measurement procedures were developed to measure EMF from AC electric lines and are applicable to most "continuous wave" ELF fields (*i.e.*, regular oscillations of any wave shape with stationary frequency spectra and slowly varying amplitudes). The extension of these procedures to transients and irregular oscillations occasionally found in occupational EMF requires additional evaluation, and should be done in consultation with engineers, physicists, and industrial hygienists experienced in EMF.

This manual's scope is limited to quantitative exposure assessment, and does not include EMF surrogates, such as job titles or wire configurations. The methods only deal with measurements of present exposure, and not the estimates of past exposures used in retrospective epidemiological studies. Finally, these methods only measure physical characteristics of EMF exposures, and not dose metrics such as internal body currents which must be calculated with models of the field's biological interactions.

How the Manual is Organized

This manual has five major components: an introduction (Part I), the summarization of electric and magnetic field exposure studies as complete methods (Part II) or partial methods (Parts III), definition of terms and units (Part IV), and an index. The core of the manual are the complete and partial methods in Part II and III. The **complete methods** is a full set of instructions for measuring a worker's exposure, usually covering the following topics:

- Equipment
- Preparation
- Sampling strategy
- Measurement
- Quality control
- Data management
- Calculation and data summarization

A **partial method** is an excerpt from a protocol or an incomplete protocol that covers one or more of these topics. The partial methods in Part III are grouped both by the topics that they cover and by the type of exposure assessment for which they are appropriate (workplace survey, personal exposure monitoring, etc.).

With this organization, the Manual contains an array of important exposure assessment methods that can be assembled into new protocols for particular applications. An industrial hygienist (IH) or other investigator can identify the desired methods by searching the indices and summary tables. The techniques obtained from such a search are the raw material from which a finished method can be written.

How the Methods are Organized

Methods have two major parts: the **method summary** and the original detailed protocols. The method summary consists of a **summary table** with the defining features of the method in a standard format (Table 1). The features in the summary tables are then used to index the methods according to their sampling strategies, instruments, and other characteristics. The most important features in each summary table are the **exposure metrics**, the EMF characteristics used to summarize exposures with a single numerical value. The method summary also includes a **critique,** briefly describing the strengths and weaknesses of each major component of the method.

The different items in the method summary are outlined below. Complete definitions of the terms in the summary table are in Part IV "Definitions".

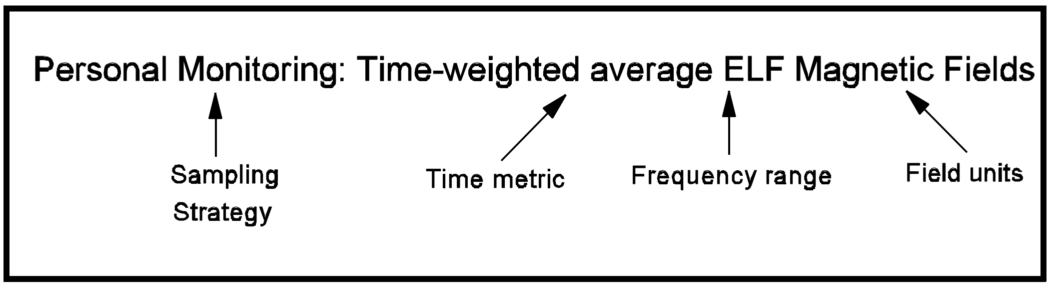
Table 1. Format of the summary table for methods.

Description and purpose	**Purpose:** **Strategy: I.** The first sampling strategy **II.** Second strategy, etc. **Study:** **Authors:** **Date:**

Sampling strategy I	**Description:** **Location:** **Duration:** **Subject (or site) selection:** **Other data:** **Instruments: A.** The first instrument **B.** Second instrument
Instrument I.A	**Model:** **Channels: 1.** The first channel **2.** Second channel, etc.
Channel I.A.1	**Description:** **Sensor:** **Frequency response:** **Time response:** **Sampling rate:** **Dynamic range:** **Accuracy:** **Output:**
Exposure metric I.A.1.a	**Final metric:** **Data processing:** **Units:**
Exposure metric I.A.1.b	**Final metric:** **Data processing:** **Units:**
Channel I.A.2	etc.

Method Title

The method title summarizes the salient features of the protocol, particularly the strategies employed, the sites where it was employed, and the exposure metric. No standard terminology for labeling methods has been previously proposed. Given the large number of parameters in exposure metrics, a method title covering all the possible options would either be a substantial sentence or a long string of manufactured abbreviations. In this manual, the title only uses words and abbreviations common in either occupational health or the standard definitions by the Institute for Electrical and Electronic Engineers.[8] The resulting titles specifies the more crucial aspects of the method, for example:



The Summary Table

The summary tables have a regular structure, as shown in Figure 1. The table's components are described below.

Description and Purpose

Purpose

The exposure assessment methods in this manual can be used for many purposes:

- Health hazard evaluation
- Epidemiology
- Hazard surveillance
- Control technology assessment
- Compliance with exposure guidelines

The summary table describes the purpose for which this method was originally developed.

Strategy

The strategies employed are classified into these broad types:

- <u>Spot measurement survey</u>: Spot (instantaneous) measurements are taken at body locations or work areas, generally with simple metrics such as the rms vector magnitude of the ELF magnetic field. Spot measurements do not capture the field's temporal variation.
- <u>Personal monitoring</u>: Personal monitors or "dosimeters" measure exposures over an hour, a shift, a day, or longer. In occupational environments, personal monitoring is usually the most accurate way to estimate a worker's exposure to one or more metrics.

- Area monitoring: An instrument takes measurements at defined locations in the workplace. Either spot measurements or continuous monitoring can be performed.
- Walkthrough survey: A monitor with a data logger is carried through the workplace, regularly measuring EMF along the way. Some monitors are designed to be attached to an electronic surveying wheel so that the location of each sample can be recorded with the field measurement.
- Source survey: Measurements are performed at specified locations around EMF sources.
- Field characterization: Measurements (either area or personal, spot or continuous) are made of detailed EMF characteristics, such as frequency, polarization, spatial orientation, and wave shapes.

Study/Author/Date

The study for which the method was developed (usually identified by a publication), the authors of the protocol, and the date of the original version.

Sampling Strategy

This section outlines the protocol's strategy for determining the locations, subjects, timing, duration, and instruments for measuring EMF exposures and collecting supplementary data. Most of the protocols in this *Manual* describe only the parts of the sampling strategy relevant to the person taking measurements. Other important components of the sampling strategy (*e.g.*. the scheme for selecting specific workers or the number of workers to monitor) are usually described in the epidemiologist's protocol and the published results.

Location

This describes where the instrument's probe is placed:

- a specified distance from sources
- typical work locations
- body parts (e.g., head, torso, gonads, extremities).
- walk-through surveys
- personal monitoring at one or more locations on the worker's body

Duration

This lists information on the timing and length of the measurements. This can include:

- Spot measurements
- Work-cycle (duty-cycle) monitoring
- Partial, full or multi-shift monitoring
- Full-day monitoring (for one or more days)
- Control assessment designs, e.g., with and without controls operating

Other data

This describes other data collected in order to assess exposure:

- Source characteristics (type , frequency, voltage, power, etc.)
- Distance to source
- Tasks performed by the worker during personal or area monitoring. They can be recorded by:

- Observation (by field personnel)
- Worker log
- Marker on the data logger (entered by worker)
- Electronic recording of tasks using barcode and data logger/sensor (e.g., TimeWand)

• Field notes or other observations

Subject (or Site) Selection
This describes a method of selecting the particular subjects and/or locations for the measurement.

Instrument

Model and manufacturer
This lists the model and manufacturer of the measurement instrument.

Channels
EMF instruments frequently have more than one sensor in order to measure an array of EMF characteristics. For example, the Positron™ monitor has a three-dimensional (3D) magnetic field sensor, an axial electric field sensor, and a high-frequency EMF "transient" sensor. Each of these probes has its own electronic circuitry for analyzing the signals and sending the output to a common datalogger. In this manual, each independent probe and the related circuitry is called a "channel". Three orthogonal (3D) probes served by identical circuitry (*e.g*. the 3D magnetic field probe in the Positron) is considered a single channel. Channels are generally defined by the type of field measured and its frequency bandwidth, *e.g*. an ELF magnetic field channel. The Multiwave™ System has multiple channels capable of recording many aspects of the electromagnetic environment such as the static magnetic field, ELF electric and magnetic fields, VLF-LF fields, transients, etc.

Sensor
This describes the type and number of sensors, including their spatial characteristics:

• For magnetic fields:
  - Induction coil (time-varying fields only)
  - Flux gate probe (low-amplitude static and ELF fields)
  - Hall effect probe (high-amplitude static and time-varying fields)

• For electric fields:
  - Free-field sensor
  - Body-grounded sensor
  - Earth-grounded sensor

Frequency Response
The instrument's frequency response includes the range and any filtering:

• Frequency ranges have been categorized as:[8]
  - Static 0 Hz
  - ULF < 3 Hz
  - ELF 3 - 3000 Hz
  - VLF 3 - 30 kHz

- Filter for the field’s frequencies, such as:
  - Narrowband
  - Broadband
  - Flat
  - Linear

The frequency response also contains more detailed filter specifications, such as the bandwidth and the frequency with unit response.

Time Response

Listed here are the instrument's methods of responding to the signal's time variations:

- True RMS (root-mean-square)
- Rectified average
- Corrected peak
- Peak
- Waveforms by analog-digital conversion
- Analog-to-digital conversion
- Integration of a dB/dt signal to obtain B

Sampling Rate

This is the rate at which monitors with digital dataloggers take and store samples (expressed as the time between the beginning of each sample).

Dynamic Range

This information includes the instrument’s range of response to field amplitudes, including the number of scales (if more than one) and whether it is a manual or auto-ranging instrument.

Accuracy

This item summarizes available data on the bias, precision, and accuracy of the instrument.

Output

The quantity which results from the analog signal processing, and the format for recording that information:

- Direct-reading (analog or digital)
- Digital data logger
- Data logger with bins
- Electrolytic cell with read-out unit

Exposure Metric

Exposure metrics are parameters selected to summarize the EMF exposure for evaluating possible health risks. Exposure metrics combine frequency, temporal, and spatial characteristics of the fields in order to arrive at a single summary value. Some examples of EMF exposure metrics are:

- RMS vector magnitude (resultant)
- Time Weighted Average (TWA)
- Geometric mean over time

- Maximum over time
- Frequency spectra
- Total harmonic distortion
- Polarization (linear, circular or elliptical)
- Maximum amplitude (the semi-major axis of an elliptically-polarized field)
- Waveforms (plots of field components vs. time)

Data Processing

How an exposure metric is calculated from the instrument's output, either by the instrument's software or during data analysis.

Units

This describes the quantity being measured, its mathematical symbol, and units in the SI and/or CGS systems:

- Electric field (E-field in volts/meter)
- Magnetic field [magnetic flux density in microtesla (μT) or milligauss (mG) or magnetic field strength in amperes/meter]
- Magnetic field derivative (dB/dt in tesla/sec)

Critique

For each strategy employed in a method, the reviewer provides a summary of the strengths, limitations, and applicability.

Protocol

The detailed instructions in the protocol are reprinted in this Manual if they are not in journals, books, or other publicly-available sources.

How to Use this Manual

Locating Complete and Partial Methods

Each method is characterized by an identification number, the authors, and the descriptors in the summary tables. The first digit (bolded below) of the 3-digit ID number indicates the protocol's primary strategy and/or technique:

000 Sampling strategies
100 Spot measurement surveys
200 Personal monitoring
300 Area measurements
400 Measuring EMF characteristics
500 Measuring EMF from sources
600 Walkthrough monitoring
700 Quality control and calibration
800 Data management
900 Calculating exposure metrics

The remaining two digits are assigned sequentially to each protocol as it is added to the manual. The complete methods in Part II and the partial methods in Part III are ordered by their unique ID numbers and listed in the table of contents.

How to Assemble a Method

This section presents some general guidelines for assembling a measurement method, either from the techniques in this manual or from other material.

- Determine clearly the purpose of the measurement, including the uses for the results and their relative importance. In an epidemiological study, the purpose is often stated as the primary and secondary hypotheses to be tested. For compliance sampling, a statement of the purpose would include the exposure limits against which the measurements will be compared. For any exposure measurement protocol, development is facilitated by a clear statement of purpose to assist in differentiating between essential and extraneous portions of the exposure assessment.

- Determine the type of exposure assessment appropriate for the study. In this manual, methods and partial methods are classified into six broad types:
    1. Spot measurement surveys
    2. Personal monitoring
    3. Area measurements
    4. Measuring EMF characteristics
    5. Source survey
    6. Walkthrough monitoring

- Determine the approximate range of frequencies and magnitudes of the fields to be measured. Information on the range of exposures may be obtained in many ways, ranging from a phone call with the facility manager to an extensive feasibility study. The most common procedure is to perform a literature search to obtain information on previously measured EMF sources that are relevant to your environment, followed by a walkthrough survey of the facility. Several of the techniques in this manual can be used for the ranging measurements taken during a walkthrough survey. The appropriate approach to the initial ranging depends on the purpose and scope of the overall study.

- Determine the exposure metrics that address the stated purpose of the study. The best exposure metrics are usually the ones that can test hypotheses about the biological mechanisms by which EMF produce a disease. Although several EMF mechanisms have been proposed (*e.g.* induced currents, free radicals, ion resonance), none can satisfactorily account for all the biological effects reported by laboratory and epidemiologic studies.[4] Although metrics based on biological mechanism is best, approximate metrics are therefore necessary and appropriate for many types of exposure assessments. For example, a preliminary workplace survey might simply use the spot measurements of the magnetic field magnitudes for its exposure metrics. The justification for such a survey is that in-depth exposure measurements based on biological mechanisms would be a waste of resources if the fields are low to start with and the mechanisms uncertain.

- Find methods or partial methods that apply to the selected exposure metrics. When the needed methods are not in this manual, the missing segments of the method often can be adapted from similar methods. From this material, write up a candidate method.

- At this stage, have an experienced investigator or expert advisory committee review the proposed method for consistency, completeness, suitability for the study's aims, and resource requirements. For each proposed method, draw up lists of the required equipment. Determine the method's total cost and personnel requirements. If the method's requirements exceed the study's resources, new candidate methods need to be devised, or more resources obtained.

- The candidate method should be pilot tested. If the needed equipment has not yet been purchased or the exact field environments are not accessible, pilot measurements in a laboratory setting with borrowed or rented equipment can help identify and avoid many errors when the actual assessment commences.

- A final review of the protocol is recommended once the investigators have assembled all the methods needed for their exposure assessment. For the initial assessment of the EMF in a workplace, an informal review of the method by an industrial hygienist who has worked with EMF should be sufficient. For research studies, a more formal review, conducted by scientists with a wide range of EMF expertise (*e.g.* epidemiology, industrial hygiene, medicine, physics, electrical engineering, instrument design, biophysics, statistics) is recommended. In light of the scientific debates surrounding the possible health effects of EMF, a diversity of scientific viewpoints is desirable for formal reviews of larger studies. In addition to assuring the study's integrity, a broad discussion of the scientific assumptions underlying the measurement methods can increase the study's potential to deepen our understanding of this challenging subject.

References

1. Theriault GP: Health effects of electromagnetic radiation on workers: Epidemiologic studies. In Bierbaum PJ, Peters JM (eds), *Proceedings of the Scientific Workshop on Health Effects of Electromagnetic Fields on Workers*. DHHS (NIOSH) Publication No. 91-111. National Institute for Occupational Safety and Health, Cincinnati, OH (1991).

2. Bierbaum PJ, Peters JM (eds): Executive Summary. *Proceedings of the Scientific Workshop on Health Effects of Electromagnetic Fields on Workers*. DHHS (NIOSH) Publication No. 91-111. National Institute for Occupational Safety and Health, Cincinnati, OH (1991).

3. Eller PM (ed): *NIOSH Manual of Analytical Methods* (3rd edition). DHHS(NIOSH) Publication 84-100 and Supplements (1984, 1985, 1987, 1989, 1990).

4. Bowman JD, Gailey PD, Gillette L, Lotz WG (eds.): *Proceedings of a Joint NIOSH/DOE Workshop on EMF Exposure Assessment and Epidemiology*: *Hypotheses, Metrics, and Measurements.* Oak Ridge National Laboratories, Oak Ridge, TN (1997).

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

6. NIOSH: *NIOSH Fact Sheet: EMFs in the Workplace*. DHHS (NIOSH) Publication No. 96-129. National Institute for Occupational Safety and Health, Cincinnati, OH (1996).

7. Bailey WH, Su SH, Bracken TD, Kavet R: Summary and evaluation of guidelines for occupational exposure to power frequency electric and magnetic fields. *Health Physics* 73:433-453 (1997).

8. Jay F, Goetz JA: *IEEE Standard Dictionary of Electrical and Electronic Terms*, Fourth Edition. IEEE, New York, NY (1988).

II. COMPLETE METHODS

This section contains complete methods, which are sets of instructions for measuring a worker's exposure to a particular agent. These methods cover most, but not necessarily all, of the following topics:

- Equipment
- Preparation
- Sampling strategy
- Measurement
- Quality control
- Data management
- Calculation and data summarization

Method #201. ELF-EMF and High-frequency Transients

Method Summary

Description and purpose	**Purpose:** Epidemiology **Strategy:** Personal monitoring **Study:** Hydro Quebec exposure assessment for the Canada-France tri-utility study of EMF and cancer[1-5] **Authors:** J.E. Deadman **Date:** 1989

Sampling strategy	**Description**: Personal monitoring **Location:** Placed on belt or in chest pocket during the day, and area monitoring at bedside during the night **Duration:** One week with additional week if needed to get a representative exposure **Subject selection:** Electric utility workers selected to assess exposures for the epidemiologic study. **Other data:** Tasks from worker log
Instrument	**Model:** IREQ / Positron electromagnetic dosimeter (Montreal, Quebec) **Channels:** **1.** ELF magnetic field **2.** ELF electric field **3.** High-frequency transients
Channel 1	**Description:** ELF magnetic field **Sensor:** Three orthogonal air-core induction coils **Frequency response:** 40-200 Hz bandwidth filter, peaking at 50 or 60 Hz with diminished response to 1 kHz. **Time response:** Peaks digitized into bins over 133 msec period **Sampling rate:** 60 seconds **Dynamic range:** 3.1 nT - 50 μT (0.031-500 mG) **Accuracy:** 25% of test fields were assigned incorrectly to bins (errors = 8-38%)[6] **Output:** Data logger for peak vector in 16 geometrical bins
Exposure metric 1	**Final metric:** Temporal metrics for the peak magnitude of the 50/60 Hz magnetic field. **Data processing:** Not described in protocol **Units:** Magnetic flux density (μT)

Channel 2	**Description:** ELF electric field **Sensor:** Single-axis parallel-plate electric field probe (perpendicular to the person's body) **Frequency response:** 40-100 Hz bandwidth filter peaking at 50/60 Hz **Time response:** Peaks digitized into bins over 133 msec period **Sampling rate:** 60 seconds **Dynamic range:** 0.6 V/m - 15 kV/m **Accuracy:** not determined **Output:** Data logger for a single peak component of the 50/60 Hz electric field in 16 geometrical bins
Exposure metric 2	**Final metric:** Temporal metrics of a peak component of the 50/60 Hz electric field **Data processing:** Not described in protocol **Units:** Electric field (V/m)
Channel 3	**Description:** High-frequency transients **Sensor:** Cube of conductive foam sensitive to high-frequency E-fields **Frequency response:** 5 - 20 MHZ **Time response:** Proportion of time E-field exceeds 200 V/m **Sampling rate:** 60 sec **Dynamic range:** 0.8 ppb - 894,800 ppm **Accuracy:** Not determined **Output:** Data logger for sensor response in 16 geometrical bins
Exposure metric 3	**Final metric:** Temporal metrics for the transient occurrence rate **Data processing:** Not described in protocol **Units:** Proportion of time transients exceed threshold (ppm)

Critique

Strengths

This method has been used successfully in monitoring exposures to ELF magnetic fields from AC electricity in homes and workplaces of Hydro Quebec employees.[1-5] The Positron monitor is unique in having an exposure metric with a narrowband frequency filter, peak time response, and output in geometric bins.[7] As a result, the monitor has the unmatched capability to monitor for 18 days. The sensors for three different fields is also a unique combination. The protocol is very thorough, and has many quality control measures which are needed to collect reliable data in a large study.

Limitations

This protocol does not include methods for calculating exposure metrics, but methods for analyzing Positron data are described in Partial Methods #901 and #902. The accuracy of the Positron monitor and its comparability with other monitors has not been fully evaluated, which is needed because of its unique design. In one test, the Positron monitor took measurements comparable to other monitors in a 50 µT (500 mG) at an electrical substation, but the Positron's TWA during a walk-through of utility offices and shops was greater than the others by a factor of two.[6] The electric field and high-frequency transient sensors are more problematic because the inherent physical difficulties in assessing worker exposures to these fields. For example, one test of the high-frequency transient (HFT) channel reported that its response characteristics "are not at all in conformity with the meter specifications".[8] Furthermore, the predominant sources of HFT exposures among electric utility workers were found to be walkie-talkies and other mobile radio communication devices with frequencies up to hundreds of MHZ. Finally, this study and most other occupational EMF epidemiologic studies have had the exposure monitor worn on the waist, even though investigators have reported that magnetic field magnitudes depend significantly on elevation.[9-11] Ideally, exposure monitors should be worn close to the target organ (*e.g.* the head for brain cancer or the pelvis for leukemia), but this is often not practical.

Method Protocol

"Technical guide for using an electromagnetic dosimeter with the epidemiologic study" by J. Deadman

Equipment

1. IREQ Dosimeter (2.3 x 8 x 14.3 cm, 218g)
2. Alkaline batteries (9 V, 0.5 A-hr)
3. Carrying pouch with belt (should be cotton for electric utility workers)
4. Computer interface
5. Laptop computer with dosimeter software
6. Diskettes with labels
7. Multimeter
8. Digital watch
9. Information sheet for participants
10. Daily exposure log sheet

Preparation

Each dosimeter used for the measurement must have successfully completed the primary calibration reliability checks (described below). They must also be checked before, during and after use, as described in the following sections. It is a good practice, at this point, to clear the meter's memory through the computer, if it has not been done after last use. We also recommend placing a seal over the joint in the meter's case (not the battery compartment), as a method for detecting whether the case has been opened.

1. Power the dosimeter

On the day prior to distributing the meters to workers, a new battery (alkaline, industrial version: 0.5 A-h, e.g., Mallory IND 1604, or equivalent) should be inserted into the meter. Check that the battery terminals are tightly fixed to the battery. Do not remove or dislodge the cube of conductive black foam; this is the High-Frequency Transients antenna. Check that the bare end of the white wire is firmly lodged into the foam cube. Close the battery compartment. Power consumption should now be 0.125 mA, the standby value.

2. Resetting the dosimeter

Prior to distributing the meters, their memories should be cleared and set to zero using the software. If desired, the meters may be reset without clearing the memory. This is done by inserting and removing the dosimeter reset key in the meter's input/output connector, or by connecting the real-time reader, and pressing once on the reset button located on the back of the reader. Dosimeter power consumption should now be at 1.20 mA.

Sampling Strategy

1. Meeting with participants.

Each group of workers should be met at the start of monitoring, so that the context and goals of the epidemiologic study, and the need for the exposure measurements can be clearly explained. A period of about one hour is usually sufficient for this first meeting. It is important to emphasize that there are no exposure standards (for the health effects that we are interested in) to which exposure values can be compared. It is informative, nonetheless to demonstrate typical exposure levels in previously sampled occupations, and in non-occupational environments.

Workers should be informed that they will receive a report of their exposures, several weeks after completing monitoring. Participants should also be provided with written information on the exposure study, and precautions for wearing the dosimeter.

A list of the participants should be prepared, showing their name, job title and class or rank within the job, region where they work, and the corresponding dosimeter number. Schedule a period during which the workers can drop off their meters and log sheets.

2. Worker instructions on wearing the dosimeter

The instructions given to the workers in the meeting emphasize these points:

a. **Measurement duration**. The worker is asked to wear the dosimeter for one week (7 days), both during and outside of work.

b. **Monitor location**. During work, the dosimeter is worn in a pouch on the worker's belt near the front of the body or at the chest level in the pocket of a shirt or overalls. The worker is asked to indicate the location on the daily log sheet. Outside of work, the worker wears the dosimeter at all times, except when it would be damaged (showering and sports). During sleep, the monitor is to be placed flat in the same place every night on a surface near the bed. If the worker has an electric blanket, heated water bed, or heating pad, the dosimeter is to be placed close to the worker (under the pillow or attached to the top center of the electric blanket).

c. **Electromagnetic artifacts**. In order to avoid interference with the dosimeter's electric field sensor, the worker is asked to keep metal objects like pens or tools away from the location where the dosimeter is worn. When the dosimeter is taken off for the night, EM field sources such as electric clocks or lamps should be avoided. The worker is asked not to lend the dosimeter to another person, or to deliberately get higher or lower EM field exposures.

d. **Operating check**. Each day, the worker checks the dosimeter operation by pressing a button in the upper right-hand corner of the battery compartment. A red LED lights while the button is held to indicate normal operation. If the LED does not light, the worker is asked to stop wearing the dosimeter, and note the date and time on the log sheet.

e. **Precautions**. The worker is asked to treat the dosimeter carefully, avoiding blows, water, and extreme heat and cold. While in extreme temperatures, the dosimeter should be worn close to the body. The battery must never be disconnected in order to avoid losing all the data stored in the dosimeter's memory.

3. Daily log sheets

A sample log sheet is shown in figure I. Information from the log sheets allows accurate estimates of exposure for each worker, for each period of the day, and permits calculation of exposure for certain tasks, if required.

The importance of the log sheets must be emphasized to the workers; they are as important as the dosimeter. One sheet must be completed for each day of monitoring.

The log sheets comprise four columns: TIME, LOCATION, TASK, WORK METHODS. TIME should be noted whenever there is a significant change in activity, e.g., putting on the dosimeter in the morning, starting a task, ending a task, changing location, etc. Under LOCATION the participant should name the area where he is working (substation, street corner, etc.). For TASK, the worker should briefly describe the activity, type of equipment worked on, voltages, loads, and so on. The WORK METHODS is reserved for noting particular work methods that could modify exposures for a similar task, such as live-line versus "dead" line work; or contact (insulated) versus distance (grounded) work. Use of specialized protective equipment that can modify exposures (e.g., conductive clothing) should also be noted here.

Exacting detail is not required, but enough information should be provided so that exposures for specific tasks can be calculated wherever required.

The bottom section of the log sheet is reserved for the worker's own assessment of how typical his day was. If at the end of the week's monitoring there is a consistent judgement that exposure was under or over-represented, and the worker's exposure data tend to confirm it, then a second week of monitoring will be carried out on the same worker, or another who is more representative of the trade.

Figure 1. Sample of log sheet for Hydro Quebec exposure assessment

D A I L Y   E X P O S U R E   L O G   S H E E T

NAME____TRADE__________________________REGION__________________

DATE________________________DOSIMETER________________________WORN ON (CIRCLE ONE):   BELT / CHEST

TIME (start and stop of activity)	LOCATION (ex.: sub-station name; worksite)	TASK / ACTIVITY (describe task performed; equipment, voltage. loads, etc.)	WORK METHODS (e.g. gloves, hot-stick; live-line; insulated; bucket, etc.) OTHER REMARKS

*   IN YOUR OPINION, YOUR EXPOSURE AT WORK TODAY WAS:

LESS THAN USUAL: (_____),   AS USUAL: (_____),   HIGHER THAN USUAL: (_____)

*   PLEASE LEAVE US YOUR PHONE NUMBER AT WORK:

4. Reporting results to workers

We have found that providing workers with the results of their exposures has encouraged participation. A results report is best kept short. The daily mean exposure for each work, non-work and sleep period, and the means for the week are presented. The table is accompanied by a short text that introduces and explains the results. In the past, we have not systematically provided copies of the log sheets, preferring to do so on a 'by request' basis--this considerably reduces paperwork. Lastly, we suggest that a thank-you letter from a highly placed authority in the utility be included. It demonstrates the utility's appreciation to the worker, and commitment to the study.

Measurement

1. Triggering the dosimeter

When the worker is ready to wear the dosimeter, data acquisition should be started by pressing once on the push-button located in the battery compartment. The LED to the left of the button should light, indicating that triggering was successful. <u>Note the exact time at which the meter was triggered</u>. Power consumption should now be near the operating value of 1.6 mA. Pushing the button again has no further effect on dosimeter operation, other than lighting the LED and consuming battery power; the meter will continue to acquire data until battery voltage is below 6.3 volts, or until memory is full, usually after 18 days.

Close the battery compartment and insert the dosimeter into its pouch. Attach the pouch to the wearer's belt, or place the dosimeter in a coveralls chest pocket. The position of the meter should be noted on the log sheets. Check your watch against the worker's. If there are irreconcilable differences, note this on the monitoring sheet.

2. Operating checks during monitoring

To avoid having the worker wear an inoperative meter, check the meter's operation by pressing once on the push-button in the battery compartment to see if the LED lights. If it does not, the worker should stop wearing the meter. Note the date and time when this occurred. For multi-day monitoring, this check must only be done at the start of the day, to avoid shortening battery life.

3. Observation during monitoring

A good understanding of how exposures occurred, gained through on-the-job observations, is essential to proper interpretation of exposure data. It gives the investigator a chance to check that workers are doing their usual jobs, and that the dosimeters are being worn properly. Qualitative assessment of exposures to external factors for the Job Exposure Matrix can also be undertaken at the same time. Also, some helpful pointers on filling out the log sheets can be provided to study participants at this time. The extent of field observation will depend on the complexity of each job, but will always serve to improve the quality of exposure measurements. As a minimum, there should be two visits per week for each group sampled.

4. Post-monitoring checks

At the end of monitoring, record end time on the Daily Exposure Log Sheet. The worker should be questioned on any unusual events that occurred during the wearing of the meter (was it dropped? forgotten at home?, etc.). Any such event should appear on the log sheets.

The meter should also be inspected for obvious damage not reported by a worker, and other oddities, such as a disconnected battery or signs of tampering (check the seal placed over the main joint of the meter's casing).

The log sheets should be rapidly checked over and completed (if necessary) with the worker; the most important item to note is a phone number where the worker can be reached. Meeting individually with the workers after the monitoring is usually quite informative and helpful in planning subsequent monitoring sessions.

5. Downloading data to a personal computer

As soon as possible after retrieving the meters, the exposure data must be downloaded onto a personal computer by means of the IREQ software. Downloading the dosimeter must not be delayed beyond the maximum waiting period established during the Calibration and Quality Control (below). In the field this operation can be performed using a laptop computer and the modified software that uses only the data acquisition portion of the original IREQ software. In the lab, a desk-top computer can be used to read the dosimeters and display graphs of exposure, using the full software package. The data is copied to diskette immediately. As a safeguard, do not clear the meters' memories until the quality of the data copied onto the diskettes has been verified.

Quality Control

Dosimeters must undergo a primary calibration as described in ANSI/IEEE Standard 644-1987.[8] Calibration should be checked periodically, initially after every two months of continuous use, until it is established that calibration remains stable over a longer or shorter period. A log book should be kept for each dosimeter, to record dates of calibration checks, results, and observations. Differences from previous calibration should be noted in the logbook. If calibration is off by more than 5% of the original value, or is drifting over time, the dosimeter should be repaired or replaced.

1. Power consumption and shutdown voltage check

IREQ dosimeters have three modes: standby (0.125 mA); reset (1.2 mA); and data acquisition (1.6 mA). Power consumption should be verified on a sample of dosimeters prior to the measurement program, and the operation of the shutdown circuit, which should stop data acquisition once the battery voltage drops to 6.3 volts, should be checked.

2. Checks on memory circuit performance

a) Zero-memory check: When left in a field-free environment, memory-cleared dosimeters should not accumulate any readings over the monitoring period.

b) Length of storage in memory: The dosimeter must be capable of maintaining the stored data in memory for a suitable period after monitoring, to permit shipment of meters. The length of memory storage should be checked on a sample of dosimeters, and the minimum value used as a maximum safe waiting period within which meters must be downloaded.

Data Management

1. Preliminary checks on data

A first check on the quality of the exposure data copied onto diskettes should be made for any obvious problems or unusual patterns, by using a condensed graph of all exposures (E-field, all three components of the B-field, and High-Frequency Transients) for the monitoring period.

As an example of a typical problem, there may be too many consecutive identical readings, which could indicate premature shutdown of the meter, or a period when the meter was not worn. Any periods considered to be non-representative should be noted on the graph for later removal in the calculation of mean exposures per period.

In general, the graph of exposure data should make sense when compared with the log sheets. There should be no major differences between the times shown on the graph and on the log sheets. It is most important that the times at which monitoring started and ended agree.

2. Data Back-up

Log sheets and data diskettes must be duplicated at this time, to help prevent possible loss of data. Store duplicates separately from the originals.

References

1. Deadman JE, Camus M, Armstrong BG, Heroux P, Cyr D, Plante M, Thériault G: Occupational and residential 60-Hz electromagnetic fields and high-frequency electric transients: Exposure assessment using a new dosimeter. *Am. Ind. Hyg. Assoc. J.* 49: 409 (1988).

2. Thériault G, Goldberg M *et al.* Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada and France: 1970-1989. *Am J Epidemiol* 139:550-572 (1994).

3. Armstrong B, Thériault G, Guénel P, Deadman J, Goldberg M, Héroux P. Association between exposure to pulsed electromagnetic fields and cancer in electric utility workers in Quebec, Canada and France. *Am J Epidemiol* 140:805-820 (1994).

4. Miller AB, To T, Agnew DA, Wall C, Green LM. Leukemia following occupational exposure to 60-Hz electric and magnetic fields among Ontario electric utility workers. *Am J Epidemiol* 144:150-160 (1996).

5. Guénel P, Nicolau J, Chevalier A, Goldberg M. Exposure to 50-Hz electric field and incidence of leukemia, brain tumours, and other cancers among French electric utility workers. *Am J Epidemiol* 144:1107-1121 (1996).

6. IEEE Magnetic Fields Task Force: An evaluation of instrumentation used to measure AC power system magnetic fields. *IEEE Trans.* PWRD-6: 373 (1991).

7. Heroux P: A dosimeter for assessment of exposures to ELF fields. *Bioelectromagnetics* 12: 241 (1991).

8. Hydro-Québec: Identification of sources responsible for utility worker exposure data obtained using Positron HFT channel. (1996).

8. ANSI/IEEE: *IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines.* ANSI/IEEE Standard 644-1987, Institute for Electrical and Electronics Engineers, New York, NY (1987).

9. Delpizzo V. Misclassification of ELF occupational exposure resulting from spatial variation of the magnetic field. *Bioelectromagnetics* 14:117-130 (1993).

10. Wenzl TB, Kriebel D, Eisen EA, Moure-Eraso M. A comparison of two methods for estimating average exposure to power-frequency magnetic fields. *Appl Occup Environ Hyg* 10:125-130 (1995).

11. Davanipour Z, Sobel E, Hietanen M, Juutalienen J, Sulkava R. Magnetic field exposure from industrial sewing machines in Finnish apparel factories. Abstract. Annual Review of Research on Biological Effects of Electric and Magnetic Fields from the Generation, Delivery and Use of Electricity, Palm Springs, CA, November 12-16 (1995).

Method #202. Time-Weighted Average (TWA) ELF Magnetic Fields

Method Summary

Description and purpose	**Purpose:** Epidemiology **Strategy:** Personal monitoring **Study:** Epidemiologic Study of Cancer Mortality in Electric Utility Workers[1] **Author:** D.R. Willett **Date:** 1992

Sampling strategy	**Description**: Personal monitoring **Location:** Waist pouch **Duration:** Full shift **Subject selection:** Random selection of employees stratified by job title **Other data:** Start and stop times
Instrument	**Model:** AMEX-3D (Enertech Consultants, Campbell, CA) **Sensor:** Three-axis induction coils **Frequency response:** 25-1200 Hz bandwidth flat filter peaking at 60 Hz **Time response:** Average-sensing rms vector magnitude integrated over time in an electrolytic cell (E-cell)[2] **Sampling rate:** Continuous monitoring **Dynamic range:** Linear response from 0.05 - 9.7 µT (0.5-97 mG) **Accuracy:** ±20% over 0.02 - 15 µT (0.2-150 mG)[2] **Output:** Charge (in µC) from the E-cell is measured by an automatic reader
Exposure metric	**Final metric:** TWA rms vector magnitude of the ELF magnetic field **Data processing:** Convert E-cell charge to cumulative exposure (in mG-hr) Divide by sampling time to obtain TWA exposure **Units:** Magnetic flux density (mG)

Critique

Strengths

This method is used to measure EMF exposures of job classifications in the electric utility industry.[1-8] The details of these methods, including occupational classification, sampling design, and data analyses are reported in several published methods papers [5-8] that were used in the final epidemiologic analysis of mortality trends among five U.S. electric utilities.[4] This sampling strategy has been measuring exposures on thousands of employees selected randomly from a dispersed work force.[6] To accomplish this efficiently, the study coordinator mails AMEXs to the subjects, and receives the used AMEXs by mail for downloading of the data. The AMEX's simplicity, low cost, and ruggedness enables this dispersed workforce to be monitored by mail. This strategy does require the subject's supervisor to be asked for assistance before the monitoring.

The three main strengths of this approach are 1) the relative simplicity and cost-efficiency of using the AMEX meter, which can be mailed to employees; 2) the weighted, stratified, random sampling design; and 3) the relatively large sample size.

Limitations

The main draw-back of the AMEX-3D for monitoring exposures is its limited dynamic range (<9.7 µT), which is below the peaks in some occupational magnetic fields. In the one field test,[2] side-by-side exposure measurements on electric power line workers with the AMEX-3D and the EMDEX did show good agreement in the full-shift TWA magnetic fields up to 1 µT.

There are also several practical field procedures that if not properly conducted can create problems when conducting surveys with the AMEX meters. Calibration must be performed on a regular basis for both the meter and the read-out device, you must be careful to "zero-out" the meter before using it, and if a large number of meters are in use, the protocols may require more than one readout device. All of the factors can become practical limitations in using the AMEX meter. Although the original protocols state that the location on the body of the meter does not matter, it is important that standard procedures are clearly defined on this issue.

Despite these limitations, the AMEX-3D can be considered for personal monitoring for many occupations. If workers are exposed to magnetic fields above the AMEX's dynamic range, validation studies are needed. Also if more detailed exposure information rather than daily TWA is required, other equipment will be required.

Method Protocol

adapted from "Epidemiologic Study of Cancer Mortality in Electric Utility Workers" by D.R. Willett

Equipment

1. Measurement kit with the following contents:
    a. Letter to supervisor
    b. Information for supervisors
    c. Instructions for using the AMEX meter
    d. Orange "Don't forget" tag
    e. AMEX meter with date/time label
    f. Meter pouch (with attached belt)
    g. Pre-addressed mailing envelope

2. Readout modules for the AMEX's electrolytic cell (E-cell).
3. Cable for the readout module and for checking the battery.
4. Multimeter.
5. Spare batteries (3.3 v lithium battery). The batteries used for AMEX meters easily last for one week.

Sampling Strategy

For each job category to be measured, employees will be selected randomly from a list of all employees of the company employees with those jobs. The selected employee, or his supervisor, will be sent an AMEX instrument which measures magnetic field exposures. Selected employees will be asked to wear the instrument in a provided belt-pouch during an entire working day. Operation of the instrument is simple: turn it on at the beginning of the day and turn it off at the end of the day. The instrument will then be returned by mail for downloading of the magnetic field measurement.

Preparation (by measurement coordinator)

1. Check the battery voltage with a Multimeter. Use the AMEX's cable to connect the Battery Voltage Jack to the Multimeter. Set the Multimeter for DC volts and switch the ON/OFF/READ switch on AMEX-3D to the ON position. Read the battery voltage from the Multimeter display. Replace the battery if the voltage measures at or below 2.5 volts.

2. Before an AMEX is used, it is necessary to "read-out" the charge from the E cell with either the manual or automatic device, following the instructions in the AMEX manual. By this means, the AMEX starts in the zero-charge state. FAILURE TO ZERO-OUT THE AMEX WILL RESULT IN ERRONEOUS MEASUREMENTS.

3. Enter the employee and supervisor names onto the forms. Enter the employee's name, Social Security number, and job title on a label (below), and attach to the front of the AMEX. Put the forms and the AMEX into the measurement kit. Mail to the supervisor.

Name:
SSN:
Job Title:
ON: _ _ / _ _ / _ _ _ _ : _ _ AM / PM
OFF: _ _ / _ _ / _ _ _ _ : _ _ AM / PM
Quit ____ Changed Job ____ Absent ____ Refused ____
NOT USED: ____

Preparation (by supervisor)

1. If the employee is absent or is no longer under your supervision, please open the information/ equipment packet intended for him. The exposure meter is a small blue plastic box with a label attached to the front. Check one of the spaces on the bottom of the label that explains why the meter could not be delivered to the employee:

    Check "Quit" if the employee no longer works for the company.

    Check "Changed Job" if the employee no longer has the job title shown on the label and is no longer under your supervision.

    Check "Absent" if the employee is absent from work due to sickness, travel, vacation, leave of absence, etc.

2. A "kit" containing a small meter, carrying pouch, and instructions is to be delivered to the employee. If the employee refuses to wear the meter, check the "Refuse" space on the bottom of the label.

3. If the employee does not refuse to wear the meter, hand him the kit and have him follow the instructions.

4. Collect the meter, pouch, and belt at the end of the workday. Repack the meter, pouch, and belt in the return container, and mail to the measurement coordinator.

Measurement (for the participant)

1. Carefully remove the pouch from the wrapping material. Be sure to <u>save</u> the wrapping material for returning the meter to the measurement coordinator.

2. Locate the pre-addressed envelope.

3. Place the wrapping material, rubber bands, and the pre-addressed envelope in a safe place. They will be needed at the end of the work day to return the meter to the measurement coordinator.

4. Locate the orange "**Don't Forget**" tag. Hang this tag in a location that will remind you to complete this procedure at the end of the day.

5. Unzip the pouch and take the meter out.

6. Look at the label attached to the <u>back</u> of the meter.

7. Check the spelling of your name, your social security number, and job title. Correct any misspelled or inaccurate information on the label by marking out the wrong information and writing in the correct information.

8. Look at the position of the small switch located in an opening on one side of the meter. Also, look at the switch position descriptions next to the switch opening. These descriptions are "**on off read**."

9. If the switch is in the **"ON"** position when you receive the meter, then do the following:

   Check the **"NOT USED"** block on the label attached to the meter. Write **"Switch ON"** next to this block.

   Go to step 19 of this procedure. Do not wear the meter during this work day.

   The meter should be worn on the next working day after receiving this package. The following steps should be followed as soon as you report to work on the day the meter is worn.

10. If the switch is either in the **"off"** position or the **"read"** position when you receive the meter, then slide the switch to the **"on"** position. The switch is recessed, so you may need to use a pen.

11. Write the date and time you turned the meter **"on"** in the appropriate space on the label attached to the back of the meter.

12. Place the meter in its carrying pouch, close the zipper, and then wear the belt attached to the pouch around your waist. It does not matter whether the pouch is worn in the front, rear, or side of the body.

13. Do not take the pouch belt off at any time during the work day. Wear it during all breaks and during lunch.

14. At the end of the work day, just prior to your leaving for home, take the belt off and remove the meter from the pouch.

15. Check the position of the switch again. If the switch is in the **"off"** position or the **"read"** position, then do the following:

    Write **"Meter was off during work day"** next to the **"Not Used"** block on the label attached to the meter.

    Go to step 18 of the procedure.

16. If the switch is in the **"on"** position, then slide the switch to the **"off"** position.

17. Write the date and time you turned the meter **"off"** in the appropriate spaces on the label attached to the back of the meter.

18. Send the meter to the measurement coordinator **NO LATER THAN** the day after the meter was worn.

19. Return the meter by doing the following:

    Place the meter back into the pouch.

    Close the zipper.

    Wrap the pouch with the wrapping material and rubber bands used to send the meter to you.

    Place the wrapped pouch into the pre-addressed envelope included in the package sent to you.

    Seal the envelope and either return to the measurement coordinator by Meter Can for the company's mail or U.S. Mail as indicated on the front of the pre-addressed envelope.

Measurement (by the measurement coordinator)

After use, the E cell must again be read out. That is, the total charge (in units of microcoulomb) accumulated on the cell since the last read-out is measured with either the automated or manual reader, following the instructions in the AMEX manual. Using the AMEX calibration factor, the total charge and the time of measurement can be converted to the TWA magnetic field exposure in milligauss.

Calculations

For the automatic reader, the TWA resultant B-field (in milligauss) is given by:

$$B_{TWA} = \frac{CQ}{T} + 0.085 \text{ mG}$$

where C = calibration constant
= 0.00174 mG-hr/μC according to the manufacturer
= 0.00184 mG-hr/μC according to the Westat pilot study[3]

Q = automatic reader output (μC)

T = elapsed time (hr) when the AMEX is on
= Time OFF - Time ON written on the AMEX's label

References

1. Enertech Consultants: Epidemiological Study of Cancer Mortality in Electric Utility Workers. (1989).

2. Kaune WT, Niple JC, Liu MJ, Silva JM: Small integrating meter assessing long-term exposure to magnetic fields. Bioelectromagnetics 1992;13: 413-428.

3. Weststat, Inc.: Childhood Leukemia and Electromagnetic Fields: Pilot Study Operations Report. Report to NCI under Contract N01-CP-95608, November 1990.

4. Savitz DA, Loomis DP. Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers. Am J Epidemiol 1995;141:123-34.

5. Loomis DP, Peipins LA, Browning SR, Howard RL, Kromhout H, Savitz DA. Organization and classification of work history data in industry-wide studies: an application to the electric power industry. Am J Industrial Medicine 1994;26:413-25.

6. Loomis DP, Kromhout H, Peipins LA, Kleckner RC, Iriye R, Savitz DA. Sampling design and field methods of a large, randomized, multi-site survey of occupational magnetic field exposure. Applied Occupational and Environmental Hygiene 1994:9:49-52.

7. Flynn MR, West S, Kaune WT, Savitz DA, Chen C-C, and Loomis DP. Validation of expert judgement in assessing occupational exposure to magnetic fields in the utility industry. Applied Occupational and Environmental Hygiene 1991;6(2);141-45.

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

.

Method #203. Occupation- and Task-Specific Measurements of ELF Magnetic Fields

Method Summary

Description and purpose	**Purpose:** Epidemiology, worker education, field management **Strategy:** Personal monitoring **Study:** Epidemiologic study of hematopoietic cancers and brain cancers among electric utility workers **Authors:** Sahl JD, Kelsh MA, Greenland S, Smith RW, Scarfuto JB, Pennino JB, et al.[1-3] **Date:** 1993, 1994, 1997

Sampling strategy	**Description**: Personal monitoring **Location:** Instrument in waist pouch **Duration:** Full shift, multiple days (1-9 days) **Site and subject selection:** Worksites selected to represent all types of utility environments (generation, transmission, distribution, substation, shop, office). Workers asked to volunteer for survey. **Other data:** Work task and task duration recorded with VIDEX TimeWands®
Instrument	**Model:** EMDEX II (Enertech Consultants, Campbell, CA) **Sensor:** Three-axis induction coils (ferrite-core) **Frequency response:** Broadband filter (40 - 800 Hz bandwidth) **Time response:** ‣ Integration of induction coil signals ‣ True rms (averaging time ≈ 100 msec) ‣ Analog-to-digital conversion **Sampling rate:** Programmed to sample every 1.5 sec. **Dynamic range:** Auto-ranging over 3 scales from 0.01 - 400 µT **Accuracy:** ± 10% over 0.01 - 10 µT; ±12% over 10.1 - 400 µT **Output:** Digital time record of rms vector components for ELF magnetic field

Exposure metric 1	**Final metric**: Mean and 95% confidence interval (CI) for TWA of the ELF magnetic field magnitude by occupations and tasks within an occupation **Data processing:** ▸ Calculate rms vector magnitude (resultant) for each time ▸ Merge magnetic field and task duration data ▸ Calculate a worker's TWA (arithmetic mean) for each task ▸ Calculate mean and 95% CI of the full-shift TWA for all workers in an occupation or a task **Units:** Magnetic flux density (µT or mG)
Exposure metric 2	**Final metric**: Mean and 95% CI for the geometric mean of the ELF magnetic field magnitude by occupations and tasks **Data processing:** ▸ As above, calculate the geometric mean of the rms vector magnitude for each task a worker performed ▸ Calculate mean full-shift geometric mean and 95% CI for all workers in an occupation **Units:** Magnetic flux density (µT or mG)
Exposure metric 3	**Final metric**: Mean and 95% CI for the standard deviation of the ELF magnetic field magnitude by occupations and tasks **Data processing:** ▸ As above, calculate the standard deviation of the rms vector magnitude for each task a worker performed ▸ Calculate mean full-shift standard deviation and 95% CI for all workers in an occupation **Units:** Magnetic flux density (µT or mG)
Exposure metric 4	**Final metric**: Mean and 95% CI for the fraction of the ELF magnetic field magnitude exceeding 0.5 µT by occupations and tasks **Data processing:** ▸ As above, calculate the fraction of rms vector magnitudes exceeding 0.5 µT for each task a worker performed ▸ Calculate mean and 95% CI of the full-shift fraction exceeding 0.5 µT for all workers in an occupation **Units:** Unitless

Critique

Strengths

This study represents one of the first attempts at collecting task-specific magnetic exposure data under "normal" work conditions. Measurements were obtained over a full-shift period and provide a better assessment of relative task duration than methods that specifically focus on task measurements only. A novel electronic method for logging task and task times was successfully introduced that minimized the survey impact on work performance and improved the accuracy of the task data. This strategy should be considered for future task-based exposure assessment protocols. The development of an occupational and task classification system was thorough and comprehensive for the electric utility industry. Workers were also blinded to their exposure levels, which can be a strength when using these data for epidemiologic analyses. However, this blinding could frustrate some worker participants who would like to learn about their workplace magnetic field exposures.

Limitations

The self-selection of workers in this approach may produce sampling biases. Although the sampling design was not strictly random, the authors believe there was no obvious reason for bias in the facilities, workers, and days chosen. The true sampling unit for this approach would be specific tasks. However, a sampling frame to this level is difficult to acquire. Practical resource limitations mandate sampling approaches that emphasize representativeness to the extent possible over true random sampling.

Method Protocol

adapted from "Exposure to sixty-Hertz magnetic fields in the electric utility work environment" by J.D. Sahl, M.A. Kelsh, R.S. Smith, and D.A. Aseltine (1994)

Magnetic fields data were collected from May, 1992 through January, 1993 at a Southern California electric utility. Volunteers were recruited at their work facility based on their occupation and work location. The goal was to collect data for one to ten consecutive work days at the participant's work location over a two-week period. The occupations selected represent a wide range of electric utility craft, tradesmen, administrative, and professional staff working in offices, field locations, shop facilities, substations (distribution and transmission), and power generation stations, including coal, nuclear, oil/gas, and hydroelectric. The criteria used to select representative work environments included the potential exposure to energized equipment, facility operating characteristics, scope of work responsibilities, and work location. Specific emphasis was placed on collecting data from craft occupations, which have higher and more variable exposures to magnetic fields than office personnel.[1,2] To generalize our results over the entire company, facilities, workers, and days were treated as random factors in our analyses. Workers were asked to perform their normal duties, and tasks were recorded as the exposure measurements were made. All analyses were specific to occupations or tasks within occupations.

Magnetic Field Measurements

Magnetic field data were captured by an EMDEX-2 gauss meter worn at the volunteer's waist. Measurements were taken every 1.5 seconds over a bandwidth of 40-800 hertz (Hz). The EMDEX-2 meter was programmed to display the elapsed time of the measurement period rather than the intensity of the magnetic field. This effectively blinded employees to their field exposure levels. Meters were calibrated at the start, mid-point, and end of the study. Reliability of the meters was checked at least once a week in "low" fields, around .1 microtesla (mT) and in "medium" fields, around 1.0 mT. Twenty to thirty EMDEX-2 meters were deployed each day. Because the EMDEX-2 meter does not record magnetic fields higher than 555.5 µT, the recorded maximum values on the EMDEX-2 meters may underestimate the true maximum.

Task Categories and Duration Measurements

Specific work activity/task codes were developed for each occupational category. Work activities encompassed the task and working area typical for each occupation. Twenty-eight separate occupation-specific task lists were created as a result of expert panel consensus, interviews with key personnel, and direct observations of personnel performing normal duties. While tasks are often unique to a specific occupational group, there are a substantial number of tasks that are shared (e.g., office work, travel, and many substation and generation station tasks). Task duration was captured simultaneous to the collection of magnetic field data using a hand-held electronic data acquisition device: the VIDEX TimeWand I.[4] Each volunteer carried credit a card-sized wand and a laminated, pocket-sized, bar code card that listed the specific tasks for the worker's occupation. Each volunteer electronically logged task information by scanning the appropriate task bar-code at the start of a task. The wand's internal clock recorded the task code and the task start times. A task end time was assumed to be immediately prior to the next task start time. For personnel working on energized equipment or in other safety sensitive tasks, trained observers recorded all task information.

Data Management and Statistical Methods

Data were transferred from the EMDEX-2 and VIDEX devices to a personal computer at the end of each work day. These data were reviewed, copied, labeled, and augmented with occupational and demographic information. Any anomalies that appeared were reviewed on a case-by-case basis in the field, most often with the volunteers themselves. In addition, where possible, time distribution data were compared with previous work management studies conducted at this utility for specific occupations. The EMDEX-2 and VIDEX data were then combined using software developed to merge these data.[5] For each occupation and task within occupation, we calculated the mean and 95% confidence interval the following summary statistics: arithmetic mean, geometric mean, standard deviation and fraction of the measurements exceeding 0.5 µT. The confidence intervals were computed from the variance of the weighted means for the facilities, where the weights were the measurement times.

The nested design of this survey allows for the examination of components of variance within tasks at the facility, worker and day levels for each occupation. For the arithmetic mean exposure summary measure, the variance components were calculated using the restricted maximum likelihood method.[6] The statistical model used for the variance components analysis included the facilities, workers, and days (nested random factors) crossed with tasks (a fixed factor). The variability of the occupational mean is also affected by the variability in the amount of time spent in the different tasks, whether or not tasks are actually recorded. The approach proposed in Smith et al.,[3] was used to estimate the variance component due to the varying task measurement times.

We used a mixed model ANOVA to test for exposure differences among tasks within an occupation. Using the methods of Box and Cox[7] we evaluated the data for normality and equal variances. Where necessary, we log-transformed the data prior to performing the ANOVA.

To identify the occupations and tasks with the highest exposures, we ranked the occupations and tasks by the average of the arithmetic mean and geometric mean exposure summaries. We calculated the 95% confidence intervals of the averages and the average percent time spent in each task out of the entire sample for that occupation (percent duration).

Magnetic field exposure is a combination of the field level for a given task and the time spent performing that task. To gain better insight into occupational exposure profiles, we examined task exposure levels and percent task duration for three craft occupations (linemen/ splicers, electricians and substation operators). These three occupations have relatively high occupational exposures compared to other utility occupations and are common occupational groups in many electric utilities. We examined the ten tasks with the highest exposures for each occupation.[8]

Detailed Protocol

Southern California Edison
Corporate EMF Study Plan
Study Protocols (1992)

Prepared by:
Jack Sahl
Southern California Edison Company, Health Research & Evaluation Division

Jim Scarfuto
Joe Pennino
Southern California Edison Company, Industrial Audits Division

Introduction/Purpose
The work is part of a corporate program to measure electric and magnetic fields (EMF) in the Edison work environment. The study examines the relationship between work activities and EMF exposure throughout the Company. Project activities are performed with the cooperation of Occupational Safety and Health Customer Service Department, Power Supply, and other organizations as appropriate.

The study is expected to be completed in four phases, as follows:

- **Phase I - Study Design/Data Requirements**
- **Phase II - Historical Work Activity Trends**
- **Phase III - Field Measurements**
- **Phase IV - Applications to Future Work Practices**

PROJECT GOALS

1. Implement Edison's EMF Policy
- Research and evaluate occupational health implications and provide employees who work near energized equipment with timely, accurate information about exposures in the work environment.
- Establish range of exposures for different occupations
- Help craft personnel better understand the work environment

2. Augment Edison's Cancer Mortality Study

3. Provide Exposure Information for Possible Changes in Work Practices
- Establish baseline data for existing work activities
- Develop data for proposed work practices
  - model
  - simulate
  - other utilities

STUDY METHODS

Phase I Study/Design Requirements
The initial phase will cover the design of the overall structure and flow of data collection, analysis, and interpretation. It will establish study methods and data processing approaches, and identify the types of equipment that will be used to capture EMF exposure and timed work activity data. This phase will also include identification of the types of comparative information that will be needed at the conclusion of the study.

Phase II Historical Work Activity Trends
The thrust of Phase II will be to identify historical trends in work activities, methods, and associated work time, as well as other factors that characterize the Company's experience relative to EMF exposure. This phase will examine long-term exposure effects, while determining the criteria for field measurements; study tasks will include:

<u>Select employee job classifications</u>
Based on past measurements and current trends, select several SCE job classifications/occupations throughout the company, representing the areas of higher potential exposure.

<u>Determine work characteristics for each job classification</u>
Evaluate work characteristics and historic changes in the work for each position selected, with regard to the effects on EMF exposure.

<u>Classify work assignments for each job classification</u>
Develop job assignment categories. Determine the general distribution of time spent in each category by interview and analysis of labor records or other means.

Develop a listing of detailed work tasks for each position and assignment
Develop a series of work tasks for each assignment for use in comparing the amount of EMF exposure that occurs while performing various aspects of the work. Use these tasks to differentiate between exposures that occur while performing hands-on work or other activities, such as working in shops or support areas, or moving between locations. If practical, make the work tasks generic so that data can be readily combined, such as:

- Positioned for hands-on work or close inspection of equipment, energized/operating
- Positioned for hands-on work or close inspection of equipment, de-energized/out of service
- Positioned to provide support in the immediate work area or walking nearby
- Working at a control point or similar location, separated from field activities
- Moving between work areas or job sites
- Working in any other area

Phase III Field Measurements
Field observation and measurement will occur during Phase III, based upon the results of Phase I and II. Measurements will be recorded over an extended period of time, including summer, in order to capture differences in both the distribution of work and electrical loading that occurs as a result of weather and other conditions. Study tasks for this phase of the project are shown below:

Conduct field measurements for each type of assignment
Conduct field measurements for each category of job assignment so that EMF exposure can be related to type of work summarized for each worker classification. Determine whether the distribution of work found in the field is consistent with expectations. Where representative work is not available for study purposes, determine whether data categories should be combined or restructured to meet changes in conditions, or whether local management can accommodate minor modifications in work scheduling to support study objectives.

Capture work activity data during execution of each assignment
To obtain a detailed examination of variations in EMF exposure throughout the day, capture timed data during job execution. Use Industrial Engineering hand-held electronic data collection devices. Provide data that can relate work activities to corresponding EMF data. The above evaluation will result in parallel databases that respectively show work activity data and EMF levels for each occupation.

I. Bar code readings for the occupation/activity data base will be self- recorded by employees where practical, provided this method does not interfere with the employee's work activities.
II. The occupation/EMF data will be compiled from EMDEX meters worn by each worker.
III. The occupation/EMF data will be merged with the occupation/activity data in order to relate various activities with EMF levels.

In addition to work activity/EMF level data, other information will be collected as a means of corroborating results. Field conditions, including weather and electrical load, will be documented for each job studied. Records will include the overall configuration of the work area showing sources of EMF, the type of work conducted, equipment utilized, and work procedures. Ergonomic factors such as body position, orientation, reach, grasping and manipulation will also be noted as appropriate for impact on the proximity and duration of the worker's exposure to EMF.

Phase IV Applications to Future Work Practices

This phase will involve a more in-depth examination of the relationship between specific work approaches and EMF exposure, with attention to future work. Study activities will include noting possible changes in the mix of work and then examining the possible effects upon EMF. Sample topics could include whether the trend toward more use of remote operating devices, which has occurred at hydroelectric facilities, or the trend toward less new overhead construction will change the study results.

<u>Deliverables</u>

The work will involve ongoing interface, coordination and status reports with project participants. All analysis and conclusions will be jointly developed by the members of the study team. Each phase of the project will be documented with a report. Interim reports may be developed, as well, to document results to date and support project direction. Reports will cover the following information:

- Descriptive information regarding the current and historic work methods for each job studied, with attention to factors that increase or decrease proximity to EMF sources;

- Summary information covering the distribution of work time by job assignments and tasks, considering both field measurements and result based on other sources;

- Data and information covering conditions observed during field measurements;

- A summary of job performance issues that affect proximity and exposure to sources of EMF;

- Data covering EMF exposure for the particular mix of work for each job classification and the relationship of this mix to specific work tasks;

- Identification of trade-offs between specific work practices and exposure levels, as appropriate.

TEAM RESPONSIBILITIES

General

- Assuring proper issue/pick up of equipment.
- Assuring data collection, accuracy of information, and preparation of forms.
- Documenting data, including preparation of hard copy files.
- Observation of work practice and environment characteristics when needed to fill data.

- Coordination of kick-off meeting at next place to be visited.
- Preparation of hand-out packages to employees for next worksite to be visited and preparation of materials for pre-visits to these locations.
- When appropriate, visit locations for updating the activity list.
- Ordering of bar codes and composing activity list descriptions of additional tasks identified during pre-visits for inclusion into hand-out materials to employees.

Training Content

Study Background/Purpose - Participating and interested Edison personnel will receive brief presentations on the study context and SCE policy regarding EMF research. The study is a follow-on to a 1991 study that measured representative daily magnetic field levels of SCE employees by occupational categories. However, this year the study is designed to take magnetic field measurements relative to defined work activities. Activities were selected in such a way as to represent different general levels of magnetic field exposure. The basic purpose of the study is to gain a better understanding of the levels of the magnetic fields that Edison personnel are exposed to by focusing magnetic field measurements at the work activity level.

- **Staff Organizational Structure/Responsibilities**. In general, the project utilizes three study teams, which includes two field teams and a data management team. A field team usually will be staffed with 2-5 personnel.

Kick-off Meetings At most locations, all available hands will attend the kick-off so that the study is properly communicated to employees. Typically, the meeting should be brief, but long enough to assure that workers at the facility understand the purpose of the study and what is expected of them. Normally, the meeting will be preceded by a courtesy visit/phone call to the local manager.

The team leader will normally conduct the meeting in conjunction with local management. The kick off meeting will generally involve the following agenda:

- Introduce the study team and the general purpose of the program.
- Emphasize the voluntary basis of the program.
- Inform workers about the study activities, timetable, and anticipated feedback regarding results.
- Display the two types of data capturing devices that will be employed to record magnetic field exposure and associated work activities.
- After local management dismisses personnel who are not participating in the study, thank the volunteers for their participation, issue work history forms and provide instructions for completing and returning forms.
- Demonstrate the use of the electronic data gathering devices.
- Arrange to begin data collection at an appropriate time that day.

Use of Equipment and Files - Train all project team members and volunteers on the care, use, handling and storage of measurement equipment. This includes the Videx wands and associated charging devices, Gauss meters, field computers, back-up diskettes, and hard copy data storage and filing. A few representative training topics will include:

- General instructions on the use of Gauss meters and Videx wands.
- Instructions on processing, filing and transmitting both hard copy information and data diskettes.
- Instructions for up loading and down loading information and recharging requirements for battery operated devices.
- Information on equipment control and security, including the tracking of instruments that are not returned at the proper time.

Maintaining Normal Work Conditions - Study team personnel are to be instructed on their general role in interfacing with crews and supervision. They need to have as little impact on normal crew activities as possible. Crews will be asked to conduct their business in a normal way. Conditions out of the ordinary should be noted.

Field Analysis - Support personnel will be expected to record information that may be helpful in analyzing results, determining historic changes in magnetic field exposure, and for identifying factors that affect magnetic field exposure. Forms are available for recording such information.

Recording Selected Health/Safety and Ergonomic Conditions - Team personnel will be instructed to be aware of job conditions other than magnetic field exposure. Some examples are shown below:

I. Any contaminants or related conditions representing an industrial hygiene condition. This can include air contaminants, use of solvents, etc., which would generally not be known to study personnel.

I. Ergonomic considerations.

I. Exposure to static electricity or other minimal electric discharges felt in equipment such as hot sticks during rainstorms or other conditions.

It is important to note that the existence of a particular conditions does not necessarily mean that a safety or health hazard exists.

Responsibility and Empowerment - Field project leadership is the responsibility of the team leader who needs to be involved on matters related to field decisions and direction. However, team members are empowered to handle problems as they arise. Team members are encouraged to take the initiative in both simple and more complex project matters such as making decisions about coordinating the transfer of equipment and data or contacting the right resource people to deal with questions regarding equipment operation. In addition, team personnel may sometimes need to interface with skilled/expert resource people on the project, such as safety/industrial hygiene personnel for questions on which impact project work.

Magnetic and Task Recording Equipment

<u>Emdex Gauss Meter</u>

1) Program/activate meter
2) Label/assign meter
3) Start/stop meter
4) Retrieve meter/upload to PC
5) Prepare back-up diskettes
6) Print results
7) Check/change batteries

<u>Videx Time Wands</u>

1) Clear memory/reset wands
2) Initialize wands
3) Label/issue wands
4) Retrieve/Edit/Upload
5) Prepare back-up diskettes
6) Print results
7) Set-up wands for charge

Refer to the Data Management Manual (published under separate cover) for complete instructions regarding operations and use of the equipment as well as management of the data.

PARTICIPANT RESPONSIBILITIES/EQUIPMENT INSTRUCTIONS

Videx Wands

1. Pick up your bar code activity card and wand,

2. Scan the **START/END SHIFT** bar code before you scan any other bar code activity. Make sure you depress the brown button on your wand while you are scanning the bar codes and you will hear the wand beep and/or see the red light flash every time you accomplish a successful scan. For best results, hold the wand at a 45 degree angle to the surface of the bar code card. Begin your scan on the white surface before the bar code and scan across the bar code lightly and rapidly on to the white portion on the other side of the bar code. Successful scans can also be done starting on either end of the bar code itself. Remember, handle the Videx wands with care. Do not scan the bar code card by depressing hard on the surface with the Videx wand. Also avoid dropping the wand or leaving it exposed to extreme heat.

3. Next, scan the correct bar code activity that you will be performing first. Every time you begin another activity, simply scan the correct bar code activity on your bar code card list. If you happen to scan the wrong bar code, scan **ERROR** and then scan the correct bar code.

4. At the end of your work shift, scan the **START/END SHIFT** bar code one time before you return your wand and bar code card.

Emdex Gauss Meters

1. At the beginning of your work shift, pick up your Emdex meter along with your Videx wand. The Emdex meter will be wrapped with two forms: the **Magnetic Field Measurement Form** and the **Log For "Other Activity".**

2. Fill out the **General Information** section of the **Magnetic Field Measurement Form** and tell the EMF study team person the sticker number on the form. While you are filling out this form, the team person will activate your Emdex meter. Strap the meter to your belt at waist level and carry on with your daily work routines.

3. At the end of your work shift, return the Emdex meter (along with your Videx wand, bar code card and **Log For "Other Activity"**) to the EMF study team person for uploading.

References

1. Sahl JD, Kelsh MA, Smith RS, Aseltine DA. Exposure to sixty-Hertz magnetic fields in the electric utility work environment. Bioelectromagnetics. 15:21-32 (1994).

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

3. Smith, R.W., Sahl, J.D., Kelsh, M.A., and J. Zalinski. Task-based exposure assessment: Analytical strategies for summarizing data by occupational groups. Am. Ind. Hyg. Assoc. J. 58:402-412 (1997).

4. Videx Portable Data Collection System. Videx Inc. Corvallis, OR. 1994.

5. Senior RS, Bracken TD, Sahl JD. SCE data management and analysis systems for EMDEX II magnetic field measurements. Southern California Edison Company. Rosemead, CA (1995).

6. SAS Institute Inc. SAS/STAT User's Guide, Version 6, Fourth Edition. Volume 2. SAS Institute Inc., Cary, NC (1990).

7. Box GEP, Cox DR. An analysis of transformations. Journal of the Royal Statistical Society, Series B. 26:211-252 (1964).

8. Sahl JD, Kelsh MA, Riege L, Scarfuto JB, Pennino JB, Haines KD. Sixty hertz magnetic field exposures among electric utility personnel: an analysis by occupation and task (submitted).

WORK CONDITIONS OBSERVATION FORM

Location _________________ Organization ______________ Date ___/___/___
Crew Type __________ Size ___ Time: From __:__ To __:__ Observer ________

EMPLOYEE POSITIONS PARTICIPATING:

Occupation	Sample #
____________________________	_______
____________________________	_______
____________________________	_______
____________________________	_______
____________________________	_______

LOCATION LOAD: **AM Load** _______ **PM Load** ________

JOB CONDITIONS:
While you are observing work in the field, look for conditions and obtain the following information. Sources of information would generally involve your own field observation of specific work approaches and conditions, as well as follow-on discussion with supervision when appropriate.

Job Site Location: (Street address, nearest cross street, type of area)

Description of Job: (What specific work or general work process are you reporting on? How representative is the work? How often does the crew perform this type of work? How typical was the work situation observed? Is the work being performed new construction or maintenance?)

Major Equipment/Tools Used: (What equipment/tools are being used? In what ways could the selection of tools or equipment have affected exposure?)

Vehicles Used: (What vehicles are being used? In what ways could the selection of vehicles have affected exposure?)

Main Sources of EMF in Vicinity (Generating equipment, power lines, motors, etc.):
(In the situation observed, what appeared to be the main source of EMF in the vicinity and what was their proximity?)

Work Methods/Habits: (Did you identify any modifications in the work methods which might change exposure without apparent impact upon safety, quality, cost, value added or overall service levels?)

Other Comments:

MAGNETIC FIELD MEASUREMENTS FORM

Place Sticker Here:

Type of Measurements: 1) __ Personal Exposure
2) __ Area
3) __ Walk-Through
4) __ Spot

General Information

Name: ______________________________

Job Title: ____________________________

Social Security Number: ____-___-_______

Date of Measurements: ____/____/____

Activities:

	Description	Code
SCE Job Number:	_________________________________	_____
EISD Job Class:	_________________________________	_____
OEM Job Class:	_________________________________	_____
Work Shift:	_________________________________	_____
SCE Facility:	_________________________________	_____
Environment:	_________________________________	_____
Location:	_________________________________	_____
Task:	_________________________________	_____

For Office Use

Date Filename: ______________._______ EMDEX #: ______ Wand #: ____

Deployer: _______________________ Date: ____/____/____

White: Jack Sahl, Senior Research Scientist, Rm 497 GO1 Pax 29696

Yellow: Division

Pink: Department

Rev 10/96

LOG FOR "OTHER ACTIVITY"

Name: ______________________________ Place Sticker Here:

Date: ______________________________

	Other Activity	Location	Approx. Start Time	Approx. Stop Time
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				

Method #301. Area Measurements of ELF Electric and Magnetic Fields

Method Summary

Description and purpose	**Purpose:** Epidemiology **Strategy:** Spot area measurements **Study:** Childhood cancer and residential electric and magnetic fields[1] **Authors:** H Wachtel and FA Barnes **Date:** 1987

Sampling strategy	**Description**: Area measurements **Location:** 1 meter plastic stand placed in center of room **Duration:** Spot (instantaneous) **Subject selection:** Children in a case-control study **Site selection:** Three or more rooms in the child's home plus front door. **Other data:** Power consumption (kWH)
Instrument	**Model:** Power-frequency Field Meter (Model 111, Electric Field Measurements, Inc., W. Stockbridge, MA) **Channels:** **1.** ELF electric field **2.** ELF magnetic field
Channel 1	**Description:** ELF electric field **Sensor:** Meter case is a free-body E-field sensor which is rotated in three orthogonal directions on the stand **Frequency response:** Flat filter (35-300 Hz) or linear filter (35-300 Hz), manually selected and varying with the range setting **Time response:** Average-sensing rms detector **Dynamic range:** Eleven ranges, manually selected, covering 1 V/m to 100 kV/m **Accuracy:** ±5 % **Output:** Analog read-out of the ELF electric field component
Exposure metric 1	**Final metric:** rms vector magnitude of the ELF electric field **Data processing:** Record three orthogonal components on data sheet Calculate magnitude (resultant) during data analysis **Units:** Electric field (V/m)

Channel 2	**Description:** ELF magnetic field **Sensor:** Single-axis induction coil (air core) placed in three orthogonal directions on stand **Frequency response:** Flat filter (35-300 Hz) or linear filter (35-300 Hz), manually selected and varying with the range setting **Time response:** ‣ Integration of induction coil's signal ‣ Average-sensing rms response **Dynamic range:** 0.01-1000 A/m (0.01 - 1250 µT) over eleven ranges, manually selected **Accuracy:** ± 8% from 0.03 - 30 µT (0.3-300 mG)[2] **Output:** Direct read-out of ELF magnetic field component
Exposure metric 2	**Final metric:** rms vector magnitude of the ELF magnetic field **Data processing:** Record three orthogonal components on data sheet Calculate magnitude (resultant) during data analysis **Units:** Magnetic flux density (mG)

Critique

Strengths

This is the first protocol for measuring exposures to ELF electric and magnetic fields in an epidemiologic study. It was developed for measuring residential exposures in the Denver case-control study of childhood cancer,[1] and modified slightly for the Los Angeles study of childhood leukemia.[3] By replacing the custom-built plastic stand with a fiber-glass pole, this method was also used to assess occupational exposures.[4] The EFM instrument (usually called the "Deno meter" after its inventor[5]) is no longer available, but the method has been used with the single-axis ELF meter from Holaday Instruments (Model HI-3600-02, Eden Prairie, MN).[6] With more modern instruments, the magnetic field portion of the method is obsolete, but the electric field procedures are still "state-of-the-art." This method gives reproducible measurements of electric field exposures that can be performed in any environment, and the result is a qualitative measure of both the strength of sources and the electric field's impact on workers.

Limitations

The measurement of electric field exposures is difficult indoors because of the strong perturbations resulting from the worker's body and other near-by objects. Although there is a standard method for measuring electric fields in open country near high-voltage transmission lines (Method #501), the accuracy of measuring electric fields indoors has not been fully evaluated. When the electric field exposures of people working outdoors was measured accurately by a conductive vest,[7-9] the induced currents depended on the person's grounding, posture, body size, and other factors in addition to the "free-space" electric field measured by this method.[10]

Method Protocol

from "Electric and Magnetic Field Measurement Manual"
by H. Wachtel and F.A. Barnes

1.0 Introduction

The major objectives of this manual are to give step-by-step instructions in performing the electric and magnetic field measurements and to insure that the measurements are done accurately and consistently by all interviewers. Various factors can affect the reading of electrical and magnetic fields, so caution must be taken to conduct the measurements in a precise manner according to the following protocol.

2.0 Equipment

The following equipment is necessary to conduct the field measurements:
1. Electric and magnetic field meter.
2. Magnetic coil.
3. Compass.
4. Stopwatch.
5. Electric and magnetic field meter stand.
6. Masking tape.
7. Mirror.
8. Flashlight.
9. Electric and magnetic field data collection forms.
10. Blue ballpoint pens.

3.0 Electric and Magnetic Field Assessment Protocol

After the interview has been conducted, take the electric and magnetic field measurements in the following sequence:

3.1 Note rooms of interest from the Questionnaire. Include all rooms where the Index Child spent one or more hours in addition to the three predesignated locations. Also include the room where the family spends most time together, even if the Index Child spends less than one hour per day there. If the Index Child and parents' bedroom is the same, measure that room and code as room 21, not as rooms 02 and 03. The rooms will be given code numbers during the editing process. For measuring apartments or condominiums, consider the "front door" measurement to be the entrance door to the apartment unit. If the parents have occupied more than one bedroom in the residence being measured, measure only the first bedroom occupied. Measure other bedrooms only if the Index Child has spent more than one hour per day in that room.

3.2 Complete CHS ID#, Residence #, interviewer's initials, street address, and city on the data collection form.

3.3 Note the date and the time the measurements begin. Use military time in recording time of day.

3.4 Set up the electric and magnetic field meter stand with the compass in place.

3.5 Turn off all major electrical appliances, including heat and air conditioning, refrigerator, television, and lights in the home. Note thermostat settings for re-setting after taking measurements. For the refrigerator, turn off both refrigerator and freezer and note both thermostat settings. Ask if they have heated waterbeds and electric blankets. Unplug them when allowed. Make a note in the Comments Section unless unplugged for both low and high power settings.

3.6 Go to the wattmeter and note the scale in revolutions per kWH. Circle the appropriate scale on the form. If the scale selection is not precoded on the form, record the scale in the space reserved for "Other". Use the mirror to look at the markings on the disc. Start watch and wait for the disc to rotate 30 units (e.g., 10 to 40 or 80 to 10). Stop the watch and record the time. If 60 seconds pass before a rotation of 30 units occurs, record it as 60 seconds. In measuring an apartment, use the wattmeter if readily accessible. Otherwise, indicate the missing values on the data form. Conduct measurements under Low and High Power conditions even in the absence of wattmeter data.

3.7 Take magnetic field measurements at all designated locations recording data under "Low Power" (See Appendix A). Measurements should be near the room center while remaining two or more feet from large metal objects or electrical appliances. The electric and magnetic field meter stand should always be used, even when furniture blocks the room center. Simply place the stand as close as possible to the center Place meter 6 feet from "front entrance." 3.8 Select a tab to determine which, if any, location will be repeated under Low Power (See Appendix B).

3.9 Return to the wattmeter and take measurements as outlined in 3.6 unless the circuit breaker has been used to establish the low power setting.

3.10 For High Power conditions, turn on the refrigerator to the highest power. Also turn on all available lights in all "living" areas. This should include all rooms listed on the questionnaire and any other accessible lights which the respondent will allow you to turn on. Do not turn on TV's for high power conditions.

3.11 Go back to the wattmeter and record the time for 3 rotations. If this takes less than 180 seconds, record the exact amount of time. If this takes longer than 180 seconds, record as 1-30.

3.12 Take electric and magnetic field measurements at all designated locations established in 3.7. Record the data under "High Power." (See Appendix A).

3.13 Select a tab to determine which, if any, location will be repeated under High Power (see Appendix B).

3.14 Return to the wattmeter and measure the time for 3 rotations again. If the time for 3 rotations takes more than twice as long or less than half as long, repeat the measurements.

3.15 Note the time the measurement protocol is completed.

3.16 Return all electrical appliances to their status prior to taking the measurements. This includes restoring the thermostats to their original settings. Pick up the masking tape from all the areas.

Appendix A. Taking Electric and Magnetic Field Measurements

A. Position electric and magnetic field measurement stand so that X-axis is aligned on a North-South axis. Mark template setting for each location with masking tape, under center of meter stand.

B. <u>Electrical Field</u>

1. Check battery. The battery should be checked weekly in the office. The battery needs to be replaced if the voltage drops below 0.85 v.

2. Hold magnetic loop in way that it will not influence electrical reading. Do not leave it on meter stand.

3. Place Mode on E.

4. Set meter upright to assess the Y-AXIS.

5. Try to stand at least 6 feet away to take reading. If this is not possible, try to have-back to wall or crouch while taking reading. Record reading immediately after selecting proper scale and positioning away from meter.

6. Record reading to nearest 0.10 on data sheet. Ex: 0.3 if less than 0.35; 0.4 if equal to or greater than 0.35. for oscillating fields, if the ratio of high/low is <2.0, simply record a middle or average value. If the ratio of high/low is >2.0, record a middle or average value and note the bounds of oscillation in the "Comments" section.

C. <u>Magnetic Field</u>

1. Plug in loop, then place Mode on H.

2. Lay loop flat and record reading immediately after selecting proper scale.

3. Record reading, again to nearest 0.10.

4. Place loop in Z-axis template, and record deflection. Keep loop in up-right position. Any tilting will cause &n inaccurate measurement.

5. Repeat for X-axis.

Appendix B. Selection of Locations for in Residence Reliability Check

A. At times indicated in the protocol (at end of Low Power and High Power Sequence), select a tab from the envelop. Be sure the tabs are well-mixed prior to selection.

B. The two digit number refers to a location, e.g., 02=Parent's Bedroom. The list ranges from 01 to 10. If the two digit number is outside the range of what was measured, replace the tab and select again. Repeat the selection process until a tab with an "in range" number is chosen.

C. Note the tab number and letter (Y or N) in the space below "Low Power" or "High Power". If the letter is Y, then return to the designated location to repeat the measurement. If the letter is N, continue through the protocol.

D. To repeat the measurement, first note the room name next to the first position, marked "R _ _ ". Orient the compass (and meter stand) to the NE-SW direction. Then take the electric and/or magnetic field readings in the usual manner. The meter will be reading in a NW-SE direction. If separate locations are measured under both low and high power conditions, use the extra line with "R _". Be careful to enter the data in the appropriate boxes.

References

1. Electric and magnetic field measurement manual. In: Savitz DA, *Case-control Study of Childhood Cancer and Residential Exposure to Electric and Magnetic Fields*. Contractors Final Report. New York State Power Line Project, Albany, NY, Appendix 3 (1987).

2. IEEE Magnetic Field Task Force, An evaluation of instrumentation used to measure AC power system magnetic fields. IEEE Trans. on Power Deliv 6:373-383 (1991).

3. Peters JM, Thomas DC, Bowman JD, Sobel E, London SJ, Cheng TC: *Childhood Leukemia and Risk Associated with Exposure to Residential Electric and Magnetic Fields.* Report on Contract RP2964-1, Electric Power Research Institute, Palo Alto, CA (1991).

4. Bowman JD, Garabrant DH, Sobel E, Peters JM: Exposures to Extremely Low Frequency (ELF) electromagnetic fields in occupations with elevated leukemia rates. *Appl. Ind. Hyg.* 3: 189-194 (1988).

5. Deno DE, *IEEE Trans. Power Apparatus and Systems* PAS- (197???).

6. Moss CE: Health Hazard Evaluation Report on Integrated Performance, Inc., Boulder, Colorado. HETA 91-166-2180. National Institute for Occupational Safety and Health, Cincinnati, OH (1992).

7. Deno DE, Silva JM: Method for evaluating human exposure to 60 Hz electric fields. *IEEE Trans. Power Apparatus and Systems* PAS-103:1699-1706 (1984).

8. Silva JM, Zaffanella LE, Humman NP: An activity systems model for estimating human exposure to 60 Hz electric fields. *IEEE Trans. Power Apparatus and Systems* PAS-104: 1923-1929 (1985).

9. Silva JM, Huber DL: Exposure to transmission line electric fields during farming operations. *IEEE Trans. Power Apparatus and Systems* PAS-104: 2632-2640 (1985).

10. Kaune WT, Anderson LE: Physical aspects of ELF electric and magnetic fields: Measurements and dosimetry. In: *Extremely Low Frequency Electromagnetic Fields: The Question of Cancer*, Wilson BW, Stevens RG, Anderson LE (eds.). Battelle Press, Columbus, OH (1990).

Method #401. EMF Survey and Magnetic Field Characterization in Manufacturing

Method Summary

Description and purpose	**Purpose: Hazard Surveillance** **Strategy: I.** Initial ELF magnetic field survey **II.** Characterization of magnetic fields **III.** Walkthrough survey of ELF magnetic fields **IV.** Survey of ELF magnetic field sources **V.** ELF electric field survey **Study:** Electric and magnetic field survey in the auto industry[1] **Authors:** T.D. Bracken, R.F. Rankin, L. Dickson **Date:** 1994

Critique

Strengths

These investigators undertook the first comprehensive EMF survey in an industry that encompassed frequencies beyond ELF and exposure metrics beyond the rms magnetic field magnitude. Consequently, their protocol has many features essential to such a pioneering venture. A systematic initial survey was essential for identifying major EMF sources and prioritizing sites for subsequent in-depth measurements. Achieving this goal required five distinct sampling strategies, which are summarized in five tables below. The strengths and limitations of each strategy are critiqued separately, and the whole measurement protocol comes at the end.

Limitations

The results of the auto industry study have not been published, which limits our critique of this protocol. The strategies do not include personal monitoring so the relationship between these area measurements and personal exposures cannot be quantified.

I. Initial ELF Magnetic Field Survey

Sampling strategy I	**Description**: Initial ELF magnetic fields survey **Site selection:** Four auto plants with different types of manufacturing **Location:** Worksites near possible sources of elevated fields **Duration:** Spot measurements

Instrument I	**Model:** EMDEX II (Enertech Consultants, Campbell, CA) **Sensor:** Three-axis induction coils (ferrite-core) **Frequency response:** Broadband filter (40-800 Hz bandwidth) **Time response:** ▸ Integration of induction coil signals ▸ True rms (averaging time ≈ 100 msec) ▸ Analog-to-digital conversion **Sampling rate:** Programmed to sample every 1.5 seconds **Dynamic range:** 0.1 - 4000 mG (auto-ranging over 3 scales) **Accuracy:** ±10% **Output:** rms vector components for ELF magnetic field
Exposure metric I	**Final metric**: Sources of ELF magnetic fields whose rms vector magnitude (resultant) at a worksite is above ambient levels **Data processing:** ▸ EMDEX calculates and displays the rms vector magnitude ▸ Operator compares read-out with magnitudes from cafeteria **Units:** None (qualitative source identification)

Critique

Strengths

An initial walkthrough is generally needed to determine the range of EMF magnitudes and frequencies in the plant. This assures the investigators that they will have instruments with the dynamic range and frequency bandwidth adequate to meet the study goals. For the initial survey, Bracken *et al* (and many other investigators) used the EMDEX II which displays the rms vector magnitude of the ELF magnetic field, the primary exposure metric in most health studies.

Limitations

A clear limitation of the initial survey is the bandwidth (40-800 Hz) of this EMDEX II, which is sometimes inadequate for the magnetic fields in large metal manufacturing plants. Therefore, Bracken *et al* relied on company personnel to identify sources of static and VLF/LF magnetic fields. However, what a manufacturing firm knows about EMF sources is seldom enough to establish the field magnitudes. Therefore, VLF fields should also be measured during the initial survey.

II. Characterization of Magnetic Fields

Sampling strategy II	**Description**: Characterization of magnetic fields **Site selection:** Worksites near sources of elevated magnetic fields **Location:** Area measurements with probes on stands 1 m high **Duration:** 5-20 min periods during normal work shifts **Other data:** Record the location of sources, probes, and workers

Instrument II	**Model:** Multiwave System (Electric Research and Management, State College, PA) **Channels**: 1. ELF-VLF magnetic field 2. Static (DC) magnetic field 3. VLF-LF magnetic field
Channel II.1	**Description:** ELF-VLF magnetic field **Sensor:** 3-axis air-core induction coils (up to eight sensors) **Frequency response:** Flat filter (10 Hz -10 kHz bandwidth) **Time response:** ‣ Integration of induction coil signals ‣ Waveform acquisition at 10 kHz A/D rate and 10 Hz base frequency. These sampling rates double when VLF is present. **Dynamic range:** 0.01 - 2000 mG (3 scales selected manually) **Sampling rate:** Programmed to sample every 10 sec (with 3 or 20 sec as alternatives) **Accuracy:** ±5% **Output:** Digital time record of three-component waveforms
Exposure metric II.1.a	**Final metric:** Range of the rms vector magnitudes (resultants) of the ELF-VLF magnetic field at each worksite **Data processing:** ‣ Fast Fourier Transform (FFT) of waveforms (10 Hz base frequency or 20 Hz when VLF is present) ‣ Calculate rms vector magnitude over 10 - 5000 Hz bandwidth (or 20 - 10,000 Hz when VLF is present) ‣ Determine min. and max. rms magnitudes of all samples from all probes **Units:** Magnetic flux density (mG)
Exposure metric II.1.b	**Final metric:** Rms vector magnitude (resultant) and frequency of worksite's principal harmonic in the ELF-VLF range **Data processing:** ‣ FFT of waveforms with the worksite's max. ELF-VLF magnitude (Exposure metric II.1.a) ‣ Calculate spectrum of rms vector magnitudes over the ELF-VLF bandwidth ‣ Determine the principal harmonic (frequency in the bandwidth with the maximum rms magnitude) **Units:** Magnetic flux density (mG) and frequency (Hz)
Exposure metric II.1.c	**Final metric:** Axial ratio of the principal harmonic for the worksite **Data processing:** ‣ FFT of waveforms with the max. ELF-VLF magnitude ‣ Calculate the axial ratio for the principal harmonic **Units:** Unitless (ratio of minor axis : major axis)

Channel II.2	**Description**: Static (DC) magnetic field **Sensor:** Two three-axis fluxgate magnetometers (Bartington, Ltd., Great Britain) **Frequency response:** Flat filter (0 - 3000 Hz bandwidth) **Time response:** Waveform acquisition (10 kHz A/D rate) **Sampling rate:** Programmed to sample every 10 sec (with 3 or 20 sec as alternatives) **Dynamic range:** 2.5 - 5000 mG **Accuracy:** ±0.5% **Output:** Digital time record of three-component waveforms
Exposure metric II.2	**Final metric**: Range for magnitudes (resultants) of the static magnetic field **Data processing:** ‣ Average each waveform to get the static field components ‣ Calculate the vector magnitudes ‣ Determine min. and max. magnitudes of all samples from all probes ‣ If static magnitudes vary over time, compare with ELF-VLF magnitudes **Units:** Magnetic flux density (mG)
Channel II.3	**Description**: VLF-LF magnetic fields **Sensor:** Two three-axis air-core induction coils (ERM Model 1186) **Frequency response:** Manually-selected bandpass filters for either VLF (3-30 kHz) or LF (30-300 kHz) **Time response:** ‣ Combine signals from the three coils to get the instantaneous dB/dt magnitude (resultant) ‣ Integration of the dB/dt magnitude ‣ True RMS ‣ Analog-to-digital conversion **Sampling rate:** Programmed to sample every 10 sec (with 3 or 20 sec as alternatives) **Dynamic range:** 2 mG - 20 G (three ranges manually selectable) **Accuracy:** ±5% **Output:** Digital time record of the rms vector magnitudes for the VLF or LF magnetic field
Exposure metric II.3	**Final metric**: Range for the VLF/LF magnetic field magnitude at each worksite **Data processing:** Determine min. and max. rms magnitudes of all samples from both probes **Units:** Magnetic flux density (mG)

Critique

Strengths
This study was a pioneering effort to characterize occupational magnetic fields with frequencies from 0-300 kHz and magnitudes up to 5000 mG. Since this range of frequencies and magnitudes is beyond the capability of any single magnetic field probe, Bracken *et al* used the Multiwave System, a computer-controlled multi-channel instrument with static, ELF-VLF, and VLF-LF probes in multiple locations. This protocol shows great care in placing two or more of these probes around each work location in order to get measurements representative of the workers' exposures and of the spatial variability around the source. To summarize the wealth of data collected by the Multiwave, the investigators reported the rms vector magnitudes in the three frequency ranges and the frequency, magnitude, and polarization of the principal ELF-VLF harmonic.

Limitations
The VLF-LF channel of the Multiwave System did not operate satisfactorily during this study, although it has worked elsewhere.[2] The dynamic ranges of the ELF-VLF probe (< 2000 mG) and static probe (<5000 mG) used by Bracken *et al* have been exceeded by magnetic fields from metal processing operations in other industries (ref. to HHEs). Therefore, the instruments for the field characterization should be based on the results of the initial survey. The selection of exposure metrics is sound, but other magnetic field characterizations can reasonably report different metrics as long as the uncertainty about EMF's biologic interaction mechanism persists.

III. Walkthrough survey of ELF magnetic fields

Sampling strategy III	**Description**: Walkthrough survey of ELF magnetic fields **Site selection:** Each of the four automobile plants **Location:** An extended walk down the plant's aisles **Duration:** Continuous sampling during the walkthrough **Other data:** Measurement locations automatically recorded by the LINDA surveyor's wheel
Instrument III	**Model**: LINDA System -- the EMDEX II on a surveyor's wheel (Enertech Consultants, Campbell, CA) **Sensor:** Three-axis induction coils (ferrite-core) **Frequency response:** Broadband filter (40-800 Hz bandwidth) **Time response:** ‣ Integration of induction coil signals ‣ True rms (averaging time ≈ 100 msec) ‣ Analog-to-digital conversion **Sampling rate:** Programmed to sample every 1.5 sec **Dynamic range:** 0.1-4000 mG (auto-ranging over 3 scales) **Accuracy:** ±10% **Output:** Digital time record of the rms vector components and the measurement location

Exposure metric III	**Final metrics**: Mean, median, and range for the ELF magnetic field magnitude during a plant walkthrough **Data processing:** ▸ Calculate rms vector magnitude (resultant) at each location ▸ Plot magnitudes vs. distance ▸ Calculate min., max., mean, and median magnitudes **Units:** Magnetic flux density (mG)

Critique

Strengths

In order to summarize an auto plant's overall EMF exposure, Bracken *et al* devised what is now called the "walkthrough survey", continuously monitoring the ELF magnetic field while walking up and down the aisles. The median and maximum of the rms vector magnitudes from each walkthrough are simple metrics that might predict EMF exposures in diverse facilities. The profiles and contour maps generated by the LINDA system indicate the location and extent of EMF sources.

Limitations

The reliability of these walkthrough metrics for predicting EMF exposures clearly depends on a systematic method for touring each plant, and needs to be validated by personal monitoring in the same plants.

IV. Survey of ELF Magnetic Field Sources

Sampling strategy IV	**Description**: Survey of ELF magnetic field sources **Site selection:** Sources of elevated magnetic fields near worksites (same as Sampling Strategy II) **Location:** Several profiles away from and parallel to the source **Duration:** Continuous sampling during each profile **Other data:** Measurement locations automatically recorded by the LINDA surveyor's wheel
Instrument IV	**Model**: LINDA System (same as Instrument III)
Exposure metric IV	**Final metric**: Profile and contour plots of ELF magnetic field magnitudes around each source **Data processing:** ▸ Calculate rms vector magnitude at each location ▸ Calculate min., max., and median magnitudes ▸ Plot magnitudes vs. distance from source ▸ EMCALC software plots magnetic field contours **Units:** Magnetic flux density (mG)

Critique

Strengths

Profiles of the rms vector magnitudes around sources have been used to compare EMF sources and construct mathematical models of exposures.[3] In a different company, such measurements have been used to paint high magnetic field exposure areas on the floor. This protocol provides a systematic method for surveying magnetic field sources.

Limitations

As the protocol indicates, the results of this survey can depend on the utilization of the magnetic field sources. The ideal source survey would take measurement as a function of the equipment's power consumption, and requires access to the equipment during downtime.

V. ELF Electric Field Survey

Sampling strategy V	**Description**: ELF electric field survey **Site selection**: Worksites near magnetic field sources, esp. with high voltage **Location:** Meter on a 0.4 m insulating rod held with extended arm so that meter is at least 1 m from objects **Duration**: One spot measurement per source
Instrument V	**Model:** EMDEX-C (Electric Field Measurement Co., Stockbridge, MA) **Sensor:** Free-body single-axis electric field probe (perpendicular to meter case) **Frequency response:** Broadband filter (40-1600 Hz bandwidth) **Time response:** ‣ Rectified average (averaging time ≈ 100 msec) ‣ Analog-to-digital conversion **Sampling rate:** Samples every 1 sec **Dynamic range:** 2 V/m - 50 kV/m **Accuracy:** ±20% (estimated) **Output:** Digital display of the rms electric field component
Exposure metric V	**Final metric:** rms component of ELF electric field perpendicular to meter case **Data processing:** Operator records display value on data sheet **Units:** Electric field strength (V/m)

Critique

Strengths

An exposure assessment is not complete without measuring the ELF electric fields. Although epidemiologic studies have only associated disease risks with ELF magnetic fields, electric fields do play a role in the biologic mechanisms involving induced currents, and cannot be totally dismissed. Recently, Miller *et al* reported the highest leukemia risks from high ELF electric field exposures.[4] This protocol is similar to the ANSI / IEEE method for electric fields from high-voltage transmission lines [Method 501], but makes modifications necessary for taking the measurements inside factories.

Limitations

Methods for measuring electric fields in “free” space are seldom valid indoors because the fields are strongly deformed by any object, including the worker. The instructions for the EMDEX C specifically states that its electric field measurements are valid only where the instrument is calibrated. For these reasons, a more valid method of exposure uses a conductive vest to measure the currents on the worker's trunk, but this vest is not commercially available.[5] Although the Bracken *et al* protocol is the most feasible approach using commercial instrumentation, the results provide only a qualitative indication of ELF electric fields exposure.

Method Protocol

from "Electric and magnetic field survey in the auto industry"
by T.D. Bracken

1.0 INTRODUCTION

1.1 Objectives

Occupational exposure to electric and magnetic fields (EMF) occurs wherever electrical energy is used in the workplace. Because electrical energy is employed in a variety of tasks in the automobile manufacturing industry, electric and magnetic fields are present and exposure invariably occurs. If in the future such exposures are found to be deleterious to human health, then quantification of the EMF levels and exposures in the automotive industry can provide guidance in managing and reducing any risks associated with EMF. The overall goal of this project was to provide quantitative assessments of EMF levels in the automotive industry. The specific aims of the project to accomplish this goal were:

1) to characterize the spatial distribution of magnetic fields in various automotive manufacturing and assembly plants;
2) to assess the temporal and spectral characteristics of magnetic fields near identified sources in these plants; and
3) to identify and characterize potential sources of electric fields in the plants.

The diverse nature of EMF exposures in a complex workplace, the variability in EMF levels by task and the limited budget of this project did not allow a statistically rigorous sampling of occupational EMF levels. However, by performing a broad collection of EMF measurements in various types of facilities, it was possible to identify those groups, areas, equipment, tasks and plant sites that could potentially result in high EMF exposures and might merit additional investigation.

2.0 METHODOLOGY

2.1 Instrumentation

Magnetic and electric fields were surveyed in eight auto plants by performing three types of measurements within each selected plant. Magnetic fields near specific sources at each plant were characterized with the Electric Research and Management, Inc. (ERM) Multiwave™ System which simultaneously recorded data from up to 12 probes deployed around the source.[6] Data collected in this manner provided temporal and spectral information about the magnetic fields at fixed locations around the source.

The spatial distribution of magnetic fields was characterized by measurements recorded along several transects using a broadband (40-800 Hz) EMDEX-II instrument triggered by a distance measuring wheel. Surveys of this type were done on long walks through the plant area and near specific sources.

Finally, measurements were made with a hand-held electric field survey meter to characterize electric fields near these same sources.

The equipment was transported on motorized carts or hand trucks furnished by plant personnel.

2.1.1 Wave capture system

The ERM Multiwave™ System was used for measuring ac and dc fields in the range from dc to 300 kHz. The Multiwave™ System used in this project consisted of: up to 12 measurement probes deployed around the source/area; the microcomputer-based control unit containing data acquisition boards and data storage; power conditioner; and the cables connecting the probes to the control unit. The control unit sends dc power and control signals to the probes and other components and the probes transmit amplified analog signals back to the control unit. An analog-to-digital converter in the control unit digitizes the analog measurement signals for processing by the Multiwave™ System software. The system used ERM Wave-C wave capture software and analyses were performed with the companion Wave-A software. The Multiwave™ System was calibrated by the manufacturer prior to use in this project.

Magnetic fields in the frequency range 10 to 3000 Hz were measured with up to eight three-axis air coil probes (ERM Model 1089). This frequency range corresponds closely to the Extremely Low Frequency (ELF) range of 3-3000 Hz. The probes were designated ELF-#, where the number ranged from 1 to 8. The maximum field the individual coils could measure without saturation was 2000 mG. In locations very close to certain sources this level was exceeded in one or more coils.

The dc magnetic field was detected with two three-axis flux-gate probes (Bartington Model MAG-03MC). These probes were designated dc-1 and dc-2.

Magnetic fields in the Very Low Frequency (VLF) band of 3 to 30 kHz and the Low Frequency (LF) band of 30 to 300 kHz were measured with two small tri-axial air-core probes and preamplifiers (ERM Model 1186). These probes were designated WB-1 and WB-2. Unfortunately, valid operation of these probes was sporadic during measurements, especially for WB-1. For example, the measured fields in one frequency range or the other would be constant at the maximum value of the probe for all or part of a measurement session at a source/area; a highly unlikely occurrence. This apparently saturated operation did not seem to be related to the fields that were being measured by other probes. The high constant measured field levels were observed in what were believed to be low field areas as well as near sources where higher frequency fields were expected. Because of its sporadic nature the problem was not recognized in the field and would have been very difficult to rectify if it had been identified given the tight schedule for the measurements. Because of the lack of confidence in these measurements no results are reported for the VLF and LF ranges. When the probes did appear to be functioning properly, there were no measured fields in these frequency ranges that exceeded 2 mG. However, as noted, the number of invalid measurements both near higher frequency sources and in low field locations precludes a conclusion that actual levels are limited to this value.

The two probe groupings that contained an ELF probe, a dc probe and a VLF/LF probe were considered the primary probes. These were generally placed close to the source. The remaining six ELF probes were deployed individually at varying distances from the source.

Up to twelve sensors linked to the control unit were deployed in the area around an EMF source. The system captured ac field waveform data from 10 Hz to 3 kHz, dc fields and rms field levels in the frequency bands of 3 to 30 kHz and 30 to 300 kHz. The Multiwave™ System simultaneously digitizes incoming analog waveforms from the distributed probes and stores these data for later analysis which employs a Fast Fourier Transform to extract frequency information. The system records spectral, temporal and spatial characteristics of the magnetic field from dc through 300 kHz. Because both phase and amplitude information were recorded, the orientation and degree of polarization of the ELF ac and dc fields can also be determined from the data.

2.1.2 EMDEX II System

The EMDEX II System manufactured by Enertech Consultants of Campbell, CA measures broadband resultant magnetic field from 40 to 800 Hz. It was used to characterize the magnetic field levels in this frequency range around each source measured by the Multiwave™ System as well as on a walk-through survey of most plants. The EMDEX II meter was calibrated by the manufacturer prior to its use in this project.

The EMDEX II was mounted on a surveyor's wheel (Enertech LINDA system) which provided a distance indicating trigger to the recording device. The EMDEX II simultaneously records magnetic field and distance traveled at 1.5 second intervals. Field versus distance 3-D field contour plots can be generated from this data with the EMCALC (Version 2.0) software supplied with the unit. The software also provides a two-dimensional plot of the path that was followed.

2.1.3 EMDEX-C

The EMDEX-C meter manufactured by Electric Field Measurements Co. of West Stockbridge, MA was used to survey electric fields at selected locations. This is a hand held microprocessor-based instrument capable of measuring both electric and magnetic fields. It has a digital display for survey use and a bandwidth of 40 to 1600 Hz for electric field measurements. The resolution of the meter is 0.002 kV/m. For electric field measurements the meter was mounted on a 0.4 m insulated rod and held at arms length away from the observer. Electric fields are problematic to measure and the measures values can only be interpreted as approximate indicators of field magnitude in these types of measurement conditions. Consequently, characterization of electric fields was not emphasized in this project.

2.2 Measurement Protocols

2.2.1 Selection of Plants

Initial discussions with Chrysler/UAW National Training Center personnel identified several types of plants where EMF sources were likely to be present. As a result of these discussions, the following types of plants were scheduled for initial survey visits: assembly, power train, stamping and foundry. Chrysler and union representatives from the four plants to be visited and other safety personnel were invited to attend a scooping meeting. The purposes of the meeting were: to review the scope of the project; to obtain information about plants and work practices; to identify types of plants for measurements; and to identify specific plants where measurements would be made. Prior to the meeting, attendees were asked to complete an EMF Source and Work Area Evaluation Form, in which they identified EMF sources and/or work areas in their respective plants. At the scooping meeting, all Chrysler plant types and plants were identified and discussed as to the sources present and their suitability for measurements. As a result of these discussions and the survey visits after the scooping meeting, the following plant types and plants were scheduled for measurements:

Plant Type	**Plant**
Assembly	Jefferson Assembly *
	Warren Truck
Power train	Detroit Axle *
	Trenton Engine
	Kokomo Transmission
Foundry	Indianapolis Foundry *
	Kokomo Casting
Stamping	Sterling Stamping *
* Visit followed scooping meeting prior to measurements.	

2.2.2 Selection of sources

The selection of measurement sites at a plant was guided by two principal criteria. First and foremost, was there a source of magnetic fields at the site which would result in fields above the ambient level? Second, were workers likely to work within relatively close proximity to the source?

The responses to the EMF Source and Work Area Evaluation Form, discussions at the scooping meeting and the initial tours of four plants identified several categories of sources that potentially met these criteria. The prospective sources included: welding equipment, induction heaters, induction furnaces, demagnetizers, hand tools, conveyor belts, robotic stations, battery charging stations, electrical service entry point, scrap metal magnets, and compressors. The initial tours of four plants included survey measurements of magnetic fields near these and other types of sources with an EMDEX II meter. In this way types of sources with elevated EMF levels were identified for more comprehensive measurements. Specific sites for measurements were also identified in the four plants.

The screening process identified the following categories of sources that would be measured: welding and brazing operations; demagnetizers; induction heaters and hardeners; induction furnaces; compressors; stamping presses; and battery chargers. The goal of the measurements program was to perform wave capture measurements near four to six sources in each of eight plants. Because of time constraints and plant work schedules, not all sources could be measured in each plant. Rather several examples of each type of source were measured by recognizing the types of sources at each plant and scheduling measurements accordingly. In addition, at each plant workers were asked or volunteered information about the presence and location of specific sources in these categories.

During the measurements, sources were operated in the as-found condition. No changes in normal operating procedures were requested.

2.2.3 Wave capture measurements

<u>Probe placement.</u>

After a source had been selected for measurements, the measurement team spent several minutes observing the workers and the work process. They evaluated how close the probes could be placed to the workers without interfering with production, the safety of workers, the measurement team or the equipment. They would then discuss the work process and placement of the probes with the accompanying plant personnel and the production workers. It was necessary to confirm that the production operation was a normal one, and that there were no additional constraints on the placement of probes or performance of the measurements. In addition, information about planned breaks and changes in work patterns was obtained. The measurements team then located the probes and cables in a manner that would not interfere with the production workers or the manufacturing process. The two primary probes were placed as close as possible to the worker and/or the source under study. The remaining probes were distributed around the source and throughout the work area.

The probes were mounted on wooden stands at a height of 1 m (3.28 ft) above the floor, if possible. Occasionally the probes had to be mounted on a permanent object or the wooden stands would have interfered with the worker's activities, then the probes may have been placed at a different height. At locations where the work area was on a platform or catwalk, the probes were located at floor level and at working heights. The full complement of eight ELF probes was not always deployed, but both dc probes and both wide band probes were always deployed.

The location of the source(s), probes, and workers were recorded on data sheets along with identifying descriptive information about the measurement site. The locations of probes and workers were characterized as distance from the source in feet. No photographs were allowed at the work sites.

Background measurements.

At each plant a set of measurements was made well away from manufacturing processes in an area, such as a cafeteria, where the fields were presumed to be low. This provided a check on the instruments and an indication of what ambient fields were in the plant away from the manufacturing processes. These background measurements were made during periods when there was no activity in the low-field areas.

Sampling parameters.

Wave capture measurements were made at 3, 10 or 20 second intervals for between five to 20 minute periods. The sampling interval was usually 10 seconds, but was occasionally adjusted to capture a rapidly changing source or to allow a longer sampling period. Recording periods were occasionally shortened by line shutdowns or scheduled breaks.

The standard operating condition for the waveform capture system was with a base frequency of 10 Hz; that is, a period for a 10 Hz wave (100 ms) was digitized during each measurement sample. There were 1024 points sampled, resulting in a sampling frequency (or A/D rate) of about 10 kHz which allows frequency components up to 5 kHz to be computed with the Fast Fourier Transform algorithm.

If the VLF and/or LF bands indicated the presence of fields in these bands near a source, then the base frequency was increased to 20 Hz to allow frequencies up to 10 kHz to be resolved in the analyses.

Data collection.

The measurements made at each location were stored on the Multiwave™ System hard disk drive. Files collected with the standard base frequency of 10 Hz were designated with an "S" as the third letter in the filename. (The first two letters were used to designate the plant name.) Files collected with the wideband 20 Hz base frequency were denoted with a "W" as the third letter in the file name.

After each day's measurements the data files were reviewed and transferred to tape for permanent storage. Review of the data consisted of the examination of waveforms from all probes to ensure functionality and consistency with observations made in the field. The cyclic or sporadic nature of the sources necessitated some trials and adjustments with sampling procedures at the first few sites.

2.2.4 Broadband magnetic field survey measurements

Plant walk-through.

The EMDEX-II/LINDA was used to measure broadband magnetic fields during an extended walk down the aisles of a plant. Though not specific to any given EMF source the recorded data provide a basic characterization of the field levels along the walkways of a plant. These data can be used to make very general comparisons of field levels at the plants.

After a walk-through was completed, the data was downloaded to a laptop computer for storage and analysis. Each file was given a unique name. Plots of field versus distance and tables of statistical measures for the measurements were reviewed to confirm the validity of the measurements.

Source/area survey.

After a source/area had been identified for measurements and the nature of the work there discussed with Chrysler personnel, the EMDEX II/LINDA system was used to characterize the broadband resultant magnetic field along a path through the work area. The paths included linear segments parallel to the source(s) as well as segments in a direction away from the source(s). The paths were selected to pass through locations near the source, work stations and remote areas. It was not possible to more than generally identify the sources that contributed to a peak in the field versus distance plot, because sufficiently detailed drawings of a site were not practical. The 1.5 second sampling rate for the EMDEX II/LINDA system and the movement of the system precluded measurements of the spatial or temporal characteristics of the field along the path for repetitive and sporadic sources. Thus, the survey measurements represent measurements along the path that probably does not capture the peak field at any specific location, but rather give an indication of the relative field distribution in areas near the sources.

After the measurements were made along a path in the vicinity of the source, the route was sketched on an annotated plan view of the area. The data were downloaded from the EMDEX II using EMCALC software supplied with the unit. A unique file name was given to each data file. Software-generated plots of the route, of field versus distance and of 3-D field contours were reviewed to confirm the validity of the measurements.

2.2.5 Electric field measurements

At each source, electric fields were surveyed with the EMDEX-C meter mounted on a 0.4 m insulating rod that was held with the arm extended away from the body. Measurements were made at distances of at least 1 m from grounded equipment or objects. Measurements were performed in the vicinity of operating equipment, especially near equipment that had high voltage associated with it.

Field readings were read visually from the meter display and recorded manually.

2.3 Work Site Characterization Parameters

After sources had been identified and measured at the eight plants, the 26 sites where measurements were made were divided into seven categories:

Welding and Brazing (5);
Demagnetizers (3);
Induction Heaters and Hardeners (3);
Induction Furnaces (3);
Compressor Room (2);
Miscellaneous (4); and
Background (6).

The number in parentheses indicates the number of measurement sites in each category. Each source/area was also characterized in terms of the following attributes:

Temporal.
The temporal nature of the magnetic fields present at a site were determined by the operation of the principal source: continuous, for sources that did not vary over time; repetitive, for sources that cycle in a regular fashion over time; and sporadic, for sources with an irregular pattern of use.

Spatial.
Each source was characterized as being a point source, that is localized to a specific small volume, or as a distributed source that contributed to fields throughout the work area. A distributed source could be either a line source or a collection of point sources. For example, a group of welding stations or a line of furnaces was treated as a distributed source.

Frequency.
The spectral content of field measurements near a source were examined to determine what frequencies were present: 60 Hz, specific harmonics or subharmonics of 60 Hz, dc, VLF or LF. Generally, 60 Hz was the predominant frequency component. However, if other frequencies were clearly present in fields above background levels then they were listed as being associated with that source. At locations where background level fields were observed, fields at frequencies other than 60 Hz could be observed at levels that were significant in terms of the 60 Hz field present but still at low levels (<1 mG).

Levels.
The field level associated with a source was the decade of the highest field measurement observed with the Multiwave™ probes (10-3000 Hz). The probes with the highest field measurements were generally those located closest to the source. This level only gives a very crude estimate of the field that was found near the source. It was not intended to provide an estimate of exposure. Because the field from most sources was repetitive, the Multiwave™ System did not necessarily capture the peak field at a location nor did the locations of the probes necessarily correspond to the location of maximum field.

Worker presence.
Each source was characterized in terms of whether a worker was continuously, frequently or seldom near the source. These assignments were based on observations during the short visit to the measurement site and on conversations with Chrysler personnel and are therefore subjective.

Other sources.
If other sources were near the primary source these were identified and noted.

2.4 Analysis and Presentation of Data

2.4.1 Waveform capture data

The approach to analysis and presentation of the large quantity of highly variable data collected with the Multiwave™ System is outlined in Table 2.1. The time course of resultant field was plotted for each ELF probe and the two samples with the largest resultant were selected for analysis and presentation. The Wave-A data analysis log was examined to determine if any sensors were saturated during the selected data points. If so, the frequency spectrum for an unsaturated coil was used to characterize frequency content. If all coils were saturated, no frequency spectrum or axial ratio was generated for that sample. For each selected sample, a waveform and unsaturated frequency spectrum were plotted. The axial ratio for the principal frequency component was determined and plotted over time for most probes. The rms magnitude of the principal frequency component was also determined and recorded as the best indicator of harmonic field magnitude. Data on magnitude, frequency content and axial ratio were then summarized in the Waveform Capture Measurement Summary form shown in Table 2.2. Whether sensors were saturated or not was also indicated on Table 2.2. If all coils were saturated, no analysis of the principal harmonic was performed. The forms as well as the plots were grouped by source category. Results embodied in the data on the forms were summarized by source type with selected plots shown for illustrative purposes.

The time courses of resultant dc field at each source/area were examined for variation. If there were changes in field present, then the dc field time source was compared with the time course for the corresponding ac probe. If the changes in dc field were coincident with those observed in the resultant ac field, operation of the source was assumed to contribute to dc field levels.

2.4.2 Survey measurements

Plant walk-throughs.

EMDEX-II magnetic field data from the plant walk-through survey measurements were plotted versus distance and summary statistics for the data generated using the EMCALC software provided with the EMDEX-II.

Source surveys.

Magnetic field data collected near sources during surveys by the EMDEX-II/Linda system were plotted as a function of distance along the path and also as a three-dimensional contour plot. Summary descriptors for the data were recorded on the Survey Measurements Summary form shown in Table 2.3. The descriptors include: resultant field maximum, minimum, median and length of path. Comments related to the measurements were also noted on the form.

Field surveys.

The range of observed electric fields near a source were recorded on the Survey Measurements Summary form for that source.

2.5 Limitations

2.5.1 Sampling

The objective of this project was to characterize electric and magnetic fields in work areas and near sources in automobile manufacturing plants. The resources available to the project dictated that this effort be concentrated on readily accessible plants and sources. No attempt was made to randomize the selection of plants, measurement locations, sources, or time of measurements. The results describe field magnitudes and spectra for numerous sources and work areas. However, extrapolation of these results to additional sources and to plants in general is not appropriate. Such an extrapolation would require data collected in a systematic fashion with a rigorous sampling strategy. The results from this project can assist in the design of such a study.

2.5.2 Field measurements

The complex temporal nature of the fields associated with sources in the automobile plants was difficult to capture with the fixed interval sampling of the available instrumentation. Cyclic or sporadic sources produced field pulses with durations on the order of seconds that repeated at intervals of tens of seconds. To capture the pulse behavior requires sampling intervals of tenths of seconds: too short for the fixed intervals of either the Multiwave™ or EMDEX-II. To capture complete frequency content data during a pulse with the Multiwave™ requires that the waveform capture occur over the duration of a pulse. This would require pre-triggering on the pulse, a wide dynamic range, and adjusting the sampling interval to that of the pulse. The first capability was not available with the commercially available Multiwave™ System that was used, and the second was not practical without the first. Specially designed instrumentation would have been necessary to achieve these capabilities for this project.

Thus, the approach taken to capture and analyze field waveforms was limited. It represents a practical compromise: the use of the peak field readings in the time course to attempt to capture pulse conditions and the use of a standardized 10 Hz base frequency for digitizing wave forms at 10-second intervals to facilitate data collection at numerous sites. Thus, the results presented here may not represent the maximum fields at the measurement locations and may not provide all the frequency components of the pulsed fields.

The 1.5 second sampling interval for the EMDEX-II field surveys imposed similar constraints on the broadband survey measurements: the pulsed nature of sources might or might not be captured during a survey around the source. The 1.5 second sampling interval might have been able to characterize the pulsed magnitude of certain sources. However, the broadband magnetic field survey measurements are further limited in their interpretation, because they represent the field at a point-in-space as well as a point-in-time.

The magnitude of fields near certain sources exceeded the 2000 mG range of the Multiwave™ sensors. In these cases, frequency content was characterized from an unsaturated coil, if any were present. If all the coils were saturated, then no frequency analysis was performed. For field measurements when saturation of a coil or coils occurred, the resultant field waveforms did not represent the true waveform and the magnitude of the resultant waveform represented a lower bound on the actual field present. For these cases, frequency content was based on analysis of a single axis and the axial ratio was based on data from saturated coils.

The autoranging feature of the Multiwave™ System adjusts gains up to three times during a sample to accommodate the signals present. If saturation of sensors remained after three gain changes, the waveform was captured anyway with saturated coils. Any such saturated signals were not specifically identified, but were treated analytically in the same manner as over range signals were.

2.5.3 Probe locations

Performing measurements in the midst of ongoing manufacturing processes limited the locations where probes could be placed. Efforts were made to place the probes and perform survey measurements near work stations. However, both these types of measurements only approximate field levels at work stations. Furthermore, the measurements were only made for a limited time at each location. Thus, these measurements cannot be used to characterize personal exposures. However, they do indicate which work areas and sources could be further investigated since these are locations where relatively high exposures occur.

References

1. Bracken TD, Rankin RF, Dickson L: Magnetic and electric field survey in the auto industry. Report to the United Auto Workers / Chrysler National Training Center, Detroit, MI (1994).

2. Bracken TD. Electric and magnetic fields in an magnetic resonance imaging facility: Measurements and exposure assessment procedures. Report to the National Institute for Occupational Safety and Health. NTIS Publication # PB-94-179489. National Technical Information Service, Springfield, VA (1994).

3. Preece AW, Kaune W, Grainger P, Preece S, Golding J. Magnetic fields from domestic appliances in the UK. Physics in Medicine and Biology 42:67-76 (1997).

4. Miller AB, To T, Agnew DA, Wall C, Green LM. Leukemia following occupational exposure to 60-Hz electric and magnetic fields among Ontario electric utility workers. *Am J Epidemiol* 144:150-160 (1996).

5. Deno DE, Silva JM: Method for evaluating human exposure to 60 Hz electric fields. *IEEE Trans. Power Apparatus and Systems* PAS-103:1699-1706 (1984).

6. Dietrich FM, Feero WE, Robertson DC, Sicree RM: Measurement of Power Systems Magnetic Fields by Waveform Capture. Report EPRI TR-100061. Electric Power Research Institute, Palo Alto, CA (1992).

Table 2.1. Waveform Capture Data Analysis Procedure: a) Sequence of activities; b) Graphic presentations.

a) Sequence of activities

1.	Plot time course of resultant field for each probe deployed at a measurement site.
2.	Examine time course of resultant for probe. Identify 2 peak sample points: note magnitude and sample number.
3.	Examine Wave-A data log to determine if any sensors were saturated during selected samples. If so, select unsaturated coil for frequency analyses. If no unsaturated coils, skip next step. If all coils saturated, do not examine principal harmonic.
4.	Plot resultant waveforms and unsaturated frequency spectra for two peak sample points. Identify principal field components in frequency spectra of selected waveforms.
5.	Plot frequency spectrum of resultant field for two sample points. Note magnitude of components of principal field components identified in unsaturated coil.
6.	Plot time course of axial ratios for principal field components for two sample points. Note axial ratio in percent for selected samples.
7.	Record values for all parameters on Waveform Capture Measurement Summary form.

b) Graphic presentations

Figure 1: Time courses

Time course of resultant

Time course of axial ratio (Principal, Component, Samples)

Figure 2: Waveforms and frequency spectra

Waveform peak resultant Sample 1	Waveform peak resultant Sample 2
Freq. spectrum peak resultant Sample 1	Freq. spectrum peak resultant Sample 2

Table 2.2. Waveform Capture Measurement Summary

WAVEFORM CAPTURE MEASUREMENT SUMMARY

Source: ______________________________ Type: ______________________

Plant: __________________ Data set: __________________ No. of Samples: ______

Comments: ____

a) ELF Measurements*

Probe	Proxi-mity to worker (feet)	Distance from source (feet)	Resultant (mG) from time course		Characteristics of the principal harmonic from 2 selected unsaturated samples							
			Maximum	Minimum	Sample No.		Frequency (Hz)		Resultant (mG)		Axial ratio (%)	
ELF-1												
ELF-2												
ELF-3												
ELF-4												
ELF-5												
ELF-6												
ELF-7												
ELF-8												

*Denote saturated sensor(s) by: Longitudinal, Transverse, Vertical, or All sensors.

b) DC Measurements

Probe	Proximity to worker	Distance from source, ft.	DC field, mG		Comments
			Maximum	Minimum	
DC-1					
DC-2					

Table 2.3. Survey Measurement Summary

SURVEY MEASUREMENT SUMMARY

Source: ____________________ Type: ________________ Plant: __________________

a) Broadband Survey			File:		Comments
Resultant Field, mG			Plots		
Max.	Min.	Median	Path	Contour	
b) Electric field:			Range: V/m		

Source: ____________________ Type: ________________ Plant: __________________

a) Broadband Survey			File:		Comments
Resultant Field, mG			Plots		
Max.	Min.	Median	Path	Contour	
b) Electric field:			Range: V/m		

Source: ____________________ Type: ________________ Plant: __________________

a) Broadband Survey			File:		Comments
Resultant Field, mG			Plots		
Max.	Min.	Median	Path	Contour	
b) Electric field:			Range: V/m		

Source: ____________________ Type: ________________ Plant: __________________

a) Broadband Survey			File:		Comments
Resultant Field, mG			Plots		
Max.	Min.	Median	Path	Contour	
b) Electric field:			Range: V/m		

Method #501. Measurement of Power-frequency EMF from AC Transmission Lines

Method Summary

Description and purpose	**Purpose: Source assessment** **Strategy: I.** Lateral profiles of electric and magnetic fields **II.** Longitudinal EMF profiles **Study:** ANSI/IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines[1] **Authors:** AC Fields Working Group of the IEEE Transmission and Distribution Committee, Corona and Field Effects Subcommittee **Date:** 1994

Sampling strategy I	**Description**: EMF profiles perpendicular to a transmission line **Site selection:** Lateral profiles midway between two towers where the ground is level and free of other power lines, buildings, trees or other structures **Location:** At least five points beneath the conductors and one meter above the ground; more measurements out to 30 m beyond the conductors **Duration:** Spot measurements **Instruments: A.** Electric field meter **B.** Single-axis magnetic field meter **C.** Three-axis magnetic field meter **Other data:** Measurement times, environmental conditions, and transmission line parameters (voltage, wire configuration, and load)
Instrument I.A	**Model:** Electric field meter which meets the specifications below **Sensor:** Single-axis free-body sensor whose axis is mounted at the end of a 2.5 m (8 ft) non-conducting handle **Sensor alignment:** Vertical **Frequency response:** Meter calibrated with power-frequency electric fields (50 or 60 Hz) **Time response:** Average-sensing or true rms response **Accuracy:** Uncertainties with calibration, EM interference, current leaking thru the handle, perturbation from objects, harmonic content, and observer proximity are estimated and should not exceed ±10% total **Output:** Vertical rms component of power-frequency electric field
Exposure metric I.A	**Final metric**: Profile of the vertical rms power-frequency electric field vs. distance from the line's center **Units:** Electric field (V/m)

Instrument I.B	**Model:** Magnetic field meter which meets the specifications below **Sensor:** Single-axis induction coils **Sensor alignment:** Rotate until maximum reading is obtained **Frequency response:** Meter calibrated with power-frequency magnetic fields (50 or 60 Hz) **Time response:** Average-sensing or true rms response **Accuracy:** Errors from calibration, EM interference, perturbations from conducting objects, and harmonic content are estimated, and their total should not exceed ±10% **Output:** Maximum rms component of the power-frequency magnetic field
Exposure metric I.B	**Final metric**: Profile of the rms maximum power-frequency magnetic field vs. distance from the transmission line's center **Units:** Magnetic flux density (mG or µT)
Instrument I.C	**Model:** Magnetic field meter which meets the specifications for I.B above **Sensor:** Three-axis induction coils **Output:** RMS vector magnitude (resultant) of the power-frequency magnetic field
Exposure metric I.C	**Final metric**: Profile of the rms power-frequency magnetic field magnitude vs. distance from the line's center **Units:** Magnetic flux density (mG or µT)

Sampling strategy II	**Description**: EMF profiles parallel to the transmission line **Site selection:** Longitudinal profiles between the same two towers **Location:** One meter above the ground at a minimum of five points along the line's center **Duration:** Spot measurements **Instruments:** **A.** Electric field meter (same as above) **B.** Single-axis magnetic field meter (same as above) **C.** Three-axis magnetic field meter (same as above)
Exposure metric II.A	**Final metric**: Plot of the vertical rms power-frequency electric field vs. distance from the towers
Exposure metric I.B	**Final metric**: Plot of the rms maximum power-frequency magnetic field vs. distance from the towers
Exposure metric II.C	**Final metric**: Plot of the rms power-frequency magnetic field magnitude vs. distance from the towers

Critique

Strengths

This classic method[1] is a consensus standard developed by a committee of the Institute for Electrical and Electronic Engineers (IEEE), and is very thorough in its description of EMF and definition of terms. These procedures have been used to measure electric and magnetic fields around high-voltage transmission lines.[2] Although this 1994 method has aged in some respects (*e.g.* mechanical perturbations on the gauge), it contains many useful procedures for meter calibration, spot measurements of electric fields, and the assessment of an EMF line source through lateral and longitudinal profiles. The magnetic field method for single-axis gaussmeters is an useful technique which uses the rms maximum component as its exposure metric. Near line sources, the rms maximum can be located easily by rotating the induction coil's axis in the plane perpendicular to the line. However, the maximum is not always easy to find in other magnetic field environments, making this method somewhat inaccurate.[3] A more convenient method for complicated magnetic field environments, and the preferred technique uses three-axis meters with the rms vector magnitude (resultant) as its exposure metric.

Limitations

Several aspects of this method assume that the field's frequency spectrum is dominated by the power frequency. Harmonics in the fields are treated as a source of error to be documented by an oscilloscope picture of the waveform and included in the estimate of measurement uncertainty. However, harmonics are always present in EMFs outside of transmission line fields. This approach of measuring the rms maximum with an average-sensing meter has been shown to produce errors as much as -22% in fields with harmonics.[4] Although the title says that the method applies to "power lines", harmonics are present in the fields from many distribution lines. For assessing other EMF sources, these procedures for calibration, measurements, and reporting of results therefore need to be modified in order to quantify accurately the fields with harmonics.

Method Protocol

"IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines"
ANSI/IEEE Standard 644-1994

This protocol is a copyrighted publication distributed by the Institute of Electrical and Electronic Engineers, New York City, NY.

References

1. ANSI/IEEE Std 644-1994: IEEE Standard Procedures for Measurement of Power Frequency Electric and Magnetic Fields from AC Power Lines. Institute for Electrical and Electronics Engineers, Inc., New York (1994).

2. Sendaula M, Hilson DW, Myers RC, Akens LG, Woolery BJ: Analysis of electric and magnetic fields measured near TVA's 500-kV transmission lines. IEEE Trans. Power Apparatus and Systems PAS-103:328-336 (1984).

3. IEEE Magnetic Fields Task Force: An evaluation of instrumentation used to measure AC power system magnetic fields. *IEEE Trans.* PWRD-6: 373 (1991).

4. Sicree RM, Rauch GB, Dietrich FM: Comparison of magnetic flux density meter responses over a database of residential measurements. IEEE Trans Power Deliv 8:607-619 (1993).

III. PARTIAL METHODS

This section contains partial methods, which contain one or more techniques useful in a full method for measuring EMF exposures. These partial methods address the following topics:

- Sampling strategy
- Personal monitoring
- Area measurements
- Spot measurements
- Field characterization
- Quality control
- Data management
- Calculation and data summarization

Partial Method #001. Initial Walkthrough Survey of ELF Magnetic Fields

Method Summary

Description and purpose	**Technique:** Sampling strategy **Purpose:** Workplace survey **Study:** Hazard Evaluations and Technical Assessments (HETA)[1-7] **Authors:** CE Moss, NIOSH **Date:** 1992

Sampling strategy	**Description**: Initial walkthrough with spot measurements **Location:** Walk-through of all work sites relevant to the HETA request **Duration:** Spot measurements **Site selection:** Potential magnetic field sources **Other data:** Interview personnel, floor plan or sketch, photos.
Instrument	**Model:** Spot measurement meter for ELF magnetic fields
Exposure metric	**Final metric:** Sources and ranges of ELF magnetic fields **Data processing:** Measurements recorded on floor plan

Critique

Strengths

This sampling strategy has been used successfully in NIOSH's Hazard Evaluation and Technical Assistance (HETA) investigations involving electric and magnetic fields (EMF) in a variety of workplaces.[1-7] The purpose is to identify EMF sources adjacent to workers as a first step in planning measurements, and to identify the instruments needed to measure exposures. These procedures are an important first step in exposure assessments for EMF for most purposes, especially those involving unfamiliar workplaces.

Limitations

The usual ELF spot measurement meters do not have the dynamic range or frequency bandwidth needed to measure all the fields that are encountered in some workplaces, *e.g.* the HETA in the electrosteel plant.[2] In order to pick the right meter for those situations, investigators can estimate the instrument specifications from the qualitative information which company personnel provides about the sources. Those estimates should be confirmed with pilot measurements. In addition, this initial walkthrough should also assess worker proximity to high voltages which may generate exposures to elevated electric fields.

Sampling Strategy

from "ELF Exposure Assessment Procedures for Use in HETA Evaluations" by C.E. Moss (1991)

1. If resources do not permit a walk-through prior to the actual conduct of the Hazard Evaluation or Technical Assistance, the Principal Investigator (PI) will have to obtain the preliminary information by phone. Some important questions are:
   - the electrical source serving the facility,
   - types of transformers,
   - locations of main cables and breakers,
   - magnitude of supply voltages, peak power, and current levels,
   - frequencies (including DC) of power supplies and electrical devices,
   - location of workers relative to known EMF,
   - presence of any motors and generators,
   - is welding being performed,
   - location of any small step-down transformers,
   - presence of small heaters or irons.

2. After the initial meeting with representatives of union, management, or requestor has occurred the PI should ask to have a walk-around tour be given to the NIOSH team. During this walk around portion the team will visually observe all possible EMF sources.

3. A sketch (or a copy of the floor plan) should be made of the areas where the sources are located. On this sketch should be room dimensions, source shapes and distances, number and location of workers in the immediate vicinity. A name of a key person who works in the room should be written down along with their telephone number.

4. If permitted, some limited "EMF sniffing" can be done with appropriate magnetic field instruments, such as the EMDEX or Holaday meters. The spot measurements should be written onto the sketch of the work site. Since measurements are not often possible on the initial walk-through, the important thing is observe where the sources are located.

5. Photographs should be made to further document the scene. Make sure to document the date, time, and location where the photograph was made for further reference.

6. For each work site identified on the walk around, ask a reliable person for information on specific jobs and tasks, as well as any prior exposure evaluations. High emphasis should be placed on learning the locations where workers are reporting medical symptoms. This linkage between job duties, medical symptoms and possible EMF exposures will be very helpful in the placement and proper distribution of the measurement equipment.

7. Only after getting some idea of how big the facility is and where the workers stay or move should one try to measure field exposures. The HHE program normally requires that a measurement protocol be developed prior to visiting the facility. That protocol should be reviewed in light of the information gathered from the walk-through. If the

original protocol is not valid and useful, it will have to be changed or modified by the PI before initiating measurements. In some cases, after the walk-through phase is completed, NIOSH investigators will return to Cincinnati to develop a complete protocol.

References

1. NIOSH Hazard Evaluation and Technical Assistance Report: Akron General Medical Center, Akron, OH. Report No. HETA 93-1120-2429. National Institute for Occupational Safety and Health, Cincinnati, 1994.

2. NIOSH Hazard Evaluation and Technical Assistance Report: Armco Steel Company, L.P., Ashland, KY. Report No. HETA 91-0140-2352. National Institute for Occupational Safety and Health, Cincinnati, 1993.

3. NIOSH Hazard Evaluation and Technical Assistance Report: Chicago Television Stations, Chicago, IL. Report No. HETA 93-0424-2486. National Institute for Occupational Safety and Health, Cincinnati. 1995.

4. NIOSH Hazard Evaluation and Technical Assistance Report: New York Telephone Company, New York, N.Y. Report No. HETA 91-0048-2506. National Institute for Occupational Safety and Health, Cincinnati, 1995.

5. NIOSH Hazard Evaluation and Technical Assistance Report: Santa Clara County Administrative Office Building, San Jose, CA. Report No. HETA 93-0734-2401. National Institute for Occupational Safety and Health, Cincinnati, 1994.

6. NIOSH Hazard Evaluation and Technical Assistance Report: U.S. Army Corps of Engineers, Ozark, AR. Report No. HETA 92-0243-2377. National Institute for Occupational Safety and Health, Cincinnati, 1994.

7. NIOSH Hazard Evaluation and Technical Assistance Report: U.S. Tsubaki, Sandusky, OH. Report No. HETA 92-0306-2465. National Institute for Occupational Safety and Health, Cincinnati, 1994.

Partial Method #002. Monitoring ELF-EMF Exposures by Work Environment with Subject Logbooks

Method Summary

Description and purpose	**Techniques:** Sampling strategy and quality control **Purpose:** Exposure assessment and training in electric utilities. **Study:** The EMDEX Project[1,5] **Authors:** T. Dan Bracken, Inc. **Date:** 1990, 1995

Sampling strategy	**Description**: Personal monitoring **Location:** Monitor in a waist pouch **Duration:** Full-shift, 24-hour and weekend **Subject selection:** Volunteers recruited to cover all work environments and time-spans in the study protocol **Other data:** Work environments recorded by subject in a logbook
Instrument	**Model**: EMDEX 100 (Enertech Consultants, Campbell, CA) **Channels:** **1.** ELF magnetic field **2.** ELF electric field
Exposure metric 1	**Final metric:** Average TWA magnitudes for the ELF magnetic field by occupational groups and work environments. **Data processing:** Details given elsewhere[2] **Units:** Magnetic flux density (mG or mT)
Exposure metric 2	**Final metric:** Average TWA magnitudes for the ELF electric field by occupational groups and work environments. **Data processing:** Details given elsewhere[2] **Units:** Electric field (V/m)

Critique

Strengths

These procedures were used successfully in the EMDEX Project to obtain a sampling of electric utility employee exposures to EMF in work and non-work environments.[2] Since these procedures depend on the subjects recording their locations in a logbook, the motivation of the volunteers is crucial to the success of this approach. Other approaches are to supplement the logbooks with researchers observations of the subject's movements,[3] or to use electronic recording devices to log work activities or locations and the duration of time in those activities.[4] (See complete method #203.)

Limitations

This was the first attempt at comprehensive electric and magnetic field exposure assessment in the electric utility industry. It's primary objectives were technology transfer of the EMDEX instrumentation and the development of exposure measurement protocols. Some limitations for use of the procedure are directed at secondary objectives. These include the non-random sampling of workers in the personal monitoring survey and the possible variation in protocol implementation by the site coordinators. The use of logbooks is an intensive procedure that can provide valuable detailed exposure information. However, it is difficult to administer and imposes a high demand on workers and site coordinators, as well as adding complexity to the data management and data analysis phases. However, the approaches developed in this project are useful to exposure assessment projects in multiple sites. The large sample size obtained overcame many of the potential study limitations.

Method Protocol

adapted from "The EMDEX Project: Technology Transfer and Occupational Measurements" by T.D. Bracken (1990).

Sampling Strategy

1. Each EMDEX site coordinator (ESC) is asked to solicit volunteers based on the study protocol. The stratification schemata for the EMDEX Project includes:
   - volunteers whose jobs are primarily associated with specific work environments (Table 1) at their company and who will wear the EMDEX for an 8-hour work period
   - volunteers willing to participate in 24-hour exposure data collection
   - volunteers willing to participate in exposure data collection over a weekend

Table 1. Work Environment Categories. For the purpose of selecting subjects, the utility work environment is divided into eight groups.

- General Facilities
- Transmission Lines
- Distribution Lines
- Substation Facilities
- Electrical Environment: including electrical and electronic engineers; engineering and electronic technicians; electronic repairers; electricians; electric crane, hoist and winch operators; and welders and cutters.
- Outdoor Non-Electrical Environment: including surveyors and surveying technicians; security guards; painters; construction workers; truck drivers; and meter-readers
- Shop Environment: including automotive mechanics; industrial machinery repairs; heating, air-conditioning and refrigeration mechanics; carpenters; plumbers and machinists
- Office/Clerical/Management

2. The EMDEX is worn in a canvas or nylon, belted pouch that is provided with the unit. The unit can be positioned on either hip. The LCD display on the front of the unit (i.e.

face-place with switches, button, etc.) should point upward when standing. When the EMDEX is worn outdoors in near or below-freezing temperatures, it should be worn inside a coat.

3. When the EMDEX has been put on by the subject and the measurement period is ready to begin, the subject should press and hold the event marker button until the Event Number is displayed on the LCD of the EMDEX. The subject should enter the EMDEX time and Event Number on the inside front cover, "Subject Start Page", of the Subject Logbook (Table 2). The work environment in which the measurements start is also checked on this page. The Subject Logbook can be kept in the pocket of the EMDEX pouch, in a shirt pocket, or in any convenient location.

4. Whenever the subject enters a new environment, the event marker button should be pressed to enter a new event in the data. Times and Event Marker Numbers are entered in the Subject Logbook with each change of environments during the entire measurement period.

5. During activities when the EMDEX cannot be worn (e.g., sleep, heavy exercise, swimming, or bathing) the EMDEX should be placed at a secure, nearby location. Event markers should be inserted in the data when the unit is taken off and when it is put back on. Each such change in EMDEX status (i.e., taken off and put back on) should result in an entry in the Subject Logbook. The appropriate status and environment boxes should also be checked in the Subject Logbook at these times. When the unit is taken off for sleeping, it should be placed with car keys, glasses, wallet or other items that will be needed in the morning. In this way, the chances of leaving the unit will be minimized.

6. At the conclusion of the measurement period, the subject presses the event marker, notes the time and Event Number in the Subject Logbook and checks "End of Measurement" on the Subject Logbook page. The EMDEX unit is then placed in a safe place until it is worn by another subject or picked up by the ESC. No switches are changed during the measurement period. The EMDEX continues to collect data while it is stored between measurements. Any comments can be recorded on the back cover of the Subject Logbook.

Table 2. Subject logbook for the EMDEX Project, listing the work environments.

EMDEX SUBJECT LOGBOOK INSTRUCTIONS	**SUBJECT START PAGE**	**TO BE COMPLETED BY THE ESC**
When the status of the EMDEX changes or when entering a new environment, please: 1) Enter the EMDEX 24-hour clock time on a new page of the logbook. 2) Press and hold the red event button until the display flashes and E# # # is shown. 3) Enter the E# # # on the same page of the logbook. 4) Check the appropriate **STATUS** boxes and **NEW ENVIRON- MENT** box on the same page.	Job Title: ________________ Work Site: ________________ Start Date: ____/_____/_____ Start Time: ________________ Event Number: E____________ **STATUS** EMDEX: worn ` not worn ` **ENVIRONMENT** (Check one only) WORK ` Generation facility ` Transmission line ` Distribution line ` Substation ` Office ` Shop ` Travel ` Other, please specify ____________________ NON-WORK ` Home ` Travel ` Other, please specify ____________________	Site # ________ ESC ______ EMDEX # ______ Date EMDEX Initialized __/__/__ Book Nos. _____ & _________ Subject Type: ` 8 hr. ` 24 hr. ` Weekend Form verified by ESC _________ Subject Job Classification: ________________ Date Subject Data File Extracted ______/______/______ Disk Set Number ___________ Subject Data File Name _______ Subject No. ______________ Problem Report: Yes ` No ` Please send this form and the logbook along with the Subject Data Disk to Project Headquarters.

Quality Control

Each subject will be instructed by the ESC in the use of the EMDEX. Each subject will receive a set of written instructions on EMDEX use. The Subject Logbook will contain abbreviated instructions for its use. At the end of each measurement period, the completeness of the Subject Logbook (i.e., entered time, event number, status and environment) will be verified by the ESC. Completeness and consistency will also be examined at Project Headquarters during data entry and analysis.

References

1. Bracken TD: The EMDEX Project: Technology Transfer and Occupational Measurements, Volume 3: Appendixes. EPRI Report EN-7048. Electric Power Research Institute, Palo Alto, CA (1990).

2. Bracken TD: The EMDEX Project: Technology Transfer and Occupational Measurements. Volume 1: Summary, Volume 2: Project Description and Results. EPRI Interim Report EN-7048. Electric Power Research Institute, Palo Alto, CA (1990).

3. Bowman JD, Garabrant DH, Sobel E, Held J, Orebaugh C: Assessment of Occupational Exposures to Electromagnetic Fields: Procedure Manual. University of Southern California, Los Angeles, CA (1988).

4. Smith, RW, Sahl, JD, Kelsh, MA, Zalinski J: Task-based exposure assessment: Analytical strategies for summarizing data by occupational groups. Am. Ind. Hyg. Assoc. J. 58:402-412 (1997).

5. Bracken TD, Rankin RF, Senior RS, Alldrege JR, Sussman SS: Magnetic field exposure among utility workers. Bioelectromagnetics 16:216-226 (1995).

Partial Method #204. Personal Monitoring of ELF Magnetic Fields for Health Hazard Evaluations

Method Summary

Description and purpose	**Technique:** Personal monitoring **Purpose:** Workplace survey **Study:** NIOSH Hazard Evaluations and Technical Assessments[1] **Authors:** CE Moss **Date:** 1992

Sampling strategy	**Description**: Personal monitoring of ELF magnetic fields. **Location:** Worn in a waist pouch **Duration:** Variable. Four hours per worker is recommended. **Subject selection:** Workers relevant to the HETA request **Other data:** Observations of work practices
Instrument	**Model:** EMDEX II (Enertech Consultants, Campbell, CA) **Sensor:** Three-axis induction coils (ferrite-core) **Frequency response:** 40 - 800 Hz filter (within 2 dB) in the Broadband mode. 100 - 800 Hz filter in the Harmonic mode[2] **Time response:** Integration of induction coil signals True rms (with crest factor) Analog-to-digital conversion **Sampling rate:** Programmed to sample every 1.5-300 sec. 1.5, 3 or 5 sec recommended. **Dynamic range:** Auto-ranging with 3 scales over 0.01 - 300 µT. **Accuracy:** ±10% over 0.01 - 10 µT ; ±12% over 10 - 300 µT **Output:** Digital time record of the rms vector components.
Exposure metric	**Final metric:** ELF magnetic field magnitudes over time. **Data processing:** Performed on a personal computer with the EMCALC software. **Units:** Magnetic flux density (mG or µT)

Critique

Strengths

This protocol for measuring personal exposures has been used successfully by NIOSH's Hazard Evaluations and Technical Assessments (HETA).[1] The EMDEX II described in this protocol and its cousins (EMDEX C, EMDEX Lite, LINDA, etc.) have been thoroughly tested in IEEE's instrument evaluation,[3] and a large exposure assessment of electric utility workers,[4] as well as many occupational and residential epidemiologic studies. This instrument has proven to be reliable, and its measurements can be compared to many others in the literature.

Limitations

Occupational ELF magnetic fields can occasionally exceed the standard EMDEX II's upper limit of 0.3 mT (3 G), so investigators may sometimes need the high field EMDEX whose upper limit is 1 mT (10 G).

Measurement Protocol

from "ELF Exposure Assessment Procedures for Use in HETA Evaluations" by C.E. Moss (1991)

1. Make sure each EMDEX is calibrated before using. Have plenty of extra batteries on hand, at least two extra for every 8 hours of data taken.

2. Remove the sliding cover on front of the meter and turn the meter on by moving the small switch.

3. Read the LCD and it will tell you how much power is left in the battery. (NOTE: if the battery is low, the LCD will display "low bat".) If the battery is low then transfer any data that has been collected to the computer and replace the old battery with a new 9 volt alkaline battery. If the battery has sufficient voltage to operate the meter, the LCD will read "STANDBY."

4. To set the rate for data collection, it is necessary to choose a sampling time (1.5, 3.0, 5.0, 10.0, 15.0, 30.0, 60.0, 120., or 300.0 seconds). Push the "+" button twice so that the LCD reads "RATE." Push the "EVENT" button, and the current sampling rate will appear. To selected another rate, push "+". It is suggested that a time interval of 1.5, 3.0, or 5.0 seconds be used. Hit "EVENT" to go back to "RATE." If measuring fields with frequencies other than 60 Hz, toggle to "MODE" and select "Broadband + Harmonic".

5. To start monitoring, push the "-" button until "RUN" appears on the LCD. and then press "EVENT" once. The LCD should now read "Start 1", then the LCD will read "Rb=x.x," which is the instantaneous measurement of the resultant B-field in the Broadband mode. This display tells you that the meter is now recording data.

6. After insuring that the meter is operating correctly, place the EMDEX meter in the carrying pouch, making sure that the number on the pouch agrees with the number on the EMDEX case.

7. Collect the data for however long it is necessary. It is suggested that a time interval of 4 hours be used to insure data can be collected for two different workers in a workday.

8. During the collection phase it may be necessary to observe the work practice of the monitored worker and to record any unique exposure considerations.

9. To stop the meter from recording data, press the "+" and "-" buttons simultaneously. Keep these two buttons depressed, and next depress the "EVENT" button. This action will stop the data collection and put the meter in a hold (sleep) position. The LCD should now read "Stop 1" - then it will automatically toggle itself to "STANDBY."

10. While the meter can collect more data, it is probably wise to download the data to both the computer files and a back-up disk to insure integrity of the collected data.

11. To download the data, have the computer operating. Connect the EMDEX's RS232 communication cable with the 25 to 9 pin adapter to the EMDEX's jack (located under cover) and the computer's serial port #1.

12. Run the "EMCALC" program on the computer.

13. Press "Enter" until EMCALC's main menu appears. Select "Communications" and enter.

14. Select "Transfer Data File, and enter.

15. Name the data file, e.g., the Julian date (mmddyy) EMDEX #. HETA #.

16. Follow instructions on screen to download the data. Since labels will not be necessary for a 4-hour sample, omit by pressing "Enter" twice.

17. After data is downloaded from all EMDEXs, copying all the data onto two different disks is suggested. Label the discs with the date and the HETA #. Carry and store the two discs separately for security.

References

1. NIOSH Hazard Evaluation and Technical Assistance Report: Armco Steel Company, L.P., Ashland, KY. Report No. HETA 91-0140-2352. National Institute for Occupational Safety and Health, Cincinnati, 1993.

2. Enertech Consultants: EMDEX II meter specifications. In EMDEX II Users Manual, Version 1.10. Enertech Consultants, Campbell, CA (1991).

3. IEEE Magnetic Fields Task Force: An evaluation of instrumentation used to measure AC power system magnetic fields. IEEE Trans. PWRD-6: 373 (1991).

4. T. Dan Bracken, Inc.: The EMDEX Project: Technology Transfer and Occupational Measurements, Volume 1: Summary. EPRI Report EN-7048. Electric Power Research Institute, Palo Alto, CA (1990).

Partial Method #302. Static Magnetic Field

Method Summary

Description and purpose	**Techniques: Area measurements and calculations** **Purpose:** Epidemiology **Study:** Assessment of Occupational Exposures to EM Fields[1] **Authors:** JD Bowman, DH Garabrant, E Sobel, J Held, C Orebaugh **Date:** 1988

Sampling strategy	**Description**: Area measurements **Location:** 1 m-high stand positioned at five points in a two-dimensional horizontal array **Duration:** Spot **Other data:** Distances between measurement points
Instrument	**Model:** MAG-01 fluxgate magnetometer (Bartington Instruments, Ltd., Oxford, England) **Sensor:** Single axis fluxgate probe **Frequency response:** 0 - 10 Hz bandwidth **Dynamic range:** 0.001 - 200 µT (0.01 mG - 2 G) **Accuracy:** ±0.005% **Output:** Digital readout of static magnetic field component
Exposure metric a	**Final metric:** Spatial average of the static magnetic field magnitude **Data processing:** Calculate resultants from the three orthogonal components and average over five points **Units:** Magnetic flux density (µT or mG)
Exposure metric b	**Final metric:** Horizontal gradient of the static magnetic field magnitude **Data processing:** Calculate the field magnitude for each point in the horizontal grid Calculate the gradient from the magnitudes and distances **Units:** microTesla per meter (µT/m)

Critique

Strengths

These procedures were used for area measurements of the static magnetic field's components over a two-dimensional array in a wide variety of workplaces.[2] From these data can be calculated the magnitude and spatial variability. The horizontal gradient in the static field is large in the vicinity of DC currents and near large steel structures. This protocol can be used for a detailed characterization of the static magnetic fields in workplaces and other environments.

Limitations
Due to the limited dynamic range of the fluxgate magnetometer, these procedures are most applicable to environments where the primary source of the static magnetic field is the earth. For static magnetic fields from high-intensity magnets or DC currents, a Hall-effect gaussmeter is required. Furthermore, the gradient calculation is approximate, and will be inaccurate when the static magnetic is non-uniform. Finally, these measurements are all taken 1 meter above the floor, so they would not characterize any variations in the static magnetic field magnitudes with elevation.

Protocol

adapted from "Assessment of Occupational Exposures to Electromagnetic Fields: Procedure Manual" by J.D. Bowman, D.H. Garabrant, E. Sobel, J. Held, C. Orebaugh

Measurements

1. Take static field measurements with an axial flux-gate magnetometer probe inserted into 3 orthogonal holes drilled into a plexiglass block mounted on a stand 1 meter above the ground. Orient the stand so the horizontal axes form a left-handed coordinate system aligned with respect to building:

   x-axis = perpendicular to the front of the building
   y = parallel
   z = vertical

   On the data sheet, record each component of the static magnetic field. If the absolute direction of the field vector may be required, record the sign of the magnetometer reading as well.

2. At each site, take 4 additional measurements at an equal distance away from the central site equal to 3 m (or a lesser distance if necessary). The 5 measurement sites form a cross along the x- and y-axes. On the data sheet, record the distance between sites as well as the static field components so that the spatial variability can be calculated as a gradient.

3. One set of measurements will be taken out-of-doors away from any building or metallic objects. At this site, use the same axes with respect to the building orientation.

Calculations

1. For each point in the five-point grid, calculate the static field magnitude by taking the resultant of the x, y, and z components. Average the field over the five points.

2. Calculate the partial derivatives in the x- and y-directions with the finite difference formulas:

$$\frac{\partial B}{\partial x} = \frac{1}{2\Delta x}\left[B(x=+\Delta x, y=0) - B(x=-\Delta x, y=0)\right]$$

$$\frac{\partial B}{\partial y} = \frac{1}{2\Delta y}\left[B(x=0, y=+\Delta y) - B(x=0, y=-\Delta y)\right]$$

where $\Delta x = \Delta y$ is the distance between points in the grid.

3. Calculate the horizontal gradient (in µT-m):

$$\left|\nabla_{\mathbf{h}}\right| = \sqrt{\left(\frac{\partial B}{\partial x}\right)^2 + \left(\frac{\partial B}{\partial y}\right)^2}$$

References

1. Bowman JD, Garabrant DH, Sobel E, Held J, Orebaugh C: Assessment of Occupational Exposures to Electromagnetic Fields: Procedure Manual. University of Southern California, Los Angeles, CA (1988).

2. Bowman JD, Kardous CA. Characteristics of static and ELF magnetic fields from occupational sources. Bioelectromagnetics Society Annual Meeting, Salt Lake City, (1993).

Partial Method #402. Area Measurements of Magnetic Field Characteristics

Method Summary

Description and purpose	**Technique: Field characterization** **Purpose:** Epidemiology **Strategies:** **I.** Walk-through survey **II.** Area measurements of magnetic field characteristics **III.** Source assessment **Studies:** Assessment of Occupational Exposures to EM Fields[1] **Authors:** JD Bowman, DH Garabrant, E Sobel, J Held, C Orebaugh **Date:** 1988

Critique

This protocol was developed to characterize in more detail the magnetic fields in the work places selected for an epidemiologic study.[2] The protocol consists of three strategies which are linked to the personal exposure measurements, giving data which can be used to estimate more complex exposure metrics that require these characteristics. These measurements also provide insight into the magnetic field characteristics and sources of the workplaces enrolled in the study.[3] The three strategies are critiqued below.

Sampling strategy I	**Description**: Walk-through survey **Location:** Work locations near potential sources **Duration:** Spot **Site selection:** Workplaces selected for an epidemiologic study **Other data:** Floor plan or sketch
Instrument I	**Model:** Milligaussmeter® (Model 42B-1, Monitor Star Industries, Boulder, CO) **Sensor:** Single-axis induction coil (air core) **Sensor alignment:** Rotate until maximum reading is obtained **Frequency response:** Flat broadband filter (40-1000 Hz bandwidth) **Time response:** True rms **Dynamic range:** 1 nT - 100 µT over 12 manually-selected ranges **Accuracy:** ±2% from 0.05 - 100 µT in a laboratory test[4] **Output:** Analog readout of the maximum ELF magnetic field component
Exposure metric I	**Final metric:** Maximum rms components of the ELF magnetic field for sources **Data processing:** Record measurement on floor plan **Units:** Magnetic flux density (µT or mG)

Critique

Strengths

A initial walk-through with a spot survey meter is an invaluable tool for occupational exposure assessments. Writing the measurements on the floor plan provides a graphic record of the fields coming from different sources.

Limitations

The strategy of measuring the maximum rms component with a single-axis gaussmeter is difficult to do accurately in many workplaces. Fields from several sources with several harmonics can be very complex in their geometric shape,[5] and the sensor coil must be rotated in all directions to find the maximum (if a single extremum even exists). In a study where several investigators measured the magnetic field near several sources, there was a four-fold variability in the measurements of the maximum component.[6] In addition, the Milligaussmeter with its single axis coil and manual range selection requires the operator's full attention during a survey, so a second person must write the results onto the floor plan. Modern three-axis gaussmeters with auto-ranging which display the rms vector magnitude (resultant) are more convenient for magnetic field surveys (see Partial Method #001).

Sampling strategy II	**Description**: Area measurements of magnetic field characteristics **Location:** 1 meter-high stand at five points in a horizontal array **Duration:** Spot **Other data:** Distances between measurement points **Instruments:** **A.** Digital Signal Analyzer **B.** Milligaussmeter **C.** Fluxgate magnetometer
Instrument II.A	**Model:** Digital Signal Analyzer (Model 3561A, Hewlett-Packard, Palo Alto, CA) **Sensor:** Single-axis induction coil (provided separately) **Sensor alignment:** Coil axis is vertical **Frequency response:** 0-100 kHz capability adjusted to 10-1010 Hz **Time responses:** Integration of induction coil signal Waveform Fourier transforms of rms magnitudes **Dynamic range:** 0.5 - 40 dB **Accuracy:** Not determined for this application **Output:** Screen display and digital data stored in memory for downloading to a computer
Exposure metric II.A.a	**Final metric:** Waveform of ELF magnetic field's vertical component **Data processing:** Multiplication by calibration coefficient **Units:** Magnetic flux density (µT) vs. time (ms)

Exposure metric II.A.b	**Final metric:** Frequency spectrum of the vertical component for the ELF magnetic field **Data processing:** Multiplication by calibration coefficient **Units:** Magnetic flux density (µT) vs. frequency (Hz)
Exposure metric II.A.c	**Final metric:** Total harmonic distortion (THD) **Data processing:** Enter 60 Hz as the fundamental frequency Record THD from the display **Units:** Percent
Instrument II.B	**Model:** Milligaussmeter (see above) **Sensor alignment:** Three orthogonal directions
Exposure metric II.B.a	**Final metric:** Spatial average rms magnitude of the ELF magnetic field **Data processing:** Details not given. (See Partial Method #302.) **Units:** Magnetic flux density (µT or mG)
Exposure metric II.B.b	**Final metric:** Horizontal gradient of the ELF magnetic field magnitude **Data processing:** Details not given. (See Partial Method #302.) **Units:** Microtesla per meter (µT/m)
Instrument II.C	**Model:** Fluxgate magnetometer (Model MAG-01, Bartington Instruments, Ltd., Oxford, England) **Sensor:** Single-axis fluxgate probe **Sensor alignment:** Three orthogonal directions **Frequency response:** 0 - 10 Hz bandwidth **Dynamic range:** 0.001 - 200 µT (0.01 mG - 2 G) **Accuracy:** ±0.005% **Output:** Digital readout of static magnetic field component
Exposure metric II.C.a	**Final metric:** Spatial average of the static magnetic field magnitude **Data processing:** Details not given. (See Partial Method #302.) **Units:** Magnetic flux density (µT or mG)
Exposure metric II.C.b	**Final metric:** Horizontal gradient of the static magnetic field **Data processing:** Details not given. (See Partial Method #302.) **Units:** Microtesla per meter (µT/m)

Critique

Strengths

Using the instruments that were available at the time, this area measurement protocol measures a number of important magnetic field characteristics: waveforms, frequency spectra, total harmonic distortion, and the static magnetic field. The protocol also measures an unusual metric: the horizontal gradient of the static and ELF fields, which summarizes the spatial variability numerically. Since the waveform and frequency data are stored as digital computer files, additional metrics can be calculated at a later time.

Limitations

These measurements are all taken 1 meter above the floor, even though investigators have reported that magnetic field magnitudes depend significantly on elevation.[7-9] The digital signal analyzer is not a convenient instrument for workplace measurements since it weighs 15 kg and requires an AC power source. Likewise, using single-axis meters for the static and ELF fields is time-consuming. Therefore, this protocol would be much more efficient with modern three-axis waveform capture instruments. In addition, the protocol for measuring the frequency spectrum lacks safeguards against "aliasing" which can produce artifacts in the Fourier transform.[10]

Sampling strategy III	**Description**: Profile of the ELF magnetic fields from EMF sources **Location:** Series of five points along a radius from the source **Duration:** Spot **Site selection:** Sources selected for Strategy II **Other data:** Distances from source
Instrument III	**Model:** Milligaussmeter (see details above) **Sensor alignment:** Rotate until maximum reading is obtained
Exposure metric III	**Final metric:** Source profile of the maximum rms component of the ELF magnetic field **Data processing:** Details not given. **Units:** Magnetic flux density (µT or mG) vs. distance

Critique

Strengths

The magnetic field profile for a source provides information for both reducing the operator's exposure and modeling the field's magnitude as a function of distance from the source.[11]

Limitations

As discussed above, this strategy would be more accurate and efficient with a three-axis magnetic field monitor.

Measurement Protocol

adapted from "Assessment of Occupational Exposures to Electromagnetic Fields: Procedure Manual" by J.D. Bowman, D.H. Garabrant, E. Sobel, J. Held, C. Orebaugh

Walk-through Survey

A) Visual identification of possible EMF sources and tasks with distinct EMF exposures will be assessed during the walk-through. Ask the company for a floor plan. If they cannot provide one, a rough site sketch will be made.

B) AC magnetic field monitoring with the Milligaussmeter will be used to confirm these sources and to identify additional sources.

Magnetic field "sniffing" will be performed by rotating the sensor coil approximately 1 meter above the ground to determine the maximum field strength at a normal working distance from the source. The maximum value and distance from the source will be recorded on the floor plan.

C) The walk-through observations are to be linked with information on jobs and tasks targeted for personal measurements as a guide to placement of area monitoring equipment.

Area Measurements

The area measurements are performed at work sites in the vicinity of major field sources identified during the walk-through survey. At each site, record the worker(s) who are at the site and wearing personal monitors, along with their job title, task and monitor ID number on the Area Measurements data sheet (see below). Also, record the equipment which is the primary EMF source and its manufacturer (if known). Obtain the equipment's electrical characteristics (voltage, amperage, power, and frequency).

A) At each site selected for area measurements, mount the Milligaussmeter on its 1-meter high stand 4 feet from the source. Orient the X and Y axes of the stand so that are parallel and perpendicular to the side of the building closest to the street. Record its spatial orientation on a sketch of the area. Measure the magnetic field in three directions, and record on data sheet.

B) The frequency spectrum and waveforms will be measured with the induction coil attached to a Hewlett-Packard Model 3561A Dynamic Signal Analyzer.

   i. Measurements will be taken with the induction coil placed in the Z (vertical) axis on the 1-meter stand at a point approximately 4 feet from the source or at the operator's station.

   ii. Display the wave form on the Dynamic Signal Analyzer, and perform the integration function. With the calibration co-efficient measured earlier with 60 Hz magnetic fields, convert the units of the wave form into Tesla. Look for usual features in the waveform. Store the waveform in the non-volatile memory for future downloading to a PC through the HPIB connector. Record the file name for the wave form on the area data sheet.

   iii. Display the frequency spectrum on the Signal Analyzer, and use the following procedure to produce a finished spectrum:
      a) Reduce the frequency span to 10 - 1010 Hz.
      b) Display the spectrum in a linear mode, and convert the units from volts to Tesla-sec. The conversion factor is 1/2NAS where N is the number of turns, A is the coil area, and S is the frequency span. For the Power-frequency Field Meter's coil, this equals 4.03×10^{-3} T-s/volt.
      c) Store the spectra in memory, and record the file name.

d) Enter 60 Hz as the fundamental frequency, and record the Total Harmonic Distortion (THD) that appears on the display.

C) The DC magnetic field will be measured with the Schonstedt fluxgate magnetometer according the attached protocol. (See Partial Method # 302.)

E) Measure out a grid of four points about the central point which form a cross. The distance between points is 3 m (10 ft) or less if there is insufficient space. Place the stand at each of these points, and take measurements with the Milligaussmeter and the magnetometer.

D) The radial distribution of ELF magnetic fields from the source will be evaluated with the Milligaussmeter. First, scan the maximum component of the ELF magnetic field (using the same procedures as the Walk-through Survey) in a 2' radius from the source. Record the maximum and minimum fields measured around the circle. In the direction of the maximum field, lay out a tape measure and measure the fields at the operator's station and in a geometric progression of distances: 1', 2', 4', 8', 16'. Record the distances from the source where employees usually work.

E) In the event of a lack of available AC power, a portable Honda generator will supply the necessary current for all 120 V equipment.

References

1. Bowman JD, Garabrant DH, Sobel E, Held J, Orebaugh C: Assessment of Occupational Exposures to Electromagnetic Fields: Procedure Manual. University of Southern California, Los Angeles, CA (1988).

2. London SJ, Bowman JD, Sobel E, Thomas DC, Garabrant DH, Pearce N, Bernstein L, Peters JM. Exposure to magnetic fields among electrical workers in relation to leukemia risk in Los Angeles County. *Am J Indust Med* 26:47-60 (1994).

3. Bowman JD, Kardous CA. Characteristics of static and ELF magnetic fields from occupational sources. Bioelectromagnetics Society Annual Meeting, Salt Lake City (1993).

4. Science Applications International. Laboratory Testing of Commercially Available Power Frequency Magnetic Field Survey Meters. EPA Report 400R-92-010. Environmental Protection Agency (1992).

5. Bowman JD, Methner MM. Hazard Surveillance for Workplace Magnetic Fields: II. Field Characteristics from Waveform Measurements. Submitted to Appl Occ Env Hygiene (1998).

6. IEEE Magnetic Fields Task Force: An evaluation of instrumentation used to measure AC power system magnetic fields. *IEEE Trans.* PWRD-6: 373 (1991).

7. Delpizzo V. Misclassification of ELF occupational exposure resulting from spatial variation of the magnetic field. *Bioelectromagnetics* 14:117-130 (1993).

8. Wenzl TB, Kriebel D, Eisen EA, Moure-Eraso M. A comparison of two methods for estimating average exposure to power-frequency magnetic fields. *Appl Occup Environ Hyg* 10:125-130 (1995).

9. Davanipour Z, Sobel E, Hietanen M, Juutalienen J, Sulkava R. Magnetic field exposure from industrial sewing machines in Finnish apparel factories. Abstract. Annual Review of Research on Biological Effects of Electric and Magnetic Fields from the Generation, Delivery and Use of Electricity, Palm Springs, CA, November 12-16 (1995).

10. Jackson LB. *Signals, Systems, and Transforms.* Addison-Wesley, Reading, MA (1991), pp. 390-396.

11. Preece AW, Kaune W, Grainger P, Preece S, Golding J. Magnetic fields from domestic appliances in the UK. Physics in Medicine and Biology 42:67-76 (1997).

AREA MEASUREMENTS DATA SHEET

DATA TO BE CODED | **COMMENTS**

1. ________________ FACILITY:

2. ________________ AREA:

3. __ __ __ __ __ __ EMDEX IDENTIFICATION

4. BOC# JOB# TASK EMDEX JOB-TASK INFORMATION FOR WORKERS:
a. ___ ___ ___ ___
b. ___ ___ ___ ___
c. ___ ___ ___ ___

5. PRIMARY FIELD SOURCE AND MANUFACTURER
____

a. ______ VOLTAGE:
b. ______ AMPERAGE:
c. ______ POWER (KILOWATTS):
d. ______ FREQUENCY:

6. SIGNAL ANALYZER:
a. ___________ WAVEFORM: FILE NAMES = AREA ID + "W"
b. ___________ FREQUENCY SPECTRUM: = AREA ID + "F"
c. ______ (%) TOTAL HARMONIC DISTORTION

7. Z X Y MILLIGAUSSMETER WITH FIVE-POINT GRID
a. _____ _____ _____ (mG), X=0, Y=0
b. _____ _____ _____ (mG), X=+1, Y=0
c. _____ _____ _____ (mG), X=-1, Y=0
d. _____ _____ _____ (mG), X=0, Y=+1
e. _____ _____ _____ (mG), X=0, Y=-1

f. _____ (ft) DISTANCE BETWEEN POINTS (DEFAULT=10')

8. Z X Y MAGNETOMETER WITH FIVE-POINT GRID
a. _____ _____ _____ (mG), X=0, Y=0
b. _____ _____ _____ (mG), X=+1, Y=0
c. _____ _____ _____ (mG), X=-1, Y=0
d. _____ _____ _____ (mG), X=0, Y=+1
e. _____ _____ _____ (mG), X=0, Y=-1

9. ft M-FIELD (mG) DISTANCE (ft) vs. MAX. MAGNETIC FIELD
a. __ ______
b. __ ______
c. __ ______
d. __ ______
e. __ ______

Partial Method #701. Precision of Area Measurements

Method Summary

Description and purpose	**Technique:** Quality control **Study:** Los Angeles Study of Childhood Leukemia[1] **Author:** JD Bowman **Date:** 1992

Sampling strategy	**Description:** Repeated area measurements **Location:** Two measurements at the same location **Site selection:** Random draw from all locations at the end of each survey **Duration:** Spot measurements
Instrument	**Description:** Any direct-reading instrument
Exposure metric	**Final metric**: Coefficient of variation (CV = std. dev. / mean) **Data processing:** ‣ Calculate exposure metric of interest from replicate measurements ‣ Calculate CV for each replicate measurement at a site ‣ Pool the CVs measured over the study **Units:** Unitless

Critique

Strengths

This procedure was used for quality control in residential epidemiologic studies,[1,2] and is also appropriate for large exposure assessment studies in workplaces. The CV calculated from this method can be used both to check the reliability of the instrument and the measurement procedures at each site, and to estimate the measurement precision over the course of the study. The random selection of sites for the repeated measurement reduces the number of extra samples without alerting the technician as to the measurement that will be repeated.

Weaknesses

The coefficient of variation (CV) calculated from this method combines measurement error with the field's temporal variability the duration of the survey. The method could be improved by using a repeated measure design and analysis of variance to estimate the measurement error independent of the temporal variability.

Quality Control Protocol

by J.D. Bowman

1. With each area measurement, mark the location of the instrument stand with masking tape. Then take the measurements according to the protocol.

2. After the first area measurement of the day, take replicate measurements at the same location. If the two measurements are not within 10%, review meter functioning and measurement procedures. Take another replicate measurement.

3. At the end of all the area measurements at a site, take replicate measurements at randomly-sampled locations. A ratio of 10 original measurements to 1 replicate is recommended. In the selected locations, place the instrument stand on the masking tape, and repeat all measurements taken there the first time.

4. At the end of each day of measurements, calculate the measurement precision as the coefficient of variation (CV = std. dev. / mean) for each randomly-selected location. For the duplicate measurements of the resultants X_{i1} and X_{i2} at a location I:

$$CV_i = \sqrt{\frac{2\,(X_{i1} - X_{i2})^2}{(X_{i1} + X_{i2})^2}}$$

   Inspect CV_i over the day's measurements and between days for any trends that may indicate quality control problems. In a long-term study, the use of control charts for CV_i is advised.

4. Assuming that the precision has been kept in control over the course of the study, the measurement precision for the study can be reported as the CV pooled over all N duplicates:

$$CV_{pool} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} CV_i^2}$$

References

1. Peters JM, Thomas DC, Bowman JD, Sobel E, London SJ, Cheng TC: *Childhood Leukemia and Risk Associated with Exposure to Residential Electric and Magnetic Fields.* Report on Contract RP2964-1, Electric Power Research Institute, Palo Alto, CA (1991).

2. Electric and magnetic field measurement manual. In: Savitz DA, *Case-control Study of Childhood Cancer and Residential Exposure to Electric and Magnetic Fields.* Contractors Final Report. New York State Power Line Project, Albany, NY, Appendix 3 (1987).

Partial Method #901. Calculating Time-weighted Averages (TWA) from Positron Monitor Data

Method Summary

Description and purpose	**Technique:** Calculations **Purpose:** Epidemiology **Study:** Los Angeles Study of Childhood Leukemia **Author:** JD Bowman **Date:** 1992

Instrument	**Model:** Positron electromagnetic dosimeter (Montreal, Quebec) **Channels:** **1.** ELF magnetic field **2.** ELF electric field **3.** High-frequency transients **Time response:** Peak response **Sampling rate:** 50 sec **Output:** Time records for the three channels are stored as integers representing 16 geometric bins
Exposure metrics	**Final metric:** Time-weighted averages (TWA) for each channel. **Data processing:** ‣ Convert bin values for each time to the means of the bin edges. ‣ Take the resultant of bin means for the 3 magnetic field components. ‣ Calculate the TWAs for all three channels **Units:** **1.** Magnetic flux density (μT) **2.** Electric field (V/m) **3.** Proportion of time when transients occurred (ppm)

Critique

Strengths

This protocol describes two ways for calculating field values from the geometric bin data recorded by the Positron monitor. The method using the geometric mean of the bin edges was developed for calculating the TWA of the ELF magnetic field for the Los Angeles childhood leukemia study,[1] and is extended in this protocol to the Positron's other two channels. Calculations using the arithmetic mean of the bin edges (which are programmed into the Positron software) were performed by the Canada-France study of electric utility workers.[2,3] (See Method #201 for the measurement protocol.)

The method using the geometric mean is a more accurate expectation value for the Positron's measurements if the data is log-normally distributed (as it usually is). However, the error in using the arithmetic mean is only 6% for the ELF electric and magnetic fields. For the high-frequency transients, the calculation from arithmetic mean causes a 25% error, and should be avoided, even though the Positron calculation software cannot be used.

Weaknesses

The system of geometric bins by design sacrifices accuracy for a large memory capacity (up to two weeks of continuous operation). Neglecting any misclassification of bins, the geometric mean of the bin edges has errors ranging from +41.1% (when the true value is at the lower bin edge) to -29.3% (at the upper edge). Especially with large fields, the Positron's level of error is much more than the ±5-10% which is maintained by the digital data-logging monitors.

Calculation Protocol

by J.D. Bowman

1. For each time t, the quantity X(t) is measured by the dosimeter and stored in the data logger's memory. With the Positron dosimeter, each measurement is recorded as a digit N from 0-15, representing the bin into which the peak of the oscillation falls (Table 1-3). The actual upper and lower edges for the bins are measured during the dosimeter's primary calibration by the manufacturer.

   The nominal bin edges form a geometric series, with each edge approximately equal to the preceding value times a constant (2 for the E and B-fields; 4 for the High-Frequency Transients). The outer edges of the highest and lowest bins have not been determined by the monitor's calibrations to date. In order to assign field values to these extreme bins, their outer edges are assumed to continue the geometric series (Tables 1-3).

   The field values are assigned to each bin by taking either the arithmetic mean (AM) or geometric mean (GM) of the upper and lower edges. The Positron software uses the AM.[3] However, the bin edges form the geometric series, so the more appropriate value for the Nth bin is the GM of the edges:

$$\bar{X}_N = \sqrt{X_N(\text{upper})\ X_N(\text{lower})}$$

   By substituting the geometric series of the bin edges into the formulas for the two means, it can be shown that the assigned values from the AM are greater than the GM by a constant ratio. For the E and B fields, the ratio between the AM and GM is (1+2) / 2√2 = 1.06, which is not a large enough systematic error to affect the outcome of most studies. For the transients, the ratio is (1+4) / 2√4 = 1.25. In either case, how the field values have been assigning to bins should be stated in any report in order to avoid confusion in comparisons with other measurements.

2. With the ELF magnetic fields, estimate the peak vector magnitude for each time t by calculating the resultant of the assigned value for the three orthogonal components:

$$B(t) = \sqrt{\bar{B}(t)_x^2 + \bar{B}(t)_y^2 + \bar{B}(t)_z^2}$$

This does not apply to the ELF electric field and high-frequency transients, each of which are measures with a single sensor by the Positron.

3. The time-weighted average for each time period of interest is then calculated from the assigned value for each sampling time t over the averaging period T:

$$X_{TWA} = \frac{1}{T} \sum_{t=0}^{T} \bar{X}(t)\ \Delta t$$

where Δt is the sampling interval. Since the dosimeter has a constant sampling interval, the TWA is also the arithmetic mean over time with $T/\Delta t$ observations. TWA exposures by task are calculated by averaging across all times in the week when the worker is doing that task (even if discontinuous).

References

1. Peters JM, Thomas DC, Bowman JD, Sobel E, London SJ, Cheng TC: *Childhood Leukemia and Risk Associated with Exposure to Residential Electric and Magnetic Fields.* Report on Contract RP2964-1, Electric Power Research Institute, Palo Alto, CA (1991).

2. Deadman JE, Camus M, Armstrong BG, Heroux P, Cyr D, Plante M, Theriault G: Occupational and residential 60-Hz electromagnetic fields and high-frequency electric transients: Exposure assessment using a new dosimeter. *Am. Ind. Hyg. Assoc. J.* 49: 409 (1988).

3. Thériault G, Goldberg M, Miller AB, Guénel P, Deadman J, Imbernon E, To T, Chevalier 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 Epidemiol 139:550-572 (1994).

Table 1. Bins for the ELF magnetic field on the Positron monitor.
The B-field value assigned to each bin is the arithmetic mean or geometric mean of the nominal bin edges. Actual bin edges need to be determined by the primary calibration, and the assigned values re-calculated.

Bin	Bin Edge (µT)		Assigned Value (µT)	
	Lower	Upper	Arith. Mean	Geo. Mean
0	0.0015*	0.0031	0.0023	0.0022
1	0.0031	0.0061	0.0046	0.0043
2	0.0061	0.0122	0.0092	0.0086
3	0.0122	0.024	0.0181	0.0171
4	0.024	0.049	0.037	0.034
5	0.049	0.10	0.075	0.070
6	0.10	0.20	0.15	0.14
7	0.20	0.39	0.30	0.28
8	0.39	0.78	0.59	0.55
9	0.78	1.56	1.17	1.10
10	1.56	3.13	2.35	2.21
11	3.13	6.25	4.69	4.42
12	6.25	12.5	9.38	8.84
13	12.5	25.0	18.75	17.7
14	25.0	50.0	37.5	35.4
15	50.0	100.0*	75.0	70.7

* Assumed value, based on the continuation of the geometric series. Actual values for the Limit of Detection and the maximum response have not been determined for this monitor.

Table 2. Bins for the ELF electric field on the Positron monitor.

Bin	Bin Edge (V/m)		Assigned Value (V/m)	
	Lower	Upper	Arith. Mean	Geo. Mean
0	0.30*	0.61	0.45	0.43
1	0.61	1.22	0.915	0.86
2	1.22	2.44	1.83	1.73
3	2.44	4.88	3.66	3.45
4	4.88	9.77	7.33	6.90
5	9.77	20	14.9	13.98
6	20	39	29.5	27.9
7	39	78	58.5	55.2
8	78	156	117	110.3
9	156	312	234	221
10	312	625	469	442
11	625	1250	938	884
12	1250	2500	1875	1768.
13	2500	5000	3750	3540
14	5000	10000	7500	7070
15	10000	20000	15000	14140

* Assumed value, based on the continuation of the geometric series. Actual values for the Limit of Detection and the maximum response have not been determined for this monitor.

Table 3. Bins for the High-Frequency Transients on the Positron monitor.

Bin	Bin Edge (ppm)		Assigned Value (ppm)	
	Lower	Upper	AM	GM
0	0.0002*	0.0008	0.0005	0.0004
1	0.0008	0.0033	0.0020	0.0016
2	0.0330	0.0133	0.0083	0.0209
3	0.0133	0.053	0.0331	0.0265
4	0.053	0.212	0.132	0.106
5	0.212	0.848	0.530	0.422
6	0.85	3.39	2.12	1.69
7	3.39	13.57	8.48	6.78
8	13.6	54.3	33.9	27.1
9	54.3	217	136	109
10	217	868	543	434
11	868	3473	2171	1736
12	3473	13983	8684	6969
13	13983	55917	34950	27962
14	55917	223700	139809	111842
15	223700	894800*	559250	447400

* Assumed value, based on the continuation of the geometric series. Actual values for the Limit of Detection and the maximum response have not been determined for this monitor.

Partial Method #902. Calculating Alternative Exposure Metrics from Time-Series Data

Method Summary

Description and purpose	**Technique:** Calculating exposure metrics **Study:** Multiple studies cited below

Exposure metrics	**Input:** Digital time-series of personal exposure or area monitoring data **Data processing:** Calculations of three types of metrics: • Traditional industrial hygiene metrics • Alternative effect functions • Time-dependent exposure metrics

Critique

Strengths

The process of calculating different magnetic field exposure metrics is useful in determining which metric produces the strongest association with disease risk. Some metrics (also called "exposure summaries" or "effects functions") can be related to hypothesized biological mechanisms while others are derived by statistical considerations. The alternate methods for summarizing exposure can produce different rankings across exposure groups (e.g., job title groups, work environment, classifications). These calculations can help resolve whether exposure information is sufficiently captured in one summary measure. This is an important issue for exposure assessment surveys for epidemiologic studies since the biological research has not conclusively identified exposure metrics that lead to disease. Several studies have examined the correlation between different magnetic field exposure metrics.[1-4] The alternate metrics in this method can be derived from time-series data produced by monitors such as the EMDEX and do not involve additional measurements or new instrumentation.

Limitations

One of the goals of evaluating alternate exposure metrics is to improve the understanding about potentially biologically relevant exposures. In this context, we are only considering summary methods for one aspect of the complex electromagnetic field environment - that is the rms field magnitude (*i.e.* the resultant) of the ELF magnetic field. Other important alternate exposure metrics are not considered. A relevant exposure metric may require faster sampling rates than what is available in many inexpensive measurement instruments. Time-dependent exposure summarization can require fairly intensive computer programming efforts to summarize data.

Calculation Protocol

by M.A. Kelsh and J.D. Bowman

This section reviews methods for summarizing EMF time-series exposure data. Exposure-response analysis of most workplace agents have relied on the time-weighted average (TWA) exposure to summarize temporal variability. For one reason, the TWA times the exposure duration is proportional to the dose of an agent that accumulates in the target organ without excretion (e.g. asbestos in the lung). Risk management then involves keeping workers' TWA exposures below not-to-exceed levels calculated from the results of workplace surveys. With EMF, the agent clearly does not accumulate in the body, and measures of "dose" have not yet been identified. Nonetheless, the TWA has been consistently used as the most plausible temporal metric by EMF epidemiologic studies in both residential and occupational settings. However, inconsistent results have led to speculation about potential alternative exposure metrics that may be more biologically relevant than traditional TWA or other summarizations. These alternate metrics are also referred to as "exposure summaries," "alternate effects functions," "indices of exposure," or "exposure signals."[2,4-7]

The goals in developing alternate metrics of EMF data are to 1) identify metrics that rank occupations (or environments) differently than traditional summarizations and 2) to define exposure metrics that may be more "biologically relevant". Some of the types of alternate exposure metrics proposed include duration above a threshold, sudden field changes, field strength windows, and variations of these general types.[6,7]

Several studies have addressed the correlation between traditional exposure metrics such as the arithmetic mean, percentiles and fraction exceeding metrics.[1-5] For the most part there has been some correlation among these type of magnetic field exposure summarizations. The main exceptions were the fraction exceeding 0.5 µT and the 20th percentile,[2,5] which seemed to be distinct from the other metrics. These findings can have important implications on exposure data collection and analysis. If one summarization adequately captures the information contained in other metrics, then the data collection and analysis can be substantially simplified. However if one summary suggests a different ranking, or is measuring some other aspect of exposure, then depending on the purpose of the survey, additional data collection and analysis will be required.

Our discussion of exposure metrics is distinct from the exposure scores that are frequently derived for subjects in epidemiologic studies. Exposure scores are functions of the exposure metric (e.g. TWA, fraction exceeding 0.5 µT) and the individual's work history. For example, the cumulative exposure is the sum over the work history of the exposure metric for each job multiplied by the time the job was held (usually in years). Other exposure scores are the TWA exposure over the work history and cumulative exposures over specific periods e.g. early history or last few years of employment. The associations of various exposure scores and health outcomes are examined to test hypotheses about potential early- or late-stage EMF exposure effects.

Table 1 reviews published studies that have summarized time-series EMF measurements collected by datalogging instruments like the EMDEX used with constant sampling rates. Time-series metrics are usually used with the rms vector magnitude of the ELF magnetic field, but they can also be applied to many other EMF characteristics such as the electric field magnitude, harmonics, polarization, static magnetic field magnitude, etc. (see Partial Method #903). The time-series exposure metrics are classified into three groups:

1. Traditional industrial hygiene metrics
2. Alternate effects functions
3. Time-dependent exposure metrics

References

1. Armstrong BG, Deadman JE, Theriault G. Comparison of indices of ambient exposure to 60-Hz electric and magnetic fields. Bioelectromagnetics 11:337-347 (1990).

2. Savitz DA, Ohya T, Loomis DP, Senior RS, Bracken TD, Howard RL. Correlations among indices of electric and magnetic field exposure in electric utility workers. Bioelectromagnetics 15:193-204 (1994).

3. Wenzl TB, Kriebel D, Eisen EA, Tolbert P, Hallock M. Magnetic field exposures in an automobile plant. Arch. Environ. Health 52:227-232 (1997).

4. Zhang J, Nair I, Sahl J. Effects function analysis of ELF magnetic field exposure in the electric utility work environment. Bioelectromagnetics 18:365-375 (1997).

5. Sahl JD, Aseltine DA, Senior RS, Rankin R, Kelsh MA, Riege LE, Smith RW, Bracken TD. An analysis of alternate summaries of magnetic field exposure data. Presented at DOE/EPRI Contractors' Review Meetings. November 1994, Albuquerque (1994).

6. Morgan MG and Nair I. Alternative functions relationships between ELF field exposure and possible health effects: Report on an expert workshop. Bioelectromagnetics 13:335-350 (1992).

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

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

9. Hansen NH, Sobel E, Davanipour Z, Gillette LM, Wilson BW, Niiranen J. EMF exposure assessment in the Finnish garment industry: Evaluation of proposed EMF exposure metrics. Bioelectromagnetics, in press (1998).

Table 1. Published exposure metrics calculated from EMF time-series data.

Exposure Metric / Effects Function	**Description/Calculation Procedure**	**Reference**
Traditional Industrial Hygiene Metrics		
Arithmetic mean or time-weighted average (TWA)	Average of measurements weighted by the time Δt_i between measurements: $TWA = \Sigma B_i \Delta t_i / T$ where T = sample duration = $\Sigma \Delta t_i$. With magnetic field monitors, the TWA equals the arithmetic mean since Δt is the constant sampling rate and the number of samples is directly proportional to the total duration.	Armstrong et al., 1990; Savitz et al., 1994; Sahl et al., 1996; Wenzl et al., 1997
Geometric mean	Average of all measurements on logarithmic scale: $GM = \exp(\Sigma \log B_i/N)$ where N = number of measurements	
Percentiles (*e.g.* 5th, 25th, median, 75th, 90th, 99th)	Percentiles of all measurements in a time period or exposure category (task, environment, etc.)	
Standard deviation	Standard deviation of measurements over the defined sample duration	
Alternate Effects Functions		
Fraction exceeding or duration above threshold	Proportion of measurements above a defined cutoff value, (e.g. 10 mG.). Defined as n_e/N, where n_e = the number of measurements above a specific magnetic field resultant level, and N=total number of measurements	Morgan et al., 1992
Field magnitude windows	Proportion of measurement above a lower bound, but less than an upper bound, e.g. proportion of measurements greater than 0.5µT but less than 1.0 µT	Morgan et al., 1992
Number of sudden field changes; called the "spikiness" or "jaggedness" metric	Count of changes in magnitude of adjacent field measurements. Size of magnitude change defined as part of metric (*e.g.* jaggedness at 0.5 µT).	Morgan et al., 1992; Wenzl et al., 1997
Rate of change	The RMS resultant change rate in components of adjacent field measurements: $RC = \frac{1}{\Delta t}\sqrt{\frac{1}{N-1}\sum_i (Bx_{i+1}-Bx_i)^2+(By_{i+1}-By_i)^2+(Bz_{i+1}-Bz_i)^2}$	Wilson et al., 1996; Hansen et al., 1998

Table 1 (cont.). Published exposure metrics calculated from EMF time-series data.

Effects Function / Exposure Metric	Description/Calculation Procedure	Reference
Time-dependent Metrics Exposure is summarized as a count of the number of times a defined exposure signal occurs. Counts are expressed as a rate per unit of time to compare data collected over different durations. These type of metrics will generally require a fast sampling rate such as 3.0 seconds or faster.		
Positive field changes within ΔT	Magnetic field increases by ΔB or more within Δt seconds, and may or may not include a duration requirement. The separation period between the end of one signal and the beginning of the next is Δt seconds.	Sahl et al., 1996
Up/down pulse with specified duration of rise and fall of exposure level	Characterized by a magnetic field increase of at least ΔB within Δt seconds, followed within Δt_d seconds by a field decrease of at least ΔB within Δt seconds.	
Threshold with specific duration	With a threshold with duration signal, the magnetic field measurement rises above the lower duration bound B_{dl} and remains there for at least Δt seconds.	

Partial Method #903. Calculating Exposure Metrics from Three-Axis EMF Waveform Data

Method Summary

Description and purpose	**Technique:** Calculating exposure metrics **Study:** Multiple studies cited below

Exposure metrics	**Input:** Digital three-axis waveforms **Data processing:** ‣ Fast Fourier transforms (FFT) of waveforms, giving the magnitude and phase spectra for each axis ‣ Calculation of various exposure metrics (formulas below)

Critique

Strengths

By measuring three-axis waveforms and taking Fast Fourier transforms (FFT), a wide array of EMF characteristics can be calculated exactly from a single measurement. Complex spatial metrics such as the axial ratio (the ratio of the semi-minor to semi-major axes of an elliptically polarized field) can be determined without special alignment of the probes. In applications of these techniques, the FFTs have been calculated by both general-purpose digital signal analyzers[1] and EMF waveform capture instruments.[2,3] The exposure metrics were then calculated by either packaged or customized computer programs.

Limitations

These exposure metrics are limited by the probe's frequency bandwidth. For example, induction coils do not respond to static magnetic fields, so three-axis fluxgate or Hall effect probes are needed for some of the metrics below. Also crucial is an accurate FFT. Artifacts in the FFT can easily result from a mismatch between the A/D frequency and the frequencies of the environmental field. With probes that respond to both static and ELF fields, probe motion can also produce artifacts.[3] Training in FFT theory, careful planning of the sampling parameters, and thorough checking of the data helps to assure accurate calculations of these exposure metrics. Lastly, the equipment may be expensive, bulky, and somewhat prone to failures.

Comparable Techniques

Some of the magnetic field metrics listed below can be measured by specialized techniques. The ELF field components parallel and normal to the static field can be determined by coordinated measurements of the static field vector and then the ELF field, using a special stand to align the two probes.[4] The frequency spectrum was also measured in workplaces with a monitor which used an array of bandpass filters to measure rms harmonic magnitudes.[5]

Exposure Metric Calculations

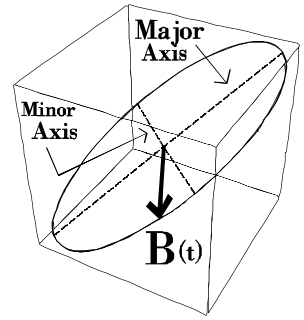
by J.D. Bowman

Most of the calculation methods summarized below were originally developed for use with the Multiwave waveform capture instruments[2] (see Method #401). The formulas can be derived by combining well-known theorems for the vector analysis of quasi-static EMF[6] (which assume the field has a single frequency) with those for discrete Fourier transforms[7] (which are generally derived for scalar signals). If the FFT is accurate (see Limitations above), the following formulas are exact methods for deriving exposure metrics from three-axis waveform data.

Definitions

Waveform for components α = x,y,z	$B_\alpha(t = n\,\Delta t)$ for n = 1,N where N = analog/digital (A/D) window $1/\Delta t$ = A/D rate
Instantaneous magnetic field vector	$\mathbf{B}(t) = \hat{\mathbf{x}}\,B_x(t) + \hat{\mathbf{y}}\,B_y(t) + \hat{\mathbf{z}}\,B_z(t)$
Static (DC) magnetic field vector	$\mathbf{B}_0 = \hat{\mathbf{x}}\,B_{0x} + \hat{\mathbf{y}}\,B_{0y} + \hat{\mathbf{z}}\,B_{0z}$
Harmonic frequencies from the FFT	Frequencies f range from zero to half the A/D rate.
RMS harmonic magnitudes	$B_{f\alpha}$ for frequency f and component α
Harmonic phases	$\phi_{f\alpha}$
Harmonic component phasor	$b_{f\alpha} = B_{f\alpha}\exp(\phi_{f\alpha})$
Harmonic vector phasor	$\mathbf{b}_f = \hat{\mathbf{x}}\,b_{fx} + \hat{\mathbf{y}}\,b_{fy} + \hat{\mathbf{z}}\,b_{fz}$
Fourier series for the instantaneous field vector	$\mathbf{B}(t) = 2\sqrt{2}\sum_f \mathrm{Re}\left[\mathbf{b_f}\,e^{i2\pi f t}\right]$
Resultant function	$\mathrm{Resultant}\left[B_\alpha\right] = \sqrt{B_x^2 + B_y^2 + B_z^2}$
Root-mean-square function	$\mathrm{RMS}\left[B(t)\right] = \sqrt{\frac{1}{N}\sum_{n=1}^{N} B(t = n\,\Delta t)^2}$

Exposure Metric	Formula
Static (DC) field components for the three axes	$B_{o\alpha} = \frac{1}{N}\sum_{n=1}^{N} B(n\Delta t)$ for α = x,y,z
Static vector magnitude	B_o = Resultant $[B_{o\alpha}]$
Harmonic rms vector magnitude	B_f = Resultant $[B_{f\alpha}]$ $= \sqrt{\mathbf{b_f} \cdot \mathbf{b_f^*}}$ where $\mathbf{b}_f^*$ is the complex conjugate of the vector phasor.
Frequency spectrum	Bar chart of B_f vs. f.
Principal frequency	Frequency for Maximum $[B_f]$
Rms components	$B_{ELF,\alpha} = RMS\left[B_\alpha(t) - B_{o\alpha}\right]$ for α = x,y,z
Rms vector magnitude	$B_{ELF} \equiv RMS\left[\,\left\|\mathbf{B}(t) - \mathbf{B_0}\right\|\,\right]$ $= \text{Resultant}\left[B_{ELF,\alpha}\right]$ $= \sqrt{\sum_{f>0} B_f^2}$
Total harmonic distortion (Also called the harmonic factor h_d.)	$THD = \frac{\sqrt{\sum_{f=nf_{power}} B_f^2}}{B_{power}}$ where n = 2,3,4 ..., f_{power} = 50 or 60 Hz, and B_{power} is its harmonic vector magnitude
Fundamental ratio	$F_r = B_{power} / B_{ELF}$ <u>Note:</u> $F_r = \text{Cos}\,[\text{Tan}^{-1}\,THD]$
Harmonic magnitude parallel to the static field vector	$B_{parallel} = RMS\ [\,\mathbf{B}_f(t) \bullet \mathbf{B}_0 / B_0]$ for f > 0.
Harmonic magnitude normal to the static field vector	$B_{normal} = \sqrt{B_f^2 - B_{parallel}^2}$ for f > 0.

Exposure Metric	Formula
RMS magnitudes of the semi-major and semi-minor axes of a harmonic	Each harmonic has either linear, circular, or elliptical polarization, and its plane of rotation may be oriented in any direction relative to other harmonics. The FFT data can be used to calculate the rms magnitudes of the semi-major axis (B_{major}) and semi-minor axis (B_{minor}) for each harmonic f.[6] 
Axial ratio	$a_f = \frac{B_{minor}(f)}{B_{major}(f)}$ for each harmonic f.
Maximum rms component for a harmonic	$B_{max}(f) = B_{major}(f)$ <u>Note:</u> The maximum rms component measured by Method #501 is approximately equal to $B_{max}(f_{power})$ when the spectrum is dominated by the power frequency.
Maximum component ratio	$m_r = B_{max}(f_{power}) / B_{power}$ <u>Note:</u> $m_r = \text{Cos}[\text{Tan}^{-1}(a_{power})]$

References

1. Bowman JD, Kardous CA. Characteristics of static and ELF magnetic fields from occupational sources. Bioelectromagnetics Society Annual Meeting, Salt Lake City, (1993).

2. Dietrich FM, Feero WE, Robertson DC, Sicree RM. *Measurement of Power System Magnetic Fields by Waveform Capture.* EPRI Report TR-100061. Electric Power Research Institute, Palo Alto, CA (1992).

3. Bowman JD, Methner MM. Hazard surveillance for workplace magnetic fields: II. Field characteristics from waveform measurements. Submitted to *Ann Occ Hyg.* (1998).

4. Kaune WT. Study of High- and Low-Current-Configuration Homes Inhabited by Case and Control Subjects from the Denver Childhood Cancer Study. Final Report, California Department of Health Services, Berkeley, CA (1994).

5. Philips KL, Morandi MT, Oehme D, Cloutier PA. Occupational exposure to low-frequency magnetic fields in health care facilities. *Am Ind Hyg Assoc J* 56:677-685 (1995).

6. Electric Power Research Institute. *Transmission Line Reference Book, 345 kV and Above,* second edition. EPRI Report EL-2500. Electric Power Research Institute, Palo Alto CA (1982).

7. Jackson LB. Signals, Systems, and Transforms. Addison-Wesley, Reading, MA (1991), Chapt. 4 and 7.

IV. DEFINITIONS

A. Terminology

AC magnetic field	A magnetic field originating from AC electricity. Commonly used as an antonym for *DC magnetic field*, regardless of the source.
A/D (analog-to-digital) conversion	A circuit whose input is an *analog signal* and whose output is the same information in the form of a *digital signal.*
A/D (analog-to-digital) rate	The rate at which digital numbers are sampled from an analog signal by an A/D converter. The units are Hertz (numbers per second).
Analog signal	An electronic signal whose information content is conveyed by the value or magnitude of some characteristic like (amplitude, phase or frequency of a voltage or the amplitude or duration of a pulse). Analog signals imply continuity while *digital signals* are concerned with discrete states.
Average-sensing rms response	Time response of a meter that gives the average of the rectified signal, calibrated to give the *root-mean-square (RMS)* of a sinusoidal *power frequency* input. If the field has *harmonics*, an average-sensing rms meter will have some errors. (See Sicree RM *et al.*, IEEE Trans Power Deliv 8:607-619, 1993.)
Axial ratio	The ratio of the rms magnitudes of the semi-minor and semi-major axes for a single frequency. Ranges from zero for linear *polarization* to one for circular polarization.
Bandwidth	The range of frequencies over which an instrument has a strong response to a signal. The bandwidth is often defined by the -3 dB points in the frequency response (relative to the peak response or some other reference frequency) .
Base frequency	The lowest non-zero frequency resulting from a *Fast Fourier transform (FFT).* All other frequencies in the spectrum are integer multiples of the base frequency. The base frequency is often selected to be the *fundamental* (*i.e.* the *power frequency*), but lower values may be used, especially when *sub-harmonics* are present.
Bin edge	The upper or lower bound on a *geometric bin* which the Positron meter used to store its data.
Channel	An independent probe and the circuitry for analyzing the probe's analog signal and generating digital output. With a 3D probe that has three orthogonal sensors, the parallel, serial or combination circuits for analyzing these three signals are all part of a single channel.

Channel (cont.)	In conventional usage, three identical parallel circuits carrying the signals from a 3D probe would comprise three “channels”. However, this *Manual* has broadened the definition of “channel” in order to consider instruments with multiple probes for different kinds of EMF. In contrast to instruments with a single 3D sensor, each channel in a multi-probe instrument has a sensor (either single axis or 3D) with distinct specifications, so that each channel requires some different circuitry for signal analysis.
Characteristics	Detailed physical properties of electric or magnetic fields, such as the magnitude, frequency spectrum, polarization, etc.
Component	See *Vector component.*
DC magnetic field	Magnetic fields originating from DC electricity. Commonly-used term for all *static magnetic fields*, including *geomagnetic fields* and those originating from permanent magnets.
Data processing	A summary table heading which describes the calculation of an *exposure metric* from an instrument’s digital *output,* whether performed on a calculator, a personal computer, or a programmed microprocessor within the instrument.
Data-logger	An digital memory device which automatically records one or more measurements along with the measurement time.
Digital signal	An electronic signal whose information content is carried by discrete states of some characteristic, such as the presence or absence of a voltage or a switch in an open or closed position. The antonym is an *analog signal.*
Dose	A toxicological term for the amount of a chemical or physical agent delivered to a target organ. Since neither the target organ nor the mechanism of delivery are well understood for most biological effects of ELF fields, an EMF dose can seldom be defined, and the concept of *exposure metric* is used instead.
Dosimeter	An instrument that can be worn on a person for measuring exposures over time. Since the *dose* cannot usually be determined for ELF fields, “dosimeter” is a misnomer, and a term like *personal monitor* or "exposure meter" is preferred.
Duration	The total time over which an instrument is regularly taking samples. (See *Sample* and *Sampling time.*)
Dynamic range	The range between an instrument's overload input and its minimum acceptable input (as determined by noise, resolution, distortion, etc.).
Effects function	See *Exposure metric.*
Electric field	A vector field **E** measured in volts / meter. At a given point in space and time, **E** is defined as the forces from all other charged particles on an infinitesimal test charge δq divided by δq.

Electromagnetic fields	The combination of electric and magnetic fields in the environment. This term is easily confused with “electromagnetic radiation”, and can therefore be misleading when used with extremely low frequencies whose radiation is barely detectable. Therefore “electric and magnetic fields” is the preferred term.
ELF (extremely low frequency)	The frequency range from 3 - 3000 Hz.
EMF	Electric and magnetic fields. "EMF" is a common shorthand for "*extremely low frequency (ELF)* fields", and is even used incorrectly for "ELF magnetic fields."
Exposure	The amount of a chemical or physical agent in the environment that a person comes in contact with over a some period of time.
Exposure assessment	The evaluation of a person's exposure by measurements, modeling, information about sources, or other means.
Exposure metric	A single number which summarizes an electric and/or magnetic field exposure. An exposure metric is usually determined by a combination of the instrument's signal processing and the data analysis performed after the measurement. Also called an “effects function” and an "exposure summary."
Exposure summary	See *Exposure metric.*
Fast Fourier transform (FFT)	An efficient mathematical algorithm for calculating the Fourier transform of a digital *waveform* which has 2^n data points. The term is also used for the output of the FFT algorithm (*i.e.* a complex number for each frequency in the Fourier series of the waveform).
Filter	Electronic components of an instrument which modify its *frequency response* to an analog or digital signal. ELF magnetic field meters generally have *bandpass filters* whose response is set equal to one at the *power frequency.* These ELF bandpass filters have been classified in various ways: *flat, linear, broadband, narrowband, fundamental,* and *harmonic.* (Also see *bandwidth* and *power-frequency*.)
Free-body sensor	An electric field sensor that is supported in space without conductive contact to any object.
Frequency response	An instrument's output as a function of frequency relative to the magnitude of the input signal. Specification of an instrument's frequency response includes the type of *filter* and its *bandwidth.*
Frequency spectrum	An EMF *characteristic* as a function of frequency, which can be plotted as a bar graph. Usually means the frequency components of the *rms vector magnitude* calculated by a *fast Fourier transform (FFT).* However, the *rms component* magnitudes, the component's *phases,* and *axial ratios* also have frequency spectra.
Fundamental (filter)	A narrowband *filter* that responds to the *power frequency* (50 or 60 Hz) but not to any *harmonics.*

Fundamental (frequency)	The lowest substantial frequency component of a *waveform*'s Fourier series. Often equals the *power frequency.* See also *Base frequency* and *Fast Fourier transform.*
Geomagnetic fields	Magnetic fields originating from the earth (including the atmosphere). Predominantly a *static magnetic field,* but includes some oscillating components and *transients.*
Geometric bins	A method for digital data storage used in the Positron monitor where the analog signal is assigned to one of a consecutive series of categories (bins), and the identification number of the bin is stored in memory. The *bin edges* form a geometric series so that the monitor can have a large dynamic range.
Ground reference sensor	An electric field sensor that measures the induced current or charge oscillating between an isolated electrode and a grounded conductor.
Harmonic (filter)	A broadband *filter* in the EMDEX-II meter that responds to the magnetic field's *harmonics* but not the 60 Hz *power frequency.*
Harmonic (frequency)	Frequencies that are integral multiples of the *power frequency* or some other reference frequency.
Hazard surveillance	Assessing exposures to chemical or physical agents in a large sample of workplaces for purposes of evaluating the extent of a health hazards and planning efforts for its evaluation and control.
Health hazard evaluation	A short-term study for the assessment of a potential health hazard in a workplace. NIOSH performs HHE s for workers and employers as a service provided by the 1970 Occupational Safety and health Act.
Intermittent fields	Fields whose *rms vector magnitude* changes rapidly. In contrast to *transients,* intermittent fields may have high levels for longer times and are generally in the *ELF* frequency range.
LF (low frequencies)	The frequency range from 30-300 kHz.
Magnetic field strength	A vector field **H** with units of ampere/meter. At any point **r** adjacent to a circuit C and free from magnetized matter, **H** can be defined by the Biot-Savart Law : $$\mathbf{H(r)} = \frac{1}{4\pi}\int_C \frac{I\,\hat{\mathbf{r}}\times d\mathbf{s}}{r^2}$$ where d**s** is a length of circuit C carrying current I. In EMF health literature, “magnetic field strength” is sometimes used incorrectly for the *rms vector magnitude (resultant)* of the *magnetic flux density.*
Magnetic field	Both the H and B fields. In health studies, these two fields are essentially interchangeable since their vectors are parallel in air, the human body, and other non-ferromagnetic materials. In studies at *extremely low frequencies*, “magnetic field” is generally used for the *magnetic flux density* (B field). When the topic is radio frequencies and microwaves, the term usually means the *magnetic field strength* (H field). (See “Units”, p. IV-9 for more discussion.)

Magnetic flux density	A vector field **B** with units of tesla (SI) or gauss (CGS). At any point in space, **B** can be defined either by: 1) the force on a test charge q with velocity **v** as expressed by the velocity-dependant component of Lorentz's Law: $\mathbf{F} = q(\mathbf{v} \times \mathbf{B} + \mathbf{E})$, or by: 2) the torque **T** on a planar circuit with area A carrying current I as expressed by: $\mathbf{T} = I\,A\,\mathbf{n} \times \mathbf{B}$ where **n** is an axial unit vector normal to the loop in the sense of the right-hand rule.
Magnitude	See *Vector magnitude.*
Maximum field	The greatest rms magnitude of an electric or magnetic field measured by rotating a single-axis sensor in all directions. For EMF with a single frequency, the maximum field is the semi-major axis of the ellipse of polarization divided by $\sqrt{2}$. (See *Polarization* and *Root-mean-square.*)
Method	A complete set of instructions for the measurement of EMF exposures in an environment. (Also see *Technique.*)
Metric	See *Exposure metric.*
Monitor	An instrument for measuring exposures over time. As a verb, to measure over time.
Output	The final numbers which an instrument routinely produces from measurements, either as its read-out or a digital *data-logger* file which can be transferred to a computer.
Personal monitor	An instrument that can be worn on a person for measuring exposure over time. (Also see *Dosimeter.*)
Phase	An angle ϕ_f for each frequency component of a *Fast Fourier Transform* which specifies the lag or advance of the waveform's peak relative to time zero. Electric and magnetic fields have three phase angles ϕ_{fx}, ϕ_{fy}, and ϕ_{fz} for each frequency f in their spectrum.
Power frequency	The frequency at which AC electricity is generated. For electric utilities, the power frequency is 60 Hz in North America, Brazil, and parts of Japan. In much of the rest of the world, it is 50 Hz. Isolated AC electrical systems may have other power frequencies, *e.g.* 440 Hz in commercial airliners. (See *Principal harmonic* and *Fundamental frequency.*)
Polarization	The shape traced by the tip of an EMF vector over a single cycle. For fields with a single frequency, the polarization is either linear, elliptical or circular. For fields with multiple frequencies, the polarization can be a complex shape, and is better expressed as a spectrum of the *axial ratio* at different frequencies.
Principal harmonic	The frequency component of a *waveform*'s Fourier series with the largest magnitude. Often equals the *power frequency.* See also *Base frequency* and *Fast Fourier transform.*

Resultant	The mathematical function used to calculate the *vector magnitude* B from the *vector components* B_x, B_y, B_z with the Pythagorean theorem: $$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$ If B_x, B_y, and B_z are the rms components of a field, the resultant equals the rms vector magnitude. (See *Root-mean-square.*) In ELF measurements, "resultant" is commonly used to mean "rms vector magnitude" of the magnetic or electric field. However, the resultant function can also be used to obtain the instantaneous vector magnitude B(t) and the magnitude B_o of the *static (DC) field.*
Root-mean-square (RMS)	The most versatile mathematical function for averaging the magnitude of time-varying electric and magnetic fields: $$\text{RMS [v]} = \sqrt{\frac{1}{T}\int_0^T v(t)^2 \, dt}$$ where v(t) is any signal measured over a *sampling time* T. Meters that measure the rms of a signal can have *true rms* or *average-sensing rms* circuitry.
Sample	A continuous measurement covering a fraction of the *duration* over which the exposure is monitored.
Sampling rate	The frequency with which samples are taken, expressed as the time between the beginning of each sample.
Sampling strategy	A strategy for determining the sites, subjects, timing, duration, and methods for measuring exposures.
Sample time	The length of a sample, *i.e.* the time over which an instrument is continuously taking measurements, (as opposed to the *duration* which is the total time the monitor is taking samples)
Semi-major axis	The longest axis of the trace of an elliptically polarized field. (See *Polarization*.)
Semi-minor axis	The shortest axis of the trace of an elliptically polarized field.
Spot measurement	An instantaneous measurements at a designated location.

Static field	A field vector that does not vary with time. In most environments, electric and magnetic fields change with time, but their *frequency spectra* has a component at 0 Hz.. This "quasi-static" component of the field is measured by an instrument with a low-pass *filter* set at a small frequency (*e.g.* 3 Hz) or by averaging the oscillating signal over the *sample time.* (See also *DC magnetic field* and *Geomagnetic field.*)
Sub-harmonics	Frequencies in the spectrum that are lower than the *power frequency.*
Three-axis (3D) sensor	A sensor with three axial probes aligned orthogonally in order to measure the field's three spatial *components* simultaneously.
Time response	The methods by which an instrument responds to the signal's variations over time, such as *A/D conversion*, the capture of digitized *waveforms*, and a true *rms* response.
Time-weighted average (TWA)	A weighted average of exposure measurements taken over a period of time with the weighting factor equal to the time interval between measurements. When the measurements are taken with a *monitor* with a fixed *sampling rate,* the TWA equals the arithmetic mean of the measurements.
Trace	The three-dimensional pattern made by the tip of an electric or magnetic field vector over one or more periods of oscillation. (Also see *Polarization.*)
Transients	Brief bursts of high frequency fields, usually resulting from mechanical switching of AC electricity. (Not to be confused with *Intermittent fields.*)
True rms response	The time response of a meter that gives the *root-mean-square (RMS)* of the input signal accurately. (Also see *average-sensing RMS*).
ULF (ultra low frequency)	The frequency range below 3 Hz.
Vector components	The length of a vector when it is projected onto three orthogonal axes.
Vector magnitude	The length of an EMF vector. (See also *Resultant.*)
VLF (very low frequency)	The frequency range from 3 - 30 kHz.
Walkthrough survey	An exposure assessment conducted by walking through a workplace or other environment while carrying a *monitor.* Exposures in the workplace are summarized from different *exposure metrics* calculated from the measurements made during the walkthrough.
Waveform	A single *component* of the field measured as a function of time by an instrument with a *response time* much faster than the field's frequency of oscillation. The term also means the shape of the wave as displayed on a graph or oscilloscope trace.

Waveform capture	Measuring *waveforms* with an oscilloscope or other instrument which can display the waveform and/or digitize the data for further calculations.

References

1. Jay F (editor): *IEEE Standard Dictionary of Electrical and Electronic Terms* (fourth edition). ANSI/IEEE Standard 100-1988. Institute of Electrical and Electronic Engineers, New York, NY (1988).

2. IEEE: Recommended practice for instrumentation: Specifications for magnetic flux density and electric field strength meters -- 10 Hz to 3 kHz. IEEE Standard 1308-1994. Institute of Electrical and Electronic Engineers, New York, NY (1994).

B. Units

Quantity	Symbol	Units	
		International System (SI)	CGS
Electric field	E	Volts / meter (V/m)	Volts / cm
Magnetic flux density	B	Tesla (T)	Gauss (G)
Magnetic field strength	H	Ampere / meter (A/m)	Gauss or Oersted
Magnetic field conversion in vacuum and non-ferromagnetic media.		$B = \mu_o H$ where $\mu_o = 4\pi x 10^{-7}$ T-m / A	B = H

There are several approaches to choosing the units for magnetic fields. In health studies, the choice between the B- and H-field is not usually a matter of scientific importance since the two vectors are parallel at any point in air, biological tissues (magnetite excepted), and any other non-ferromagnetic medium.[1] Although the two magnetic fields are different physical quantities, only a simple units conversion (see Table) distinguishes them in the practical viewpoint of health studies.

In occupational and environmental health, either the B- or H-field is chosen as the single quantity for measuring magnetic fields by consensus among researchers. For radio frequencies (RF), microwaves, and above, the non-ionizing radiation community uses the magnetic field strength (H-field) with the SI units of amperes / meter[2]. One reason is that the Poynting vector and energy density for radiating fields are conveniently expressed in terms of the H-field. Since ELF fields hardly radiate, the ELF community uses the magnetic flux density (B-field) because important formulas such as the Lorentz's and Faraday's laws are conveniently expressed in this form.[1]

With the public, the distinction between "magnetic field strength" and "magnetic flux density" is an unnecessary distraction in discussing health effects. Without compromising rigor, the colloquial "magnetic field" can be applied to the H-field at radio frequencies and the B-field for extremely low frequencies. As a rule, the precise terms for the two magnetic fields are needed only when communicating with both RF and ELF health researchers or with the broader engineering and physics communities (which also have a variety of conventions about magnetic fields).

The ELF community In the U.S. is also split on its choice of units for the B-field. The general public and many medical researchers are accustomed to the CGS units of milligauss (mG). Engineers and physical scientists generally insist that the B-field be expressed in the SI units of Tesla (T), because unit manipulations become unnecessarily arcane in the CGS systems.[3]

For exposure assessments, the choice between SI or CGS therefore depends mainly on the audience. One attractive approach[1] is to use microtesla as the primary unit for the B-field, and to attach the milligauss conversion in parentheses to quantities in texts, *e.g.* 1.8 µT (18 mG). This technique adheres to international scientific conventions, while making reports, abstracts and executive summaries accessible to broader audiences in the U.S.

Useful conversion factors for the B-field are:

$$1\ \mu T = 10\ mG$$
$$1\ mT = 10\ G$$
$$1\ T = 10\ kG$$

References:

1. Kaune WT and Anderson LE: Physical aspects of ELF electric and magnetic fields: measurements and dosimetry. In: *Extremely Low Frequency Electromagnetic Fields: The Question of Cancer*, Wilson BW, Stevens RG, Anderson LE (eds). Battelle Press, Columbus, OH, pp. 22-23 (1990).

2. International Radiation Protection Association: Review of concepts, quantities, units and terminology for non-ionizing radiation protection. *Health Phys.* 49: 1329 (1985).

3. Crooks JE: SI units. In: *The Spectrum in Chemistry.* Academic Press, London, pp. 279-283 (1978).

V. INDEX

A. Authors

B. Instruments

C. Exposure metrics