RECOMMENDATIONS FOR GUIDELINES FOR ENVIRONMENT-SPECIFIC MAGNETIC-FIELD MEASUREMENTS

RAPID PROGRAM ENGINEERING PROJECT #2

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EXECUTIVE SUMMARY

Purpose and Focus

The purpose of this project was to document widely applicable methods for characterizing the magnetic fields in a given environment, recognizing the many sources co-existing within that space. The guidelines are designed to allow the reader to follow an efficient process to (1) plan the goals and requirements of a magnetic-field study, (2) develop a study structure and protocol, and (3) document and carry out the plan. These guidelines take the reader first through the process of developing a basic study strategy, then through planning and performing the data collection. Last, the critical factors of data management, analysis reporting, and quality assurance are discussed. The guidelines are structured to allow the researcher to develop a protocol that responds to specific site and project needs.

The Research and Public Information Dissemination Program (RAPID) is based on exposure to magnetic fields and the potential health effects. Therefore, the most important focus for these magnetic-field measurement guidelines is **relevance to exposure**. The assumed objective of an environment-specific measurement is to characterize the environment (given a set of occupants and magnetic-field sources) so that information about the exposure of the occupants may be inferred.

Ideally, the researcher seeks to obtain complete or "perfect" information about these magnetic fields, so that personal exposure might also be modeled perfectly. However, complete data collection is not feasible. In fact, it has been made more difficult as the research field has moved to expand the list of field parameters measured, increasing the cost and complexity of performing a measurement and analyzing the data.

The guidelines address this issue by guiding the user to design **a measurement protocol that will gather the most exposure-relevant information based on the locations of people in relation to the sources.** We suggest that the "microenvironment" become the base unit of area in a study, with boundaries defined by the occupant's activity patterns and the field variation from the sources affecting the area. Such a stratification allows the researcher to determine which microenvironments are of most interest, and to methodically focus the measurements in those areas, in order to gather the most relevant set of data.

Developing the Basic Study Strategy

The first step in developing a responsive protocol for performing magnetic-field measurements in a given environment is to design the research strategy to best characterize the exposures. This step will help to limit and optimize the measurement tasks. The strategy development must take into account the study purpose, the project resources, the physical characteristics of the environment, the field parameters desired for measurement, and the instrumentation to be used in the study. The guidelines describe the study strategy development in six steps, summarized below.

Determining and documenting the study purpose. A statement of purpose should be developed and understood by the investigators and the study sponsor or client. That statement should answer the following five questions:

1. What is the goal of the study?
2. Who is the audience?
3. What circumstances initiated the study?
4. What is the desired output of the study?
5. How will the final data be used?

Documenting the study purpose will provide a basis for actions and help ensure that each task is optimized to provide the desired product.

Determining the environment classification. The guidelines next present a method for classifying the environment type, based on Standard Industrial Classification code numbers for establishments. Such classification will encourage focus on the environment's properties, stratification within databases, and comparisons with similarly classified environments previously studied.

Determining the project resources. The scope of studies will almost always be limited by project resources. The financial resources, staff availability, instrumentation availability, and any time constraints should be assessed early in the planning process.

Reviewing the physical characteristics of the environment. Preliminary information on the environment's characteristics and sources will highlight important features that should be considered in the measurement plan. These include features that may indicate what field parameters might be of interest, as well as the scope of measurements that might be necessary, based on the size and complexity of the environment.

Selecting field parameters for measurement. The dose metrics of magnetic-field exposure have not been defined. Therefore, the investigator will want to obtain information on multiple parameters. The guidelines discuss parameters that may be selected for measurement, but leave choices open to the investigator, based on the study purpose, site characteristics, and practicality of measurement. The guidelines acknowledge that performing rms magnetic flux density measurements will continue to be a focus of environment-specific measurements because this measurement is easy to perform, is readily understood by the research community and general public, and has been the focus of most previous studies.

Selecting instrumentation. The investigators should select instrumentation based on measurement and memory capabilities suited to the study goals, as well as on efficiency, reliability, convenience, and price. However, availability is usually the most prevalent factor. The guidelines discuss single-axis and three-axis rms meters and commercially available waveform capture systems, and the nature and potential functions of each class of instrument.

Developing a measurement strategy and data collection structure. Outlining a plan for data collection is the next natural step. The measurement strategy, a part of this plan, is the decision-making process by which it is ultimately determined where, when, and how magnetic-field data will be collected. The guidelines stress designing the measurements to gather *only* the most exposure-relevant information, and describe the use of the microenvironment to determine what information is most relevant.

The standard structure for performing magnetic-field characterization is suggested in a four-step process.

1. Gather the basic information about sources, people, and other site information.
2. Identify microenvironments.
3. Weight the efforts to be spent in each microenvironment.
4. Perform focused magnetic-field data collection.

The guidelines provide examples of data-collection structures, and the possible tasks that may be involved.

Performing the Data Collection

Having guided the reader through the factors of a study strategy, the guidelines focus on the specific steps of performing the data collection and determining the appropriate data to consider collecting. **Magnetic-field characteristics cannot be properly described by a single measurement or series of measurements.** Many factors, including the physical parameters of the environment; the location and operation of sources; the activity patterns of the occupants; and the spatial, temporal, frequency, and other parameters of the magnetic fields together paint a picture that characterizes magnetic-field exposure.

Developing the data-collection protocol. Before the researcher begins to collect data collection, it is most important to produce a written data collection protocol. This helps to ensure that relevant information is collected; that magnetic-field measurements are completed most completely, efficiently, and systematically; and that disruption to the environment is minimized. The guidelines provide examples of protocol formats, each organized in a chronological sequence. Objective, easy-to-use data-collection forms are the most reliable means to obtain and confirm a complete data set from the field. Their development is a part of generating the data-collection protocol. Examples of several forms have been included in the guidelines.

The guidelines describe the specifics of data collection, following below.

Identifying magnetic-field sources. The guidelines describe methods of source identification, including visual inspection, gathering source information from an informant, performing exploratory measurements, performing field mapping, or using such tools as a clamp-on ammeter to identify sources of net current. The guidelines further detail methods for documenting the source locations, and defining the source characteristics such as source type, level of magnetic-field magnitude, and temporal characteristics.

Gathering activity-pattern data. It is assumed that the goal of activity-pattern data collection is to provide the minimal data set of information required to properly include exposure-relevancy in the magnetic-field measurement study design. The guidelines describe methods of data collection (including interviews, questionnaires, and observation techniques) and outline the ways to choose the appropriate technique based on the study parameters. Recommendations are also given as to whether a site informant or the site's occupants are most appropriate providers of activity-pattern data. The guidelines furnish tips for constructing activity-pattern questions, as well as examples of data collection tools, such as questionnaires and interview protocols.

Gathering non-magnetic field data. Other information about the environment and its sources may provide additional insight into the characteristics of magnetic-field exposure, painting a more complete picture of the environment's magnetic-field characteristics. The guidelines describe possible appropriate information, such as: site characteristics (i.e., building age); additional source information (i.e., sizes of motors); utility information (i.e., circuit loads); and occupant information (i.e., job descriptions and ages).

Planning and performing focused magnetic-field data collection. The three tasks described above provide the information required to plan further, more focused magnetic-field measurements. A magnetic-field measurement plan will aim to finalize the locations of measurements, timing of measurements, measurement sampling rates, and the inclusion of temporal measurements. The guidelines direct the reader through the necessary steps:

- identifying microenvironments and weighting them for assessment;
- determining the number of measurements to perform and the locations of the measurements;
- determining the timing factors of measurements, and
- planning and performing temporal and other special measurements.

It is assumed that these data will comprise the substance of the report on magnetic-field data.

Data Management, Analysis and Reporting

Guidance is provided for managing, compiling, analyzing, and reporting the collected data to the study audience. Data management methods are described, including the following:

- protocols for documenting the measurement data,

- conventions for naming or labeling all data,
- structures for organizing the data for analysis, and
- plans for maintaining the integrity of the data.

Options for methods and tools for data analysis are discussed. The researcher should bear in mind that the choices of methods must be based on the questions the study has been designed to answer, and upon the study resources and parameters.

The project report should be a compilation of all effort expended in the study, presented in a format tailored to convey the information to the appropriate audience. Reports generally will include the following primary areas: Introduction, Methods, Results, and Discussion. The data may be conveyed in the form of descriptions, tables, graphics, and/or electronic media. The guidelines describe sample content for each report section. Three pilot study reports are included as examples of a report format.

Quality Assurance Methods

A quality assurance plan seeks to ensure that the data collected and reported are valid and consistent. The plan should be developed during the study planning process. Quality assurance steps can and should be specified for each phase of the study. Steps described in the guidelines include the following:

- Minimizing Subjectivity Throughout the Project
- Developing Forms and Checklists to Assure Completeness and Consistency
- Ensuring that Technicians Have the Appropriate Expertise to Perform Data Collection
- Ensuring the Accuracy of the Study Instrumentation
- Collecting Duplicate Information
- Clearly Identifying All Information
- Inspecting and Analyzing Data in a Timely Manner
- Backing Up Everything
- Performing Pilot Studies.

Conclusion

The guidelines provide flexible, widely applicable methods for performing exposure- relevant magnetic-field measurements. They may be used to produce a targeted, efficient, and useful study that collects, analyzes, and reports the data appropriate for the goals of the study.

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SECTION 1: INTRODUCTION

1.1 Purpose

This purpose of developing these guidelines for environment-specific magnetic-field measurements was to document widely applicable methods for characterizing the magnetic fields in a given environment, recognizing the many sources and occupants co-existing within the given space.

The guidelines further aimed to be clear, easy to use, and flexible enough to assist in study development for any of the anticipated users – researchers in the Research and Public Information Dissemination Program (RAPID) program itself, as well as engineers, epidemiologists, industrial hygienists, and so on. The goal was to allow the reader to follow the most efficient process for thinking out the requirements and goals of measurement, developing a structure and protocol, documenting a plan, and building in quality assurance.

The guidelines were developed as part of the Electric and Magnetic Field (EMF) RAPID program, a "comprehensive program to determine whether or not exposure to EMF from the generation, transmission, and use of electricity affects human health." The engineering portion of that program was designed to encourage consistent gathering and reporting of magnetic-field data. Three related sets of guidelines spring from this goal:

Guidelines for Magnetic-field Source Characterization
Guidelines for Environment-specific Measurements, and
Guidelines for EMF Personal-exposure Measurements

Because the three projects represent complementary efforts, the guidelines in this document do not attempt to provide complete information about source characterization or personal-exposure (PE) assessment. (For example, though source characterization, with respect to occupants, is discussed in this document as an integral part of characterizing an environment, the source characterization guidelines provide more complete information for fully characterizing the magnetic-field attributes of a source, irrespective of its environment.) Researchers are encouraged to consult the source-characterization and personal-exposure measurement guidelines as applicable to their needs, to expand on some of the ideas expressed within this document.

Because the RAPID program is based on exposure and potential health effects, the most important focus for these guidelines is **relevancy to exposure.** The assumed objective of an environment-specific measurement is thus to characterize the environment, given a set of occupants and sources, so that information about the exposure of the occupants may be inferred. How much information should be gathered, and in what area, are critical questions.

Research in magnetic-field exposure and potential health effects has accelerated over the past 20 years. However, it is as yet far from clear which aspects of EMF are relevant to human biology. As a result, the recent direction in environment-specific measurements has been to expand the list of field parameters beyond the historical focus on resultant alternating current (ac) fields, to include such parameters as the frequency components, polarization, and transient events. However, capturing additional field parameters may result in the collection of immense quantities of cumbersome data, increasing the cost and complexity of performing a measurement and analyzing the data. The guidelines recommended within address this issue by guiding the user to design a measurement protocol that will **gather the most exposure-relevant information based on the locations of people in relation to sources.**

Ideally, the researcher seeks to obtain complete or "perfect" information about the magnetic fields in the specific environment, so that personal exposure might also be modeled perfectly. However, such a goal of complete data collection is not feasible, even in the best of circumstances. The researcher would have to understand fully every detail of the activity patterns of each person and the field characterization of each source. As the best approximation of this goal, we suggest that **the "microenvironment" become a base unit of area in a study,** with boundaries defined by the occupants' activity patterns and the field variation from sources affecting the area. Such a stratification allows the researcher to determine which microenvironments are of most interest (i.e., those most frequently occupied by people, and those with the magnetic-field characteristics of greatest interest), and to methodically focus the measurements in those areas in order to gather the most relevant set of data.

In order to provide wide applicability, these guidelines acknowledge the following factors that must be taken into account in designing a measurement study:

- No two environments are alike. **Different protocols** will be appropriate in different environments.
- Users of the guidelines may include people **with a variety of skills, interests, and goals**, including industrial hygienists, epidemiologists, engineers, and utility representatives.
- Virtually every study will be **limited by time and cost considerations.** The incremental value of additional information and accuracy must be weighed for each study's resources.
- **Available instrumentation** will vary from study to study. Its performance, portability, and recordability will influence the study design.

1.2 Guideline Development

These guidelines were developed based on the premise that good research principles and engineering principles had been practiced in past measurements of environments and sources, and that some industry standards had developed over time. We anticipated two hurdles that had not been consistently addressed in previous measurements:

1) to consistently and appropriately account for human activity patterns in the measurements, and
2) to expand the list of field parameters measured.

1.2.1 Reviews

We took lessons learned from past research efforts as a substantial starting point for the guideline design. We reviewed the literature on environment and source measurement studies in order to summarize the considerations previously included and methods practiced. We also reviewed published measurement protocols and guidelines (see Appendix A.1 and A.2 for a summary intended to help you refer to related studies when designing your own).

Research literature on the characterization of activity patterns in exposure studies was assessed, alone and with respect to EMF. The literature for exposures of pollutants provided information on the concept of the microenvironment in exposure assessment. (A summary of this review is included in Appendix A.3.)

To help direct the researcher to the appropriate selection of parameters for measurement, we reviewed magnetic-field parameters and their possible health impacts; this included a review of the laboratory and epidemiological studies, the interactive mechanism hypotheses, and known physical phenomena (see Appendix A.4 for this summary). Given the uncertainty of relevance to human biology, this review netted little direction for recommending field parameters for measurement. We have therefore elected to discuss considerations for selecting field parameters, but to leave the options to the researcher.

1.2.2 Plan Development

Based on these review efforts, a basic flexible plan was developed for gathering exposure-relevant data on an expanded list of magnetic-field parameters. We tested the plan outline in pre-pilot studies, then formalized the modified plan. We conducted three pilot studies in representative environments in order to test the strategies and recommendations, using both sophisticated and basic instrumentation: a school environment, an industrial environment, and a retail environment.

(The pilot study reports are included as Appendix B.) Observations from the pilot studies were included in the final guidelines.

1.3 Using These Guidelines

We have designed this document not as a model protocol, but as a guide to help you consider all factors when you **develop your own specific protocol that responds to your needs.** It takes you through the necessary steps for a thorough planning process: identifying scope and need (thinking), anticipating considerations (developing), targeting appropriate methods and techniques (giving form), building in checkpoints (assuring quality), and reporting out (documenting results). Tables and sample forms have been included for use as templates for your own documents. We also provide helpful **"P.S.'s,"** boxed examples taken from our Pilot Studies. They help to illustrate use of the guideline principles.

The guidelines first help to determine **what information is relevant** to the study and how it may be used in creating the study design. These steps include the following:

- determining the study purpose,
- understanding the project resources, and
- understanding the physical characteristics of the site.

We provide considerations for **selecting the field parameters** for measurement and **selecting instrumentation,** based on the study purpose and scope. We then provide guidance in how to integrate this information to develop a exposure-relevant strategy for the study design.

The concept of the "microenvironment" is suggested as the basis for a **strategy to integrate magnetic-field information with occupant information** in order to assure that the measurements most efficiently provide data relevant to exposure. The suggested strategy is two-tiered:

1) first, gather site-wide activity and source data;

2) then, use this data to determine the appropriate focused, or intensive, measurements to perform in the areas of most interest.

The guidelines for **collecting the data** are based on this strategy. Steps are outlined for developing the study strategy into a **written protocol,** and producing the appropriate **forms** for data collection. We've highlighted techniques and **considerations** for data collection in each task group, including the following:

- identifying magnetic-field sources;
- gathering activity-pattern data;
- gathering non-magnetic-field data;
- planning intensive magnetic-field data collection based on identifying the micro-environments with activities and sources of most interest; and
- gathering general and intensive magnetic-field data.

Finally, **quality assurance, data management**, and **data analysis and reporting** techniques are discussed in order to assure that the information gathered is optimally maintained and communicated. We have also included information for developing the data in a format acceptable for the RAPID EMF Database.

1.4 Conclusion

Our purpose in developing these guidelines was to provide flexible, widely applicable methods for performing exposure-relevant magnetic-field measurements using good engineering principles. Your purpose in using these guidelines should be to produce a targeted, efficient, and useful study that collects precisely the data you need, and analyzes and reports the data appropriately for your study goals. We suggest that you review each section of the guidelines and take notes on the points that apply to your goals and scope of study. Then refer to the tables, sample forms, and documents to use as templates to help you structure the process and details for your own study.

Finally, the companion documents, *Guidelines for Source Characterization* and *Guidelines for EMF Personal Exposure Measurements*, will provide relevant information from a correlated perspective for gathering information within your own study.

SECTION 2: DEVELOPING THE BASIC STUDY STRATEGY

To develop a responsive protocol for performing magnetic-field measurements in a given environment, you should first develop a study strategy. The magnetic-field environment can be complex; to gather all spatial and temporal information about all magnetic-field characteristics in a given area of possible exposure would be an immeasurable task. Outlining a strategy to best characterize field exposures within an environment will assist in limiting and optimizing the measurement tasks.

Developing the basic study strategy requires the following seven steps (keyed to sub-sections):

2.1. Determining and documenting the study purpose

2.2. Determining the environment classification

2.3. Determining the project resources

2.4. Reviewing the physical characteristics of the environment

2.5. Selecting field parameters for measurement

2.6. Selecting instrumentation

2.7 Developing the measurement strategy.

These steps are in many ways mutually dependent. For example, you might select *field parameters* based wholly on what *instrumentation* is currently available, because *project resources* for other instrumentation are limited. If that situation changes, you will modify your strategy. Thus the strategy, and the decisions made, will continue to evolve throughout the development process.

This development process is enhanced by good documentation of the information gathered. As you develop the framework, maintain an outline of the information specific to your study that is relevant to its design. As that information expands and your strategy unfolds, make and modify your decisions. Documenting the rationale behind each decision point will enable you to evaluate whether it meets the study goals, and to target study strategy areas that need more work.

2.1 Determining and Documenting the Study Purpose

A statement of study purpose should be developed and understood by both the investigators and the party requesting the measurements (the study sponsor, customer, or client). This task will help ensure that the project goals are agreed upon and accomplished. It will also help ensure that the study is designed such that each task is optimized to provide the desired product.

The statement of purpose is the key to the shape and success of the study. The statement should answer the following five questions:

1. What is the goal of the study?
2. Who is the audience?
3. What circumstances initiated the study?
4. What is the desired output of the study?
5. How will the final data be used?

Table 2.1, below, provides typical responses to these questions.

TABLE 2.1
TYPICAL RESPONSES TO QUESTIONS OF STUDY PURPOSE

QUESTIONS	EXAMPLES
What is the goal of the study?	• to provide surrogate exposure data for an epidemiology study • to provide base information for public decision-making • to generally characterize an environment of interest • to compare and evaluate methods of exposure assessment • to determine sources of interference and assess methods of field management
Who is the audience?	• the client only • a utility customer • public document, such as an Environmental Impact Report • employees at a worksite • users of a database • the epidemiology researcher
What circumstances initiated the study?	• illness • general health concern • suspected areas or sources of elevated magnetic fields • observed magnetic-field interference of VDT or other equipment • research program: epidemiology or other
What is the desired output of the study?	• bulk measurement data for database or research • documentation describing the environment characteristics • identification of previously unknown source • health hazards evaluation report • assessment of field management methods
How will the final data be used?	• to communicate an understanding of field levels in an environment • to provide environmental field information for an epidemiological study • for incorporation into a database • to identify sources of elevated fields • as a basis for reviewing field management options • to assure compliance with exposure standards or guidelines

When answers to these questions have been thoroughly explored, you will have determined the scope of the study. It is important that the statement of purpose — including answers to all five questions — be documented. That written statement provides the basis for all actions, as well as a checkpoint for discussions between the investigators and the client.

2.2 Determining the Environment Classification

Once the study purpose is established, you should acknowledge what type of environment will be investigated. This step helps focus the study, and assists in directing a literature review to studies of similar environments.

A reference for classifying environment type is the Environmental Classification Table, a categorized listing of environments where the population spends its time. Appendix A.5 contains a description of the table development; the full table is included as Table A.3. It is logically organized in environmental groups, environments, and sub-environments. Each environment has been assigned a unique reference code number that corresponds to, or parallels, Standard Industrial Classification code numbers for establishments. The environments have been categorized into nine environment groups based on similar uses, on occupancy by similar groups of people, and, to some extent, on similar expected magnetic-field exposures, as follows:

- Residential
- School
- Transportation and Public Utilities (Non-electric)
- Medical Services
- Agricultural
- Industrial
- Commercial Office
- Trade and Service
- Electrical Generation, Transmission, and Distribution.

The table is comprehensive and easy to use. With your purpose established, you can quickly and easily locate the environment of interest and its code number in the Environmental Classification Table.

Subenvironments have also been included for identification and stratification of environments into subset areas with similar qualities. For example, "Office" may be a sub-environment found in an industrial environment, a commercial office building, or a school.

We suggest determining and documenting the classification of the environment you are studying for the following reasons:

- Acknowledgement of the environment classification, and the subenvironments and features present, will assist you in focusing your study development criteria on the environment's properties.
- By comparing your subject environment with other environments in the group, you may locate documentation of study methods used in past research for similar environments, and incorporate those appropriate methods in your own study design.
- Wide use of the Environment Classification Table, particularly with respect to the RAPID EMF Database, will allow codification and stratification helpful for meta-analysis and other data review in the future.

***P.S.:** When we carried out this step for the pilot studies, their environments were classified as follows:*

Study Subject	*Environmental Group*	*Environment*	*Code Number*	*Subenvironment Classifications*	
Day Care Center	*School*	*Child Day Care Center*	*8292*	*A-Classroom*	*W-Yard*
Metal Fabrication Shop	*Industrial*	*Metal Fabrication Plant*	*3400*	*C-Locker Room* *H-Welding Area* *T-Break Room* *W-Yard*	*E-Production (3 areas)* *I-Machining Area* *V-Repair Shop* *X-Office (3 areas)*
Grocery Outlet	*Trade and Services*	*Food Store*	*5400*	*A-Merchandise Area* *C-Refrigerated Area* *T-Mechanical Area* *X-Office*	*B-Cash Register Area* *S-Stock Room* *U-Shipping/Loading*

2.3 Determining the Project Resources

Environment-specific measurement studies will almost always be limited by project resources — both financial and time resources — of the client, investigator, and subject. In developing the study framework, the following resources should be assessed:

- The project's financial resources
- Investigator's staff availability
- Instrumentation availability
- Available time for study completion
- Site time constraints: e.g., site informant availability and permitted measurement times.

We suggest that you use the following rule-of-thumb. The appropriate level of project effort is a balance between cost and incremental benefit, and what the "market will bear." Experience has shown that a team of two-to-three technicians may spend two days performing field work to develop quality data and a reasonable portrait of the exposure characteristics in a typical large environment (e.g., a school or a mid-size industrial site). Residences and small, simple environments would require less time and staff; larger industrial sites or large medical facilities would require more time. At some time-threshold, additional time spent in the field will reap only marginal benefits. If a standard protocol is used for a multi-site study, efficiencies may increase.

Analysis and documentation must be considered a substantial portion of the allotted resources. For a complete stand-alone site study, the analysis and documentation may require 100%-200% of the resources allocated to field work. Analysis resources will decrease for multi-site studies or other platforms in which specific protocols are used and/or specific data will be reported.

2.4 Reviewing the Physical Characteristics of the Environment

Some preliminary information on the environment's sources and characteristics will highlight important features that should be considered in the measurement plan. Investigators can gather "early" information via initial phone calls or visual drive-by inspections. You can also forward a questionnaire to the site informant prior to the study for more complete preliminary information (see Appendix C.2 for a sample questionnaire). This task should include a review of the environment characteristics presented in Table 2.2.

TABLE 2.2
SAMPLE PRELIMINARY INFORMATION ABOUT AN ENVIRONMENT'S CHARACTERISTICS

CHARACTERISTIC	POTENTIAL INFORMATION
Classification of environment	Gives general indications of the sources present and the activity patterns expected.
Size of environment	Suggests the best methods of performing source identification. For example, in a very large environment, area mapping is usually most efficient, and instrument portability will be important.
Age of environment	Indicates the type of interior wiring, and the probability of net currents from retrofitted electrical systems.
Construction type	Points to the locations of wiring and electrical system sources. Also, a multi-story building may require additional investigation to determine sources on contiguous floor to the area of interest.
Number of sources	Indicates the number of microenvironments that might be identified at the site for characterization.
Types of sources	Gives clues to special field characteristics that might be expected, such as high harmonics, transients, or spatial and temporal variation. This information will influence the instrumentation selection.
Number of people	Indicates the number of microenvironments that might be identified at the site for characterization, and how much detail on activity patterns may be collected.
Mobility of people	Suggests the type of activity-pattern data that will be collected.
Operating hours	Indicates the appropriate time of the day/week to perform measurements.

> ***P.S.*** *Preliminary environment information was gathered in the pilot studies via telephone conversations and/or a pre-study questionnaire. Knowledge of the site sizes and the numbers of occupants gave indications of the magnitude of the field work. The operating hours provided the window of time during which the study should be performed. At the metal fabrication plant, knowledge of the extent of welding processes suggested that measurements should be designed to gather harmonic and transient information. Because the daycare center was in a multi-use inner-city building, it was understood that sources contiguous to the site could be important — particularly because few or no major sources were expected within the site.*
>
> *Perhaps the most important fact not gathered with the preliminary environment information was the mobility of the people and equipment within the metal fabrication. The constant relocation of all of the processes within the plant made the activity-pattern data and source location data extremely difficult to document. Early knowledge of this would have facilitated project planning and better streamlined the field tasks.*

2.5 Selecting Field Parameters for Measurement

The characteristics of magnetic fields in any given environment include the field strength, frequency components, phase angles, polarization, orientation, transient events, and spatial and temporal distribution. (Definitions of common magnetic-field parameters are described in Appendix D.) The root-mean-square (rms) measurement of the ac magnetic-field magnitude has been the focus of most environment-specific measurements performed to date. However, health research has not determined what, if any, characteristics of magnetic-field exposure might be biologically significant. The extensive research on the ac magnetic-field magnitude, as measured by rms, has failed to prove a correlation with bioeffects. The continuing quest for a biological correlation suggests that the list of parameters reviewed for measurement should be expanded. **Because the dose metrics of magnetic-field exposure have not been defined, information on multiple parameters is desirable.**

Gathering data on an extended list requires more, and more substantial, instrumentation than does simply performing rms measurements. To date, this data cannot be gathered in PE assessment, because it is not practical to burden a subject with effectively non-portable meters. Both environment-specific measurements and source characterizations offer the researcher test conditions that are more stationary, so that less portable equipment can be used, the source operations may be controlled, and the location of the sources relative to the instrumentation can be accurately determined.

Table 2.3 lists field parameters that may be considered for measurement, and describes correlated bio-mechanisms and instrumentation requirements. In determining what characteristics of magnetic fields should be included in the measurement plan, you should consider the following elements (keyed to sub-sections):

- The purpose of the study
- Physical characteristics of the site
- Plausibility of bio-effects
- Practicality of measurement and available project resources
- The continuing practice of performing measurements of rms ac field magnitude.

TABLE 2.3
SELECTED MAGNETIC-FIELD PARAMETERS WITH REFERENCE TO BIOLOGICAL GROUP AND INSTRUMENTATION REQUIREMENTS

Specific Measure	Applicable Research Areas				Equipment Available									
	Resonances	Coherence-Intermittency	Induced Currents	Magnetic Moment	DC Survey Meter	Broadband Survey Meter	Narrowband Survey Meter	Single-Axis RMS Recorder	Three-Axis RMS Recorder	Single-sensor Wave Capture	Multi-sensor Wave Capture	Transient Meter	Transient Wave Capture	Not Fully Designed
AC-DC Angle	x			x	x					x	x			
AC-DC Parallel Magnitude	x			x	x					x	x			
AC-DC Perpendicular Magnitude	x			x	x					x	x			
AC RMS						x	x	x	x	x	x			
Analog AC RMS						x	x	x	x					
Coherency Index		x												x
DC	x			x	x					x	x			
Harmonic Magnitude	x	x	x	x			x			x	x			
Harmonic Phase	x	x		x						x	x			
Intermittency Index		x												x
Low Frequency RMS			x			x		x	x	x	x		x	
Maximum Spatial Component	x	x		x						x	x			
Maximum Spatial Phase	x	x		x						x	x			
Minimum Spatial Component	x	x		x						x	x			
Minimum Spatial Phase	x	x		x						x	x			
Peak Magnitude			x	x						x	x	x	x	
Peak Rate-of-Change			x							x	x	x	x	
Peak Resultant			x	x						x	x		x	
Peak-to-Peak Magnitude			x	x						x	x		x	
Polarization	x	x		x				x		x	x			
Rate-of-Change Intermittency		x	x									x	x	x
Resonance Indices	x			x										x
Resultant	x	x		x		x	x	x	x	x	x			
Transient Indices of Rise Time, Over-shoot, Settling Time, Natural Frequency			x										x	x
Transient Peak Rate-of-Change			x									x	x	x
Very-Low-Frequency RMS			x			x		x	x		x		x	

Source: *Recommendations for Guidelines for Source Measurements*, Electric Research & Management, Inc., May, 1997.

2.5.1 Considering the Purpose of the Study

A review of the documented study purpose will highlight parameters appropriate to include in the measurement plan. The magnetic-field parameters selected should be consistent with the project goals. For example:

- The purpose of an epidemiology study may be to **evaluate** a specific mechanism hypothesis; the parameters measured should include all those correlated with the hypothesis of interest.
- A study performed to **assure compliance** with exposure standards should incorporate those magnetic-field parameters on which the standards are based.
- A study to **repeat or compare** the data collection of a prior study should, as a minimum, repeat the measurement of the field parameters of that study.
- A study performed to **communicate an understanding** of magnetic fields to a group of employees should include measurement of field magnitude because, presently, magnitude is the parameter most familiar to the general public.

2.5.2 Considering the Physical Characteristics of the Site

Some advance knowledge of the environment's sources and characteristics will highlight parameters that should be considered for measurement (see Section 2.4). You should review expected sources in the environment and compare them with measurements performed in previous studies to assess the likelihood of a presence of specific characteristics. For example:

- A frequency spectrum will be of interest in an environment containing variable-frequency-controlled drive motors.
- Harmonic content may be of interest near devices such as ac-to-dc converters.
- Non-harmonic frequencies of power frequencies have been shown to be of interest in transportation technologies.

2.5.3 Considering the Plausibility of Bio-effects

Many magnetic-field measurements are performed because there is concern over potential health impacts of magnetic fields. Yet, uncertainty exists as to which, if any, of the magnetic-field parameters might have a bio-effect. Suggestion for the capability of certain parameters to affect human health is summarized in Appendix A.4. This includes: biological studies and epidemiology studies; laboratory studies of interaction mechanisms between magnetic fields and biological systems; and Federal Drug Administration approval of electromagnetic medical devices for clinical treatment and therapy.

The preceding Table 2.3 presents a list of magnetic-field parameters, and identifies hypothetical biological mechanisms with which each parameter may be correlated. These mechanisms include: ion parametric resonance, magnetic-moment effects, coherence, induced currents, and transients. However, even with guidance from the study purpose or other elements of the study framework, the researcher can still only use his or her best judgement to select parameters in a frequency of interest, because the appropriate metrics have not yet been ascertained. We recommend that, whenever possible, data be collected in waveform so that if, in the future, research points to specific biological mechanisms and metrics, raw waveform data can be reanalyzed accordingly.

2.5.4 Considering the Practicality of Measurement and Available Project Resources

The option to measure certain field parameters may be minimized or eliminated by the type and number of instruments available, as well as by general time constraints. Note that these instruments are described in Section 2.6, following.

Instrumentation Type. No one meter is best suited to perform all tasks. Survey and/or recording rms magnetic flux density meters are more convenient for field mobility, scoping measurements, and large-area data collection. However, waveform capture systems provide the greatest flexibility in the selection of field parameters for measurement.

Unfortunately, the selection of instrumentation is often limited to what is on hand. If only rms magnetic flux density meters are available, only field magnitude and correlated variability can be measured. Unless the researcher is assured that only one frequency field exists in the environment, the interpretation of the magnitude data will be limited. The rms instrumentation can be supplemented by oscilloscopes or other equipment to expand the information collected.

Quantity of Instrumentation. The measurement of some parameters may also be limited by the number of available meters. Long-term and transient data collection requires that a meter be stationed at a single location for a designated period of time. In a highly complicated magnetic-field environment, instrumentation may not be available to station at a representative set of locations, and the researcher must prioritize the locations, the sample period, and/or the selected parameters.

Time Constraints. Temporal data collection is a time-consuming (and thus costly) method of measurement. Again, resources may be limited. In order to analyze ac- or direct current (dc)-field temporal variability and to capture transients, instrumentation must be committed for the period of the sample, and staff is tied to the setup and retrieval tasks. In the context of the purpose of the study and the physical characteristics of the site, the researcher must carefully evaluate and optimize the sample period (such as an 8-hour day, 24-hour day, or a short series of 60-second duty cycles) for collecting data on the temporal characteristics of interest.

The portability and recording features of data-collection instrumentation are also of note. RMS magnetic flux density meters, particularly in use with a mapping wheel, may be used to collect data over a large area in a short period of time, but only for field magnitude, and perhaps some frequency band information. If waveform capture is planned within strict time constraints, a commercial waveform system that collects, records, and analyzes data may be used to expedite the measurement process and expand the possibilities in parameter selection. Oscilloscopes and digital recorders can prove cumbersome and time-consuming.

2.5.5 The Continuing Practice of Performing RMS Magnetic Flux Density Measurements

Despite the lack of biological evidence correlating magnetic-field magnitude with health effects, ac-rms magnitude continues to be a focus of environment-specific measurements. The measurement of ac magnitude has the following benefits:

- The instrumentation is widely available and easy to use.
- The metrics related to magnitude are physically understood by the research and health community and comprehended by the general public, while other parameters are less so.
- The metric has been the focus of most previous studies, and collection of ac magnitude data will allow comparison between studies. AC field magnitude will continue to be the focus in PE measurements, given the instrumentation/portability constraints involved in "wearing" a meter.
- Because ac-magnitude measurements are easy to perform, they are a valuable tool in focusing other measurements to the areas of most interest. Areas of elevated fields determined using rms measurements will, to some extent, lead the researcher to sources of interest with respect to other parameters. Once these areas are identified and assessed for exposure-relevancy, more intense field characterization may take place. However, this practice does not ensure that all of the exposure-relevant areas of interest will be identified.

In addition, the ac magnitude will continue to be examined because the lack of understanding of the definition of "dose" of magnetic-field exposure leads both the research community and public to the default definition that "less is better" (albeit without any biological substantiation).

> ***P.S. Field Parameter Selection:*** *The pilot studies gathered data in a two-tiered approach. First tier: AC magnitude in the x, y, and z directions was measured over a large area and near many sources. This parameter was chosen because the ease of performing ac magnitude measurements with a three-axis recording meter allowed data collection over a large area. The ac magnitude information provided indications of the locations of elevated fields in a frequency range set by the instrumentation. Second tier: Measurements focused on the exposure-relevant areas of the sites where sources of fields had been identified. At carefully selected exposure-relevant locations, a waveform capture system was used to gather "focused" information about the simultaneous ac- and dc- field magnitudes in frequencies of interest, orientation, polarization, temporal variability, and total harmonic distortion. At selected locations, long-term measurements were performed.*
>
> *Although using a two-tiered system allows the researcher to focus on the exposure-relevant areas, it is acknowledged that relevant dc fields, high-frequency fields, and intermittent and transient events can remain unidentified in the first tier, and therefore ignored in the second-tier measurements.*

2.6 Selecting Study Instrumentation

2.6.1 Background

The availability of instrumentation has evolved with epidemiological and biological research and hypotheses for a biological mechanism. Early studies were performed using single-axis magnetic flux density meters. In some studies, oscilloscopes and other instruments were carried into the field to gather frequency and other waveform data. Continuing research into the correlation between rms fields and health effects spurred the development of three-axis recording meters for better ease and accuracy of rms measurements, and for use in PE assessments.

The most recent, and most sophisticated, instrument employed is the commercially available waveform capture system, offering advantages in being able to highlight other magnetic-field parameters. Waveform capture systems, magnetic flux density meters, and other specialized instrumentation are discussed below.

2.6.2 Factors in Selecting the Appropriate Instrumentation

It is likely that, in any study performed in response to health concerns, magnetic-field parameters with potential biological significance will be of interest to the investigator. Waveform capture is the only sufficient method of collecting the necessary data to quantify field conditions for evaluation of the interaction mechanisms discussed in Table 2.3. Environment-specific measurements offer the opportunity to study magnetic-field characteristics to an extent not presently possible in PE measurements, where an instrument must be conveniently worn.

However, no one meter is best suited to perform all tasks. While waveform capture systems are most appropriate for gathering complete data at selected locations, survey and/or recording rms magnetic flux density meters are more convenient for performing scoping measurements, for field mobility, and for gathering field-magnitude information over a large area. Table 2.4 compares instrumentation types; Table 2.5 presents a sample list of commercially available meters.

TABLE 2.4
GENERAL CHARACTERISTICS OF INSTRUMENT TYPES
Page 1 of 2

Meter-type	Primary Uses	Field Parameters Measured	Data-collection Features	Cost	Ease of Use	Data recording	Portability
Computer-based waveform measurement systems	Spot measurements Mapping Long-term Waveform capture Transient capture	DC Field Magnitude (x,y,z, resultant) AC Field Magnitude at each frequency of interest (x,y,z, resultant) AC Field Polarization AC-DC Orientation Peak-to-Peak	Full waveform capture Highest quantification content in data collection	Very High	Use of systems requires higher technical understanding The vast quantities of data collected are more difficult to manage (at least 64X bytes for an average spot measurement vs. X bytes with a three-axis ac-field recording meter	FFT and digitized recording features	Less portable than typical rms meters 12 lb. "portable" commercially system available
Three-axis ac-field recording rms meter	Personal exposure Spot measurements Mapping Long-term Exploratory measurements	AC Field Magnitude (x,y,z axes, resultant) in a bandwidth dependent upon model Some models can provide harmonic content	Many have software for mapping capabilities if used with mapping wheel.	Medium-High	Almost no instruction required for accurate resultant measurements More difficult to use for exploratory measurements ("sniffing") than single-axis meters because of delay between readouts	Recording features	Small, portable
Three-axis cumulative exposure meter with display	Personal exposure Spot Measurements Exploratroy measurements Long-term for cumulative info	AC Field Magnitude (x,y,z axes, resultant) in a bandwidth dependent upon model	Most frequently used for personal exposure measurements	Medium	Almost no instruction required for accurate resultant measurements	Records accumulated data, rather than individual samples	Small, portable

TABLE 2.4
GENERAL CHARACTERISTICS OF INSTRUMENT TYPES
Page 2 of 2

Meter-type	Primary Uses	Field Parameters Measured	Data-collection Features	Cost	Ease of Use	Data recording	Portability
Three-axis ac-field survey meter	Spot measurements Exploratory measurements	AC-Field Magnitude (x,y,z axes, resultant) in a bandwidth dependent upon model Some models can provide total harmonic content	Similar to three-axis recording meters, with recording capabilities	Medium	Almost no instruction required for accurate resultant measurement More difficult to use for exploratory measurements ("sniffing") than single-axis meters because of delay between readouts	No recording feature	Small, portable
Single-axis ac-field survey meter	Exploratory measurements Spot measurements	AC Field Magnitude in one direction, in a bandwidth dependant upon model Some models can be switched from flat to linear response to provide rough data on presence of harmonics	Can use to determine polarization Easy determination of direction of field Can be used with an audio attachment for exploratory measurements	Low	Continuous readout provides easy source investigation Must "find" maximum field by properly rotating the meter, or measure in three directions to calculate the resultant field	No recording feature	Small, portable

TABLE 2.5
COMMERCIALLY AVAILABLE MAGNETIC-FIELD INSTRUMENTATION

COMPUTER-BASED WAVEFORM MEASUREMENT SYSTEMS	
Multiwave System II	Electric Research & Management, Inc., State College, PA (814) 238-6887
3-AXIS RECORDING METERS	
EMDEX II	Enertech Consultants, Campbell, CA, (408) 866-7266
EMDEX Lite	Enertech Consultants, Campbell, CA, (408) 866-7266
Field Star 1000	Dexsil Corporation, Hamden CT, (208) 288-3509
EMDEX-C	Electric Field Measurement Co., W. Stockbridge, MA (413) 637-1929
EFA-2	Wandel & Goltermann, Research Triangle Park, NC (919) 941-5730
MFG 10	Combinova AB, Bromma, Sweden, 46 (0)8-627 93 10 U.S. Rep: Ergonomics, Southampton, PA (215) 357-5124
3-AXIS CUMULATIVE EXPOSURE METERS	
EMDEX Mate	Enertech Consultants, Campbell, CA, (408) 866-7266
3-AXIS SURVEY METERS	
Combinova FD1	Combinova AB, Bromma, Sweden, 46 (0)8-627 93 10 U.S. Rep: Ergonomics, Southampton, PA (215) 357-5124
Holaday HI3627	Holaday Industries, Eden Prairie, MN (612) 934-4920
Magnum 310	Dexsil Corporation, Hamden, CT, (208) 288-3509
Model 70	Teslatronics, Inc., Orlando, FL, (407) 481-0160
EMDEX Snap	Enertech Consultants, Campbell, CA, (408) 866-7266
EFA-1	Wandel & Goltermann, Research Triangle Park, NC (919) 941-5730
SINGLE-AXIS SURVEY METERS	
Holaday 3624	Holaday Industries, Eden Prairie, MN (612) 934-4920
EFM 110-113 Series	Electric Field Measurement Co., W. Stockbridge, MA (413) 637-1929
FGM-3D1	Walker Scientific Inc., Worchester, MA (508) 852-3674
Monitor 42B1	Monitor Industries, Boulder, CO (303) 442-3773
ELF 66D	Walker Scientific Inc., Worchester, MA (508) 852-3674
MSI Model 25	Magnetic Sciences International, Tucson, AZ (602) 822-2355
Bell Model 4060	F.W. Bell, Orlando, FL (407) 678-6900
DC FIELD METERS	
Bartington MAG-03	GMW, Redwood City, CA (650) 802-8292
FGM-3D1	Walker Scientific, Inc., Worchester MA (508) 852-3674

Instrumentation should be selected based on measurement and memory capabilities suited to the study goals, as well as on efficiency, reliability, availability, convenience, and price. However, we acknowledge that, more frequently, the instrumentation available is what is used. Magnetic flux density meters are much more readily available because of the research attention on field magnitude over the past decade, and because the cost of a waveform capture system makes it prohibitively expensive for many applications. The next sections detail the nature and functions of the instruments you may consider for your project.

2.6.3 Waveform Capture Systems

Multiwave System II. At the time of this writing, the Multiwave System II, manufactured by Electric Research and Management, Inc., is the only commercially available portable waveform capture system. The system has a frequency bandwidth of dc to 3 kilohertz (kHz). The standard sensor head is a 3-axis fluxgate with a maximum per-axis range of 10 Gauss. The display unit can be programmed to read out dc magnitude and components, ac full bandwidth magnitude and components, power-frequency magnitude and components, and harmonic magnitude and components. The complete waveform sensed by each axis of the fluxgate is stored for later analysis. The unit can be used for spot measurements, timed sampling, event triggering, or area mapping. Software supplied with the unit allows for rapid review of waveforms captured on a notebook computer from floppy disks supplied by the System, and allows programming to determine the calculations to be performed on the data.

Although the Multiwave System II is an irreplaceable instrument for gathering information on a range of field parameters, complexity, convenience, and cost have limited its use in routine EMF measurements. Where elementary operation of most rms meters requires minimal instruction, use of the Multiwave requires some level of preparation or training. Though considered "portable," the unit weighs 12 lbs., and approximates the size of two laptop computers. Additionally, the cost of this complex instrument prohibits most researchers, industrial hygienists, and utility employees from keeping one or more Multiwaves in their equipment inventory. The instruments are available for lease for short-term uses.

Other Waveform Measurement Systems. Researchers have been assembling waveform measurement systems for the past decade. Using commercially available probes, researchers have used Fast Fourier Transform (FFT) analyzers, spectrum analyzers, oscilloscopes, and digital tape recorders to document information about the waveforms and frequency content of the magnetic fields in the studied environment (Enk and Martin (1984), Stuchly and Lecuyer (1985), Stuchly and Lecuyer (1989), Dietrich et al. (1993), Feero and Dietrich (1994), Anger and Carlsson (1995), Berisha et al. (1995), Dietrich et al (1995b), Hansen et al. (1995), Hayashi et al. (1995), Linde et al. (1995), Thansandote et al. (1995)). Such instrumentation can be used to gather specific information:

- FFT analyzers may be used to calculate the frequency spectrum;
- Frequency spectrum analyzers may be used to obtain the amplitudes of the fundamental and harmonic components of the magnetic field;
- Digital audiotape recorders may be connected to sensors for continuous waveform recording; and
- Portable digital multi-meters may be used with single-axis coils to observe the derivative waveform of the magnetic field.

These types of instrumentation have two drawbacks: first, their non-portability (relative to rms meters and the portable Multiwave System II) complicates the measurement protocol; second, the investigator must be experienced in interpreting the data from such instrumentation — no software allows for a quantitative analysis and storage as is provided in the Multiwave. Nevertheless, these systems are capable of gathering data similar to that gathered by the Multiwave System II. For example, in Bowman (1992) pages 601-1 to 601-3, the methods for setting up and using such a system are discussed in a description of a strategy used for performing area measurements.

Digitizing waveform capture instrumentation (using a Multiwave System or other) has a definitive advantage: additional information can be extracted from digitized and recorded data in the future if it is determined what parameters of magnetic fields are correlated with biological mechanisms. Table 2.4 compares the attributes of a waveform capture system with those of magnetic flux density meters.

2.6.4 Magnetic Flux Density Meters

Magnetic flux density meters have the advantages of portability, simplicity, and price over waveform capture systems. The IEEE and other groups have addressed the selection and calibration of magnetic flux density meters in many articles (IEEE (1990a), IEEE (1990b), Patterson (1992), ANSI/IEEE (1994), IEEE (1994)). These sources should be referred to with respect to operational considerations and calibration methods of the meters. Hand-held magnetic flux density meters can be discussed in terms of four groups: single-axis "survey" meters, three-axis "survey" meters, cumulative exposure meters, and three-axis "recording" meters. Table 2.4 lists the attributes and primary uses of each meter type. Once the appropriate meter type is selected (considering study purpose, resources, site physical characteristics, and needed parameters), you should consider the features of the specific models. These features are discussed below.

Readout. Digital readouts are generally preferred over analog because numerical values are more quickly and accurately noted.

Frequency Range. Narrow-band (50- or 60-Hz) meters are frequently used by utility industry representatives for measurements in areas of utility facilities where the harmonic component of the field is assumed to be small. However, the harmonics are substantial in most industrial and residential settings. Measurements using a narrow-band instrument may be understated compared with a broadband ELF measurement in areas of high harmonics.

The frequency range of some meters includes frequencies as low as 5 Hz. (This threshold is in response to the Swedish measurement standard for VDT emissions.) These low frequencies can cause erroneous readings as the sensor coil moves through the earth's static field. The investigators must take care to minimize meter movement when using a meter with a low frequency threshold outside a stationary setting.

Flat vs. Linear Frequency Response. Roughly speaking, a measurement taken by a flat-response meter will equal the total of magnetic fields at all frequencies within the meter's frequency range. In a linear-response meter, the magnetic field response is weighted by the frequency; that is a 10 mG field at 100 kHz will give twice the meter response of a 100 mG at 50 Hz. The field calibration of a linear response meter is valid at only one frequency. Therefore, if you use a linear-response meter near a source with high harmonics, the field magnitude will be substantially overstated. A linear response is not desired, though it is prevalent among poor-quality single-axis meters.

Some meters include a switchable filter, which allows both flat- and linear-response readings. Using this feature provides a rough indication of the harmonic content.

Harmonic Information. Meters are readily available that will provide measurements in a frequency range as well as in narrow frequency bands (such as 60 Hz or 180 Hz). If harmonic content is of interest, and waveform capture systems are not available, then measurements made with both broadband response and narrow-band filters are useful.

Detector Type: True RMS vs. Average Sensing: True root-mean-square detectors determine magnetic flux densities such that harmonics in the field are correctly combined with the fundamental to give a true measure of the energy in the field regardless of the actual waveform of the field. Average detectors assume the waveform is sinusoidal, or very nearly so, and use a correction factor to give an equivalent rms value. In areas with strong harmonics, this can result in considerable error.

Mapping Capabilities. Some three-axis recording meters have incorporated software which, with a mapping wheel, will record the location in terms of x,y coordinates correlated with each measurement.

Battery Life and Storage. If you intend to use a recording meter to perform long-term measurements, you should consider the battery life and storage capabilities of the instrument. The EMDEX Lite made by Enertech Consultants, for example, is capable of storing up to 303 days of information at a sample interval of 20 minutes, using a lithium battery.

Location of Coils. In using any meter, the technician should understand the location of the coil within the meter, so that the appropriate distance from magnetic-field sources can be recorded. It is preferable that the three coils of a three-axis meter be positioned as close together as possible, so that the three vector components simultaneously measured have as nearly equal an origin as possible.

Accuracy. Most quality commercially available meters are accurate to within 5 percent. Sources of uncertainty in measurement usually are more of a function of field spatial and temporal variation than of meter accuracy. Accuracy within ±5 percent is normally sufficient. However, some meters may sacrifice accuracy for other attributes.

Size of the Coil. Sensitivity of a meter is a design feature where the size of the coil is just one of the parameters. However, for single-axis meters, a larger sensing coil can be useful in determining field direction because the plane of the coil is more readily observed by the user.

Magnetic-field Range. The magnetic-field range of meters varies, and must be considered to assure that the appropriate information is captured. Most meters have a range to 1 Gauss or more, which is sufficient for most non-industrial, non-utility environment measurements. If the study includes an environment where very high magnetic-field exposures are suspected, special high-field meters are available, with ranges of up to 120 Gauss. Note that these meters typically forfeit resolution for range, so they are not appropriate for use in low-field environments.

2.6.5 Other Instrumentation Useful in Field

In addition to magnetic flux density meters, auxiliary tools can enhance and/or expedite the data-collection process, and provide extraneous data associated with the magnetic-field characteristics of the site. Such tools include the following.

Mapping Wheels. The use of a mapping wheel with a three-axis magnetic flux density meter allows you to record field magnitude together with the corresponding location. A triggering device on the wheel prompts the execution of a measurement every foot (or other selected distance) along the path of the wheel. Turns in the wheel's path are recorded using a keypad. The magnitude and location information is combined to provide graphical information about the spatial variation of the field. The use of a wheel expedites the collection of magnitude data in large environments. Dexsil Corporation manufactures the VANA wheel for use with the Field Star 1000 meter; Enertech Consultants manufactures the LINDA wheel to be used with the EMDEX II. A wheel is also available for use with the Multiwave System II waveform capture system. (These manufacturers are noted in Table 2.5.)

Ammeters. Ammeters can be used to measure the current on interior wiring or grounding systems, in order to identify and quantify sources of net currents and ground currents. They are readily available from Fluke, Hewlett Packard, and other instrumentation firms. The jaw size appropriate for clamping around piping and/or for clamping around wiring in a small junction box should be considered when selecting an ammeter. Both the EMDEX II and Multiwave System II can be equipped to read clamp-on ammeters.

Audio Attachments. Audio attachments can be purchased or home-made for single-axis meters. The volume of the tone or buzz from the attachment will increase as the measured field increases, providing assistance when attempting to locate magnetic-field sources. Use of this attachment can be quite disturbing to the environment's occupants, however, so headphones are frequently used to contain the sound.

Finally, technicians can carry a stock of supplies into the field for collecting and documenting environment data. Table 2.6 presents a Field Kit Checklist of useful field supplies.

P.S. Instrumentation. *In the project pilot studies, the investigator used three-axis meters in survey and/or mapping modes to locate sources and areas of elevated fields. The Multiwave System II was used to perform waveform capture measurements at selected exposure-relevant locations for the main body of reported data. The Multiwave System II and EMDEX II were stationed to collect long-term data.*

In two of the three pilot studies, the Field Star 1000 with a 60-Hz narrow-band frequency response was used for the area mapping and source location. In hindsight, a narrow-band instrument was a poor choice for the industrial and commercial environments where extensive harmonics were suspected. AC magnitude in the mapping process was understated because of filtering to 60 Hz, and sources of high harmonic fields might have been missed.

TABLE 2.6
FIELD KIT CHECKLIST (LIST OF POTENTIAL FIELD SUPPLIES)

Primary Instrumentation

_____ Waveform capture system
_____ Three-axis recording rms meters
_____ Three-axis survey rms meters
_____ Single-axis survey rms meters
_____ DC field meters

Waveform Instrumentation

_____ Oscilloscopes
_____ FFT analyzers
_____ Spectrum analyzers
_____ Digital tape recorders
_____ Digital multi-meters

Auxiliary Instrumentation

_____ Ammeter
_____ Mapping wheels
_____ Audio attachments

Instrumentation Supplies

_____ Downloading equipment for instrumentation (i.e., required cables, software, floppy disks, etc.)
_____ Extra batteries for instrumentation
_____ Instrumentation instruction manuals

Computer

_____ Notebook PC (fully charged)
_____ Backup disks
_____ Copies of instrumentation software

Documentation Supplies

_____ Portable computer
_____ Field forms/notebook
_____ Sample pre-filled data-collection forms
_____ Informational documents, such as Department of Energy brochure
_____ Drawings previously provided of site
_____ Copies of pre-visit site questionnaires and/or notes
_____ Field kit checklist
_____ Graph paper for sketches
_____ Clipboard
_____ Pens/pencils

Measurement Supplies

_____ Architect's scale
_____ Non-metallic measuring tape
_____ Measuring wheel
_____ Cable height meter

Recording Supplies

_____ Camera, film, extra battery
_____ Video camera, tapes, batteries
_____ Photograph log
_____ Dictaphone

2.7 Developing the Measurement Strategy Using the Micro-environment

The **measurement strategy** is a sub-set of the overall study strategy. It is the guidance of a decision-making process by which you will ultimately decide where, when, and how magnetic-field data will be collected. With some exceptions (e.g., heavily structured protocols for research data collection), **the final determination of where, when, and how measurements will be performed will not occur until other preliminary information is gathered in the field.** (This final determination is referred to herein as the measurement plan.) A solid measurement strategy will set the stage for making efficient, consistent decisions at that time.

It is vital to remember that magnetic-field measurement seeks *both* to characterize the environment and to facilitate an understanding of the exposure of the occupants of the space. Exposure to any parameter of magnetic field is a product of two factors: the locations and magnetic-field characteristics of *sources*, and the locations of the *occupants* with respect to those sources. Measurement strategies to date have generally been based on one of three concepts: 1) locating and characterizing sources: 2) taking spot measurements near occupants: or 3) mapping the environment using a profile wheel in conjunction with a recording instrument. These strategies may be deficient, in that either the locations of the sources, the locations of the occupants, or both, may not have been given sufficient consideration.

The collection of additional data under the expanded list of measurement parameters, however, can mean data overload and management complications. This increases the cost and complexity of performing a measurement and analyzing the data. This issue must be addressed by **designing the measurements to gather only the most exposure-relevant information based on the locations of people in relation to sources.** The carefully designed measurement plan will include the following:

- Locations of measurements: where measurements should be performed in order to gain the most information about the environment characteristics with respect to occupant exposure.

- Timing of measurements: times representative of typical use and activity, taking into account times convenient to the site occupants for measurement.
- Temporal measurements: any appropriate time-related measurements which will provide valuable information about the magnetic-field variability over time with respect to the occupants.

In relatively simple studies, you may be able to plan exposure-relevant measurements intuitively — for example, in a study of an environment with few sources and/or occupants, and a limited list of field parameters being assessed. Enhanced instrumentation capabilities also increase latitude in measurement planning; resultant ac field may be measured such that the magnetic-field data, the time of measurement, and the location of each measurement may be stored. Therefore, taking a broad series of measurements throughout the environment may be accomplished quickly and the data easily managed.

However, in more complicated environments or with additional field parameters, you must set up a strategy to make measurement decisions to ensure that fewer, higher quality, exposure-relevant measurements are selected. The tool for accomplishing the appropriate design is the use of the **"microenvironment"** as a base unit of area in a study: its boundaries are defined by the occupants' activity patterns and the field variation from sources affecting the area.

2.7.1 The Microenvironment Defined

For the purpose of environment-specific magnetic-field measurements, a microenvironment may be defined as follows:

> ***A portion of the environment defined by the homogeneity of occupancy or use and the homogeneity of the magnetic-field variability.***

Two sets of information are used to determine the microenvironment boundaries: information about the ***magnetic-field sources*** and information about ***activity patterns relative to the sources.*** The microenvironment boundaries may be thought of in terms of a transparency overlay of a map of the location patterns of occupants, and a map of one or more parameters of the magnetic fields surrounding sources. A simple example is shown in Figure 3.3. The variation in intensity at which the information on these two maps intersects will define the boundaries, and will highlight which microenvironments may deserve weighted attention in the measurement plan.

The microenvironment has been used as a unit of space in past exposure studies (Duan (1985), Navidi and Lurman (1995)), and has been used informally in many magnetic-field assessments. It is likely that you have developed measurement plans based on the microenvironment unit in the past. For example, you may have performed measurements in an office setting, selecting locations such as the following:

- "at an individual's desk" — an area defined by the long-term occupancy of one individual, with possible exposure from monitors or other sources;
- "in front of the copier" — defined by the short-term use by several people in a similar manner, and the elevated magnetic fields falling off quickly with distance from the copier;
- "at the table in the conference room" — defined by medium-term use of the occupants and a relatively constant magnetic-field level throughout the room.

The determination of the microenvironment boundaries is a subjective process, further described in Section 3.5.1.

2.7.2 Standard Structure for an Environment-specific Measurement Protocol

As noted above, the microenvironment is defined by ascertaining numbers of people and locations where those people spend time in relation to the environment and its identified magnetic-field sources. The microenvironment definition allows a planned, weighted attention to exposure-relevant measurement points. The appropriate weight, or focus, may be determined based on the extent of use by occupants and the extent of magnetic-field variability. For example: more densely spaced points of measurement are required to characterize the environment in front of the copier (a microenvironment in which greater total time is spent and where appliances are present) than in a large room affected by few constant sources, such as perhaps a conference room. A short-term temporal measurement with a high sample rate would provide variance information in a microenvironment influenced by a copier operation; no temporal data might be required in the conference room influenced only by constant usage of lights. The study resources can thus be optimized by weighting these two areas so that quality, exposure-relevant measurements are selected that together best characterize the overall site.

Using the microenvironment as the base sampling unit, you can break the performance of the magnetic-field characterization into a four-step process:

1. **Gather the basic information about sources, people and other site information,** by visual inspection, interview/questionnaire, and, for all but the simplest of studies, preliminary magnetic-field measurements.

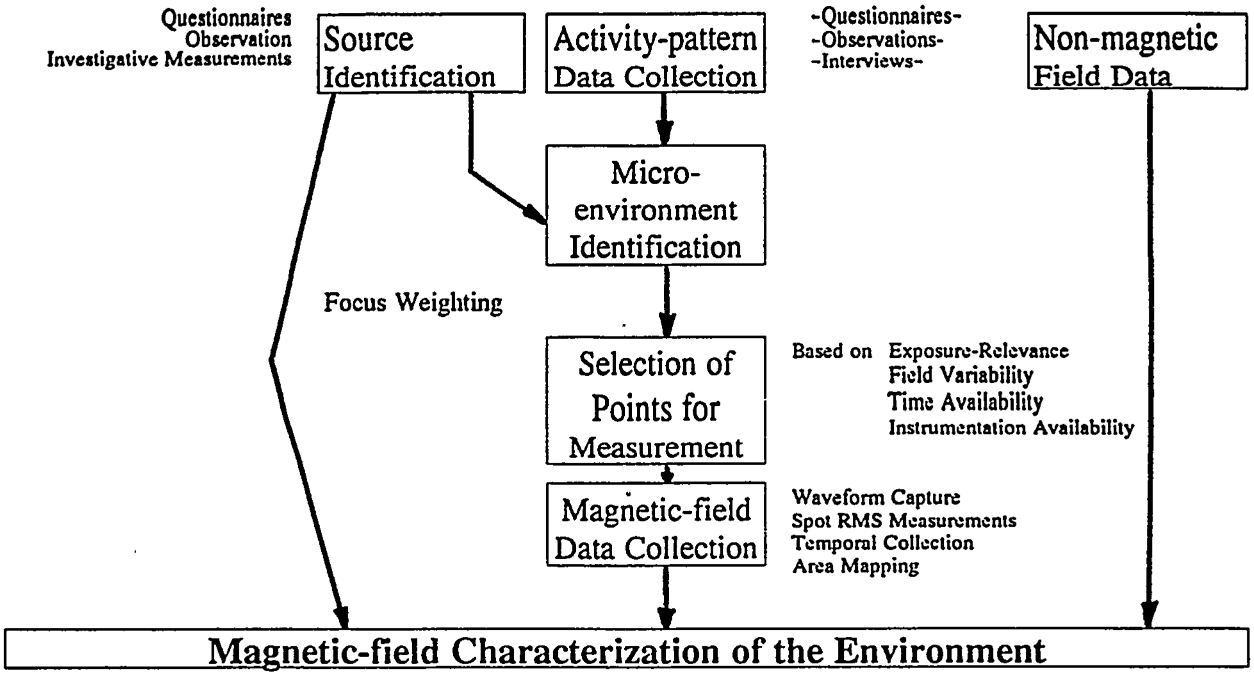
2. **Identify microenvironments**, using the basic information gathered.

3. **Weight the effort to be spent in each microenvironment** based on the extent of use and the variability of the magnetic-field parameters of interest, and select the locations of the spot and temporal measurements.

4. **Perform focused magnetic-field data collection**, concentrating the data-gathering effort according to the weighting defined in Step #3.

Step #1 creates a "First Tier" of data — base magnetic-field data and source and activity information that together paint a broad picture of the environment's characteristics. Step #4 creates the "Second Tier" of data — focused magnetic-field information on the exposure-relevant areas of the site. Both tiers are vital to the resulting magnetic-field characterization of the environment. Figure 2.1 illustrates the flow of information using this measurement plan.

FIGURE 2.1
FLOW OF DATA IN THE ENVIRONMENT-SPECIFIC MAGNETIC-FIELD MEASUREMENT PLAN



2.7.3 Structuring Your Data-Collection Plan

The effort put into each of the flow-chart steps will depend on the study's size and focus. Using the flow chart, a plan can be developed for any given environment, with any level of detail. Table 2.7 compares the data-collection plan for each step in a very simple survey versus a full large-environment characterization. Review these examples, following the flow chart of Figure 2.2. You may outline a draft structure for your own data collection, including the thoughts and tasks which may be involved in each structure step:

TABLE 2.7

EXAMPLES OF DATA-COLLECTION PLANS DEVELOPED FOR TWO ENVIRONMENT-SPECIFIC MAGNETIC-FIELD STUDIES

	Home Survey by Utility	Characterization of an Industrial Facility	Outline for Your Study
Source Identification	*Make a quick walk-through of the house and yard to identify location of power facilities and typical sources. Question homeowner about specific sources, and any source of special interest to him/her.*	*Send pre-visit facility questionnaires, for informant to identify sources. Observe and document on pre-supplied maps during initial walk-through. Perform investigative measurements using hand-held meter or mapping wheel.*	
Activity-pattern Data Collection	*Assume that this home is like most others: e.g., occupants sleep in the bedrooms, occupy the living area frequently, use appliances most frequently in the kitchen, etc. Clarify any assumptions w/homeowner as necessary.*	*Use questionnaires to informants or observation using pre-designed forms and maps.*	
Non-magnetic-field Data	*Observe, or question homeowner about age of home, type of wiring, or other info.*	*Use questionnaires to informants, observation using pre-designed forms, or outside data from maps, drawings, and utility engineers.*	
Microenvironment Identification	*Review notes about sources and uses to informally determine most exposure-relevant measurement points.*	*Compile and review information from activity-pattern maps and source identification maps. Develop sketches of the microenvironments. Confirm with notes and questionnaire responses.*	
Selection of Points for Measurement	*Per utility standard protocol, select center of rooms and corners of house. Choose other locations based on microenvironments of most interest, and as requested by homeowner.*	*Use a decision matrix identifying the occupancy and field types of each microenvironment in order to determine appropriate weighting (see Appendix C.9).*	
Magnetic-field Data Collection	*Use a hand-held rms meter to perform spot measurements at the selected locations.*	*Perform spot measurements using a waveform capture system at a sample rate appropriate to identify ultra-low frequency information. Station a meter to gather temporal data near a dominant source identified to fluctuate in time.*	

Having followed the guidelines through this Section 2, you have gathered information about:

- the study purpose
- the type of environment
- the project resources
- the physical characteristics of the environment
- the field parameters selected for measurement
- the instrumentation.

Based on this information, you have created an outline of the strategy and possible tasks appropriate for your own magnetic-field study. The process of performing each step of data collection is detailed in Section 3, Performing the Data Collection. Reviewing Section 3 will assist you in developing, documenting, and executing a data-collection protocol and measurement plan based on your strategy.

SECTION 3: PERFORMING THE DATA COLLECTION

The magnetic-field characteristics in a given environment cannot be properly described by a single measurement or series of measurements. A magnetic-field assessment must provide information about the exposure of the occupants in the environment, recognizing the many sources co-existing within a given space. Many factors, including the physical parameters of the environment; the locations and operations of the sources; the activity patterns of the occupants within the environment; and the spatial, temporal, frequency, and other properties of the magnetic fields, together paint a picture that characterizes the magnetic-field exposure. This section describes the **methods of data collection and the appropriate data to consider collecting.**

3.1 Developing the Data-collection Protocol

A protocol documents the tasks to be performed in an orderly fashion, according to the goals and resources and any set parameters required of the study. Creating a comprehensive plan for performing the data collection will help ensure that you meet your goals:

- collect the relevant information
- perform magnetic-field measurements most completely, efficiently and systematically
- minimize the disruption in the environment
- optimize the site contact's time.

3.1.1 Producing a Written Protocol

The importance of a written protocol cannot be overstated. In large data-collection projects, a written protocol is vital to assuring that standardized methods are being used. This is particularly true if data collection is being performed by more than one investigator. In any study, a written protocol helps to ensure that no study tasks are overlooked, and that you have accurately documented the study methods and results.

Performing the Data Collection

To produce a written protocol, we suggest you begin by outlining the tasks that will be required for collection of all study data. The remainder of Section 3 will help you determine those required tasks. Organize the tasks in a chronological sequence, and describe each task, including instrumentation, tools, and manpower, as clearly and succinctly as possible. When the protocol is drafted, it is important that it be tested in the field, preferably by a third party, ensuring that the instructions are succinct. Refinements to the protocol can then be identified and made prior to your study. (This also allows you the opportunity to ensure that the protocol and study strategy "work" within the parameters of your study.) The best sources of templates for producing a written protocol and ensuring that all tasks have been carefully described are protocols written for previous studies, including those listed in Section 5, References.

You may produce the written protocol in any of several forms. For instance, Figure 3.1 shows a protocol developed by an IEEE task force (IEEE (1993)) for use by utilities for performing standardized measurements at customers' residences. This very limited protocol performs only measurement of magnitude. Little consideration has been given to the exposure relevance of the data collected. But its succinct design provides for uniformity in measurement procedures, and ensures that the base required data is collected within any time restrictions placed on the technician; additional data may be collected as time and interest allow.

By contrast, Appendix C.1 is a sample of a checklist-style protocol. The protocol is divided into the time frames for the project: prior to the site visit, the initial study day, after the initial study day, and the focused measurement day. Its step-by-step style was designed to ensure that all data-collection tasks were performed within a limited period of time.

> ***P.S.** A check-list style protocol, similar to that in Appendix C-1, was used for all three pilot studies. The "outline" level of detail in this style was appropriate because the investigators were familiar with the protocol, and did not require explicit direction. Tasks were assigned in advance so that each technician understood his/her responsibilities. The action of checking off completed tasks helped to ensure that the study was fully completed within the project time constraints.*

FIGURE 3.1
SAMPLE MEASUREMENT PROTOCOL
Source: *A Protocol for Spot Measurements of Residential Power Frequency Magnetic Fields* (IEEE (1993)).

MEASUREMENT PROTOCOL

A sample data sheet and residential plan for recording spot measurements of the magnetic field are shown in Figure 1. Provision is made on the data sheet for indicating the address of the residence and important characteristics of the instrumentation that will be used, e.g., frequency response, accuracy, detector type (true rms, average-sensing rms, number of axes). When visiting a residence to perform measurements, the following procedures should be followed after initial contacts with occupants of the residence:

- All lights and appliances should be left as found.
- A sketch, roughly to scale, of the rooms and outside perimeter of the house should be prepared as indicated in Figure 1. A separate plan view should be prepared for each level of the residence. Electric utility equipment in close proximity to the residence may be indicated on the plan view.
- The information called for at the top of the data sheet (i.e., data, time of measurements, temperature, meter model, etc. should be recorded.
- All measurements should be performed at a height of about 1 m (39 inches or "waist high") above the floor (indoor measurements or ground (outdoor measurements). IN order to more clearly understand the measurement results, the occupants of the residence should be encouraged to observe the performance of the measurements.
- Spot measurements of the maximum magnetic field should be performed in at least three rooms (e.g., bedroom, family room, kitchen) frequently used by the occupants. Measurements should be of the ambient magnetic field near the center if each room away from appliances. The approximate location should be indicated on the plan view with a dot and number, and the field value should be recorded on the data sheet with the corresponding number (Fig.1). If fluctuations of the field reading occur during the measurements, an approximate average value over a 5-second interval may be recorded.

  Note: The resultant magnetic field is normally obtained directly with a field meter that employs a three-axis probe. However, a field meter with a single-axis probe can be used to measure the rms values of the three orthogonal spatial components in order to calculate the resultant magnetic field (see Section 3). To aid in this calculation, columns are provided on the data sheet for recording the rms values of the three orthogonal spatial field components. The z-component is normally in the vertical direction, and the x- and y-directions are arbitrarily chosen in the horizontal plane. Measurements of the resultant magnetic field with a single-axis probe may be expedited by using a platform and template to position the probe. This procedure can also reduce measurement "jitter" for those field meters that are sensitive to the motion of the probe in the earth's magnetic field and reduce operator error resulting form misalignment of the prober.

- Following the indoor measurements, spot measurements should be performed and recorded along the outside perimeter of the residence at roughly 3 m (10 feet) intervals beginning form a corner of the residence. A distance of about 1 m to 2 m (3 to 6 feet) should be maintained between the magnetic field probe and the outside wall of the building. It may be necessary to use more than one data sheet for the interior and exterior measurements. Outdoor perimeter measurements will in general not be possible for apartment buildings.
- Spot measurements should be repeated in three rooms where occupants spend significant amounts of time, following the outdoor measurements. These repeat measurements provide limited information on the short-term stability of the field vales.
- Upon completion of the above measurements, spot measurements should be performed and recorded at locations of interest to the occupants of the residence. The number of these measurements will be governed, in part, by available time. If measurements are requested near power lines. procedures in IEEE Std 644-1987 should be followed.
- Before leaving the residence, occupants should be informed that spot measurements represent a "snapshot"in time of the magnetic field level and do not provide information regarding its temporal variation. Similarly, it should be noted that spot measurements at the centers of rooms provide very limited information on the spatial variation of the field. Copies of the measurement results should be provided to the residents.

3.1.2 Outlining the Data-collection Methods

Under Section 2, you outlined your study strategy. Now you must determine the methods and tools to accomplish each of the data-collection tasks. Questionnaires, interviews, observations, and a variety of measurement techniques may be used to obtain the study data, which can be accumulated on collection forms or on magnetic media. Based on the parameters and resources of your study, outline the methods appropriate for each category of data. Table 3.1 shows examples of methods and tool options for each. Sections 3.2 through 3.5 provide specific guidelines for each step.

TABLE 3.1
DATA-COLLECTION METHODS

DATA-COLLECTION CATEGORIES	SAMPLE DATA TO BE COLLECTED	METHODS AND TOOLS OF COLLECTION
Source Data	Number of sources Types of sources Locations of sources Base magnetic-field data: magnitude, spatial variability, temporal variability	Questionnaires Observation Investigative measurements Mapping Data-collection forms "Focused" measurements
Activity-pattern Data	Number of people Categories of people (age, job, etc.) Potential people groups Locations of people Activities of people Equipment usage	Questionnaires Observations Interviews Data-collection forms
Non-magnetic-field Data	Weather conditions Electric usage Area power facilities Physical site characteristics	Questionnaires Observations Data-collection forms
Microenvironment Identification and Selection of Points for Measurement	Determine boundaries Determine weighting	Review of site sketches and notes Decision matrices
Focused Magnetic-field Data Collection Based on Source and Activity Data	Spot measurements Temporal measurements	Temporal measurements Spot measurements Waveform capture Mapping Data-collection forms Recorded measurement

3.1.3 The Data-collection Schedule and Sequence of Tasks

Before developing the data-collection protocol, you should have an indication of any project time constraints (see Section 2.3). The sequence of the protocol may be built to fit those constraints. Table 3.2 shows a sample schedule, built to fit an on-site time limitation of two days.

TABLE 3.2
SAMPLE DATA-COLLECTION SCHEDULE FOR TWO DAYS OF FIELD WORK

TIME PERIOD	DATA-COLLECTION TASKS
Prior to Site Visit (via phone, mail, questionnaire)	Obtain maps of site. Gather base data on physical site. Gather base data on occupants. Gather base data on sources present. Divide the space into subenvironments based on the map and physical site information.
Initial Study Day ("Pre-Measurement Walk-through")	Take initial tour for site familiarization. Identify and locate sources. Gather activity-pattern data. Perform mapping measurements and/or scoping measurements. Determine the appropriate locations for long-term meters, and set up. Gather non-magnetic-field data. Confirm pre-site visit information.
After Initial Study Day	Identify the microenvironments. Select the appropriate locations for focused measurements, based on a weighting. Determine the parameters and locations of any special measurements required (transients, short temporal, operating on/off, etc).
Focused Measurement Day	Perform waveform capture measurements at the selected locations. Verify any conditions or changes in conditions from the initial study day. Retrieve long-term instrumentation. Gather detailed information about selected exposure-relevant locations.

Many tasks and much planning can begin before the initial site visit. You should anticipate that a team of two-to-three technicians may spend two days performing field work to develop quality data and a reasonable portrait of the exposure characteristics in a typical large environment (such as offices or a mid-size industrial site). Residences and small, simple environments would require less time; larger industrial sites or large medical facilities would require more. At some point, additional time spent in the field will add only diminishing marginal benefits. Efficiencies may be realized when performing data collection using a standardized protocol.

You may design a schedule allowing less time according to the same format. For example, in a residential study, these tasks may be compressed into two hours:

- A quick tour with the occupant will provide the preliminary information;
- The "initial study day" tasks can then be performed;
- You may take a break to identify the microenvironments and select locations for measurement; and
- You may then return to perform the focused measurements.

Pre-setting the data-collection schedule will allow you to prioritize the data you intend to collect. For example, in a larger environment with many similar subenvironments, it may be necessary to select just a sample of the subenvironments in which to perform measurements. Also, understanding the schedule will allow you to estimate how many spot measurements can be performed within the allotted time, and to prioritize the measurements accordingly.

3.1.4 Using the Environment Grid to Document Location

Before collecting any data at the site, you must determine the method by which you will document the relative locations of the sources, occupants, and magnetic-field measurements. In many cases it will suffice to, as accurately as possible, draw the sources and occupants on an accurate sketch of the site. Measurement locations may be identified as a distance relative to the sources or other physical features. If time allows, or if specific relative measurements are required, set up an x,y coordinate system for the site.

Obtain maps or building plans before the first site visit. Early plans will allow you to determine a preliminary x,y coordinate plan. Suggestions for determining and using such a plan include the following:

- Select the x,y coordinate base lines based on the position of the building, by locating the axes along perpendicular walls of the building. There is typically no need to attempt to set up the project grid in a north-south direction.

- If possible, set the base point (0,0) in the corner of the environment such that all points within the environment have positive x- and y-coordinates. This will simplify location recording and data management.

- If you intend to divide the environment into subenvironments, you may select a new x,y, base point in each subenvironment. Place the base point (0,0) of each subenvironment in the same relative corner. This effort will make determining the relative locations between the subenvironments easier. Then, if the study design requires relative locations of all points, you may adjust the x,y coordinates of all points in a subenvironment by the same factor.

- Use existing site grids to document location. Many environments have a grid system built into the physical structure. Particularly in industrial settings, the building structural steel is visible and may be used as a reference grid simply by determining the width of each bay. Even if you intend to use a sketch to document locations, drawing the building steel frame onto the sketch before data collection will make your final sketches more accurate.

  The acoustic ceilings in commercial offices and retail facilities can act as a location grid. Ceiling tiles are made in standard sizes: 1'x1', 2'x2', and 2'x4'. You may refer to the tile grid in order to ascertain a relative location within a subenvironment, simply by counting tiles. Note, however, that the grid system between offices is often not continuous.

3.1.5 Developing the Data-collection Forms

Data-collection forms are the most reliable means to obtain and confirm a complete data set from the field. Well-designed forms will minimize data subjectivity and provide an excellent data management tool. Site maps and sketches on the forms provide an excellent format for recording data, though the relative dimensions must be documented to ensure location clarity. Follow these basic principles when designing the data collection forms for your study:

1. Ease of Use:
   - Design the forms in an orderly fashion, based on the chronology of data collection expected at the sight. Avoid constant searching and flipping of pages.

- Allow room for the technician to write a full response in each blank.

- Have sample pre-filled forms available in the field kit that the technician may use to confirm proper use of the forms.

- Where possible, streamline the data input, e.g., by providing a choice of answers to circle.

2. Objectivity:

- Design the questions to request objective responses.

- Consider offering choices of responses to circle.

- Consider codifying the data so that it is readily and objectively transferable from the data-collection form to a database or other stratification media.

- Ensure that the technician understands the units in which to report (milligauss, feet, etc.).

3. Identification:

- Provide a name for the form type in an obvious location at the top of the form.

- Number and identify each page of multiple page forms.

- Include space for identifying information, including:

  - study name or number
  - name describing the environment
  - area of the environment the form pertains to
  - technician's name
  - any code numbers or names given to the study, environment, or area.

- Provide space to identify the name or number of any corresponding forms.

4. Testing:

- Be sure to test the use of the forms in a pilot study or other format, in order to reveal subjectivity, ambiguities, or use challenges.

Appendix C contains samples of useful forms. Forms that may be appropriate for environment-specific measurement studies include:

- Facility Questionnaire for completion by site contact prior to study

- Site Sketch Form

- Non-magnetic-field Data Sheet
- Photograph Log
- Spot Measurement Data-collection Form
- Source Identification Sketch and Data Form
- Activity-pattern Data-collection Questionnaire
- Activity-pattern Data Interview Form
- Spot Measurement Location Decision Matrix.

> ***P.S.*** *Several data-collection forms were used in the pilot studies, including the Initial Walk-through: Subenvironment Data Sheet, the Activity-Pattern Data Interview, and the Spot Measurement Location Decision Matrix. Some of the completed forms are included with the pilot study in Appendix B.1.*

3.2 Identifying Magnetic-field Sources

The locations of sources with respect to the environment and with respect to its occupants are critical information for defining the microenvironment and characterizing the environment. The extent of data that should be collected about a given source will depend upon the study goals. Source data will be collected during various tasks of the study. Methods for identifying the sources are detailed below, and some description of the basic considerations for collection of source data described. Gathering further technical information about each source is discussed in Section 3.4, Gathering Non-magnetic-field Data. Performing more focused measurements at sources with respect to the environment and its occupants is discussed in Sections 3.5. Refer to *Guidelines for Magnetic Field Source Characterization* (Feero (1997)) for an expanded description of full characterization of sources, both in a typical environment, and in a controlled setting.

Frequently, source identification requires a bit of detective work. You may assume that you will not identify every source, particularly in a complex magnetic-field environment. In some cases, you may locate an elevated magnetic field, but be unable to identify its source (such as sources behind walls). Also, most real-world situations involve contributions from two or more sources simultaneously. The level of effort appropriate for source identification should be based on the goals and resources of the study, such that enough source information is gathered to properly characterize the environment.

Also note that source identification is an **ongoing process** throughout the study. Each additional task, from the pre-study questionnaire and initial site tour, through a review of the focused measurement data, may reveal information leading to additional sources.

3.2.1 Methods of Source Identification

You may use a combination of the following tools to locate sources within the given environment: visual inspection, information from the site contact, exploratory measurements, field mapping, and use of an ammeter. The use and characteristics of each of these methods are highlighted in Table 3.3, and discussed below.

TABLE 3.3
SOURCE IDENTIFICATION METHODS

IDENTIFICATION METHOD	STUDY TIMING	INSTRUMENTS	ADVANTAGES	DISADVANTAGES
Visual Inspection	Any time at site Review of photographs	None or Camera	Any visible sources, whether operating or not. Very beneficial in early planning stages. Time and hands are available to record product information.	Hidden sources, such as sources inside walls, are missed. Data may be collected on items not creating a field.
Informant	Questionnaire Introductory tour Interview Questions during activity pattern interview	Questionnaire Source list Conversation	Can get preliminary information in questionnaire, which is helpful for planning study. Can identify source of special interest to informant.	Reliant on the informant's knowledge and interest in providing thorough information.
Exploratory or Scoping Measurements	Initial day	1-axis meter 3-axis meter Audio tracer	Can use for locating non-visible sources. Can use to hone in on a field variance identified in field mapping.	Will not detect sources not in operation.
Field Mapping	Initial day	3-axis meter w/mapping wheel	Can use for locating non-visible (such as in-wall sources). Can use multiple meters at various heights to identify vertical variance indicating floor or ceiling sources.	Will not detect sources not in operation.
Clamp-On Ammeter	Initial day	Ammeter	Detects net current fields on wiring sources, grounded piping, and structural steel.	Ammeter must have jaws large enough to fit around pipes and small enough to fit in outlet boxes.

Visual Inspection. A visual inspection will be used in virtually every study. The visual inspection is quick and requires no instrumentation. It allows immediate precursory information about the site's characteristics relative to its sources. The greatest benefit of visual inspection will be the identification of a source, irrespective of whether the source is in operation or not. The visual inspection will begin with an initial site tour, and will continue with each additional site walk-through.

Informant Interview or Questionnaire. Use the pre-study questionnaire to solicit the site contact's knowledge of typical sources within the environment. Consider including a list of typical sources in the questionnaire package, and request that the informant locate the presence of these sources on a site plan. Although this third-party information can be very helpful (adding insight to the measurement plan development), the information should be verified at the site. A sample set of standard sources is included as Appendix C.3.

The informant may also be asked to provide information about the sources identified by the technician, e.g., about their use and their typical operating conditions. The activity-pattern interview provides a good opportunity to ask these questions. It also provides an opportunity to ask explicitly about any appliances or other sources that might not have been visible during the technician's source investigation walk-through.

Frequently the most reliable providers of information are the individual users of the sources, such as plant equipment operators or clerical staff. When site conditions allow communication with the occupants, source users may be asked to provide first-hand information about the use of equipment.

Field Mapping. Mapping provides a graphical representation of the locations and magnitude of sources in the area. The process provides an excellent basis for exploratory measurements, providing a picture of where elevated magnetic fields, and thus potential sources, are located. The data may also be used for reporting and analysis, providing a "snapshot in time" of the magnetic-field environment.

Verify the locations of sources identified during the visual inspection by comparing the map with earlier sketches. Return to site areas of elevated magnetic fields apparent from the mapping to further explore and locate previously unidentified sources.

Methods of Mapping: Mapping may be performed using a wheel system, using a hand-held system or by performing and analyzing a series of spot measurements. Typical mapping setups involve a three-axis magnetic-field recorder or waveform capture system **mounted to wheel of a defined perimeter.** Sensors are attached to the wheel at defined distances along its perimeter; usually one foot. For some systems, the measurement frequency is based on distance (i.e., the Field Star 1000 by Dexsil); with each pass of a sensor, a measurement is triggered and the x,y location logged. For some systems, the measurement is based on time (i.e., the EMDEX II on the Linda wheel by Enertech); regardless of the speed the wheel is moving, the meter continues to record at the set time increment (i.e., 1.5 seconds). Distance-based frequency provides a uniform distribution of measurements, which is more appropriate if the data will be analyzed for averages or other metrics. Time-based frequency can be beneficial in exploratory measurements, because data can be collected more densely in areas of magnetic-field interest simply by slowing down the speed of the wheel.

Software has also been developed for the EMDEX II whereby the instrument is **hand-held** and floated carefully through the desired path. At each turn, the data is marked with an event, and the direction of turn later entered into the data. This method allows freer movement over and under sources because no wheel is attached. However it increases the degree of uncertainty, because the path distances will lack accuracy, and the instrument height is difficult to maintain.

You may also develop magnetic-field maps by recording a grid of **spot measurements** and their respective x,y locations, then entering the data points in a three-dimensional interpolation program such as Surfer® (Golden Software, Inc., Golden, CO). This method can be very successful for sources such as utility facilities for which the magnetic fields fall off predictably, and over large distances. However, in environments with more spatial variability, it would prove difficult to perform spot measurements densely enough to provide the spatial information desired.

Selecting Mapping Patterns: Design the mapping pattern based on whether the goal of mapping is for sources identification, or for further data analysis.

For source identification, focus the path near where sources might be. A path around each room's perimeter will identify many elevated fields, because, in general, most sources in a room are located around the perimeter or in the walls. Likewise, in a manufacturing facility, select a path along the edges of equipment aisleways.

If the data will be used for **further analysis** such as calculating area averages, attempt to select a path as uniformly distributed as possible, such as a continuing S-pattern through the area. Note that if you base analysis off of a source-focussed pattern, such as the perimeter suggested above, the data will be skewed to higher average, and the reporting will be unrealistic. Keep in mind the exposure-relevance of the path; maintain a reasonable distance from walls, because, in general, people spend most of their time in the middle two-thirds of most areas.

Using Two Meters: If performing the mapping for identifying sources, consider setting up two meters at two different heights (say, six inches and three feet from the floor) which will conduct measurements simultaneously. A comparison of the two resulting maps will determine whether an elevated field comes from a source above or below the meters.

Taking Field Notes: For most mapping wheels, at each turn (left, right, back, or any 45-degree angle), you press a button to mark the data with the appropriate turn. It is inevitable that you may make one or more turn errors in an extensive mapping, which can make the location data completely erroneous. Therefore, document the path of the wheel on a site sketch as you perform the mapping, including the location and number of each turn, so that the path data can be readily reviewed and corrected. For this reason field mapping is most efficiently performed with two technicians.

Profile Measurements: Profile measurements are a two-dimensional version of field mapping, using the same methods and instrumentation. **Lateral profiles** are performed to show fall-off with distance from the source. (Taking a series of spot measurements at three distances from a piece of equipment is a simple lateral profile.) Consider performing a lateral profile from a utility line away from the study environment so that you may identify the contribution from the utility line only. **Perimeter profiles** may be performed around the exterior of an environment to identify locations of outside sources. When performing a perimeter profile, maintain a distance of 3-6 feet (1-2 meters) from the environment wall, so that outside sources, rather than inside sources, are recognized.

Exploratory Measurements. Exploratory or scoping measurements involve walking the perimeter of an area with hand-held meter; and watching for changes in readings. These measurements are most convenient when trying to identify the source of an elevated field that was detected using some other source identification method, such as field mapping. However, in smaller environments, you may perform the base source-identification steps by tracing down sources with exploratory measurements. Single-axis hand-held magnetic flux density meters or audio attachments are most convenient for performing the exploratory measurements because they provide continuous instantaneous information about field fluctuation. But because they must be held in the proper orientation to capture peak information, they are most convenient for identifying the field change (and thus a source), rather than for data collection. You may also use a three-axis magnetic flux density meter for scoping, although the 1.5-second or more delay between readouts slows down the investigation. Use a hand-held meter and/or audio attachment to scope using the following methods:

- **Point Source:** Locate a prevalent point source by orienting the single-axis meter in the direction of the greatest magnitude in the area of elevated fields, then move the meter within that plane to find the direction of increasing fields, and thus the source.
- **Wiring Source:** Trace the path of a wiring source within a wall by identifying a "line" of elevated fields, until a visible portion of the wiring source may be located.

Exploratory measurement is best used after a visual inspection and/or field mapping. In a large environment, exploratory measurement is a cumbersome first basis for source identification.

Ammeters. Ammeters are helpful to identify a wiring source, grounded pipe, or structural steel. By clamping the ammeter around a conduit, pipe or steel member, you can determine whether the conduit, pipe, steel member, or wiring within conduit is carrying a net current. A net current of 1 amp on a pipe or conduit will produce a 2-mG magnetic field at a distance of one meter. The use of ammeters is most important when the goal of a study includes positive identification of sources for the purpose of possible field management.

Temporal Measurements and Other Data-Collection Tasks. Data gathered during other data-collection tasks may provide information which leads you to further sources. For example, when reviewing the data from a 24-hour measurement, you may note an intermittent magnetic field that indicates a source not identified in the previous day's field work. You should look for such indications of additional sources throughout data review, and investigate as resources permit.

> ***P.S.*** *In the Daycare Center pilot study, visual inspection and scoping measurements were used to identify magnetic-field sources because of the small size of the space. However, a substantial non-visible source within a wall was missed during the initial walk-though, and only later identified during review of the focused measurements. Field mapping, together with visual inspection and informant questioning, was used to identifying sources in the Metal Fabrication Plant and Grocery Store pilot studies. Scoping measurements were then used to return to areas of elevated fields indicated during the field mapping which were not recognized visually.*

3.2.2 Documenting the Source Location

Once it has been identified, carefully document the location of a source within the environment. Indicating a source on a site map is most convenient. The site map may be sketched, if a workable map has not been provided by the site contact. Appendix C.4 is a sample form on which to identify sources within a subenvironment of the site on a self-drawn sketch. Be sure to note a measurement or estimate of distance from the source to a reference point on the sketch.

Each source should be **uniquely identified** on the site map. Preferably the identification will include a description that provides further information about the magnetic-field characteristics. Select a reference name for the source based on any of the following information:

- Description of source (e.g., "fan")
- Size (e.g., "12-inch," "2-HP motor," etc.)
- Physical description (e.g., "blue," "square," etc)
- Familiar names of users (e.g., "Lisa's monitor")
- Name Brand (e.g., "General Electric").

3.2.3 Preliminary Definition of Source Characteristics

You must understand the basic source characteristics in order to identify microenvironments and develop the measurement plan. (More in-depth characterization may take place during the focussed measurements, as discussed in Section 3.5.) Basic source characteristics include:

- the type of source,
- the level of magnitude of magnetic field from the source, and
- the basic temporal characteristics of the source.

Determining the Type of Source. Three types of magnetic fields exist: point sources, wiring sources, and single wire or net current sources. If you know which type of source is present, you can preliminarily characterize the source and make judgements about the selection of measurement locations in the given microenvironment. Examples of these types are shown in Table 3.4.

TABLE 3.4

SOURCE TYPES

Source Type	Examples	Magnetic-field Falloff Rate
Point or Coil Source	Small motors Transformers	$1/d^3$
Wiring Source	Utility circuits Knob and tube wiring	$1/d^2$
Net Current or Unbalanced Source	Grounding systems Unbalanced wiring	1/d
Combination*	See description below	

*Combination: some sources may involve a combination of source types: for example, a building transformer is made up of one or more coils, or point sources. However, the wiring leading to the coils may be separated in such a manner that they create a wiring source.

Point sources are usually recognizable, and are often referred to as equipment sources. In general, these include any motors, transformers, heaters, or other equipment containing a coil.

It is more difficult to differentiate between wiring sources and net current sources; in fact, a source may be a combination of both. The distance ratio method to determine identity is as follows:

1) Perform a spot measurement at a definitive distance from the source.
2) Perform a second measurement at double the distance from the source.
3) Calculate the ratio of the two measurements. If the ratio equals approximately *1/2*, the fields are diminishing at a rate of 1/d and a net current source is present. If the ratio is *1/4*, the magnetic field is falling off at a rate of $1/d^2$, and a typical wiring source is present. If the ratio is between 1/4 and 1/2, then a combination of both most likely exists.

Note that discerning the type of field present becomes even more difficult in a location with many sources present, such as in a switchgear room.

Determining the Level of Magnitude of Magnetic Fields. If instrumentation is used during the source identification, information about the level of magnetic field from the various sources will inevitably be collected as well. You should document this information so that it may be considered in the focussed measurement planning, and/or included in the study report. During exploratory measurements, the level of magnitude may be documented on the data-collection form (Appendix C.4). If field mapping is performed, the map printouts will provide similar information.

Identifying Basic Temporal Characteristics of Magnetic Fields. The most critical temporal information about a source is its operating condition during the periods of site occupancy. Note in the data-collection forms whether each source is:

- Always or Usually **ON** (such as a clock or ceiling lights)
- Always or Usually **OFF** (such as an rarely used electric typewriter sitting on a secretary's desk)
- Has **RECURRING** operation (such as a cycling refrigerator motor), or
- Operates **INTERMITTENTLY** (such as a tool at a work station or a television).

Other temporal characteristics of the source are much more difficult to characterize during an initial review. However, you can anticipate some temporal variability, such as fluctuations in load on power lines or the presence of transients from welding processes. Any expected temporal characteristics may be documented in the field notes, because these, as well as the operating conditions, will influence the choice of focussed and temporal magnetic-field measurements to perform later on.

3.2.4 Classification of sources

Guidelines for Magnetic Field Source Characterization (Feero (1997)) has developed a relatively simple means for classifying the general magnetic-field characteristics that may be expected from point sources. The classification system is based on identifying the source's common name, followed by alphanumeric descriptors and a four-digit code box. An example would read: UPS-brandxx50KVA208V 4238. (The development of the code is described in Appendix A.6.) The intention of the classification system is that, over time, a database of source codes will be developed and included in the RAPID EMF Measurement Database, contributed by ongoing magnetic-field research. The database will be readily available for public use. The user should refer to the originating document (Feero (1997)) for more information about classifying sources by using the code.

The four digits of the code are designed to indicate the following information:

1) Range of magnetic-field magnitude at one foot from the source
2) Frequency of the most dominant magnitude
3) Point source intermittency
4) Spatial attenuation and polarization.

For an environment-specific study, if the specific point source has previously been classified and logged in the RAPID EMF Measurement Database, the measurement protocol can make use of the classification. Simple measurements should be taken to verify that the classification is correct. If it is confirmed, then the source location can be noted and the study continued without further attention to the source's characteristics.

Should a point source be encountered that has not yet been classified, then the in-situ measurement protocol set forth in the report (Feero (1997)) may be followed. The extent to which these extensive protocols should be followed will depend on the activity in the immediate vicinity of the point source, and the goals of the particular study. However, it will always be desirable to try to gather enough data to log a source classification if the project resources permit.

3.3 Gathering Activity-pattern Data

The concept of activity pattern refers to the global complex of human actions, locations and times. Within that data universe, certain locations may be of special importance because they contain EMF sources, just as certain activities may be a focus of investigation because they involve the use of EMF sources.

3.3.1 The Goals of Activity-pattern Assessment in Environment-specific Measurements

Our guidelines assume that the goal of activity-pattern assessment is to provide the information required to include exposure-relevancy in the magnetic-field measurement study design. Generally, the data collection will determine where and how people spend their time within the environment; that information will help the investigator to make decisions about where, when, and how to make more extensive, or focussed, measurements of magnetic fields. **Activity patterns, together with source and preliminary field information, define the boundaries of the microenvironments to be studied in greater detail with focussed measurements.** The investigator should consider the environment in three aspects:

1) locations that **definitely require** focussed magnetic-field measurement (e.g., high density of persons near important sources at particular times)

2) locations and time periods that **should be definitely excluded** (e.g., because no one ever goes there and there are no significant EMF sources)

3) locations and time periods that **may or may not require** additional examination, depending on the EMF and/or activity-pattern thresholds the investigator wishes to impose on the decision-making process.

Locations of the first and second type may be obvious. On the other hand, locations in the third category may comprise the bulk of the environment. In that case, you must make sure that an activity-pattern protocol provides appropriate data for choices about field measurements — that is, data consistent with your activity and field thresholds. Superfluous data is a distraction and a waste of limited resources. Too little data leaves the investigator with no firm basis for making decisions about additional field measurements.

Given resource constraints, you should focus on the **minimum information** needed to choose locations or microenvironments to study in detail. The procedures we recommend may also be adapted for other purposes (e.g., modeling personal or group exposures, computing time-weighted average (TWA) exposures, or selecting samples of persons for personal-exposure monitoring), but they have been designed primarily to assist in the selection of microenvironments for focussed magnetic-field measurements. To make such choices, you may not need to collect quantitative information about the components of activity patterns. Qualitative data (e.g., yes or no, more or less) about activities, locations, source use, or time spans are sometimes sufficient.

3.3.2 Selecting Methods of Activity-pattern Assessment

Designing an activity-pattern data-collection protocol for all or part of an environment requires answers to three questions:

1) Who is the primary source of information about activity patterns?
2) How will the data be collected?
3) What kind of data will be collected — in particular, how much detail is needed?

Table 3.5 indicates the main options for each of these components.

TABLE 3.5
ALTERNATIVES FOR ACTIVITY-PATTERN PROTOCOL DESIGN

Protocol Component	Principal Options
Primary Source of Information	• Local informants • Sample of occupants • Observers
Data-collection Tools	• Self-administered questionnaires • Structured interviews • Observer notes and logs
Types/amounts of Information to be Collected	• Qualitative data on use of selected locations • Person-time estimates by locations • Activity profiles by locations • Characteristics of persons (e.g., age, gender, occupation) • Proximity to specific sources and source use

How the elements of Table 3.5 are combined into an activity-pattern protocol depends on several factors:

- The nature and complexity of the environment to be assessed

- The minimal data requirements for making decisions about additional field measurements
- Resources available to implement the protocol.

Below, we discuss generally how these factors are related to the choice of a protocol. More specific guidelines for implementing activity-pattern data collection are given in Section 3.3.3, Principles of Activity-pattern Data Collection.

Restrictions on the resources available to support activity-pattern data collection constrain choices. In general, protocols that use informants as the primary sources of information cost less than procedures that call for trained observers or interviews with occupants. When data must be collected from a large number of occupants, it will generally be cheaper to use a questionnaire than to conduct interviews. In almost all cases, reducing the number of data elements to be collected cuts the cost of implementing a protocol. If the data-collection phase of the complete protocol, including the EMF measurement portion, must be completed by two persons in two days (as in the pilot studies done in this project), data collection should be restricted to the minimum needed to make decisions about field measurements.

The generally high costs (mostly labor) of collecting activity-pattern information in most environments suggests that investigators should pay careful attention to **the problem of defining the minimal data** set for activity patterns. Two specifications will drive the selection of components for an activity-pattern protocol:

1) What activity-pattern data are needed, and
2) How accurate the data need to be for decision-making.

Table 3.6 shows some of those characteristics of the environment and its inhabitants that may affect the selection of a strategy for collecting activity-pattern data. (This relationship will be discussed in more detail in Section 3.3.3.) Here we note that complex, densely populated environments present a special challenge to activity-pattern assessment where project resources are limited. What works for a small bounded office environment inhabited by a few occupants whose movements are known to each other will probably not work in a large research facility. **In general, greater population size and spatial complexity bias the choice of protocol toward mass data-collection procedures (e.g., questionnaires, summaries for groups) or very restricted minimal data sets.**

TABLE 3.6
ENVIRONMENTAL VARIATIONS AFFECTING THE CHOICE OF PROTOCOL

PHYSICAL STRUCTURE	PERSONS	ACTIVITIES	FIELD SOURCES
Size of environment Partitioning of spaces Age of structures	Number, density, and mobility of persons Regular occupants vs. visitors Distribution of persons by job, age, etc.	Individual versus group patterns Variability of activities over time and persons Presence of activity cycles	Types of sources--office, retail, home, industrial Mobility of sources Power usage Hidden sources

3.3.3 Principles of Activity-Pattern Data Collection

Preliminary Steps. A number of steps may be taken in advance of actual data collection to increase the effectiveness of an activity-pattern protocol. The most important of these are listed below.

a) **Advance contacts** with persons familiar with the site are important to determine the size of the task. In most cases, you can collect **pre-site-visit data** through phone contacts with informants or by sending a **self-administered questionnaire** with a return envelope. Useful information about the physical characteristics of the site, the number and types of occupants, and presence of EMF sources can be gathered in this way. (See Appendix C.2 for a sample pre-site-visit questionnaire.)

b) **An up-to-date site map** is extremely helpful. In most, if not all, activity-pattern protocols, the data to be collected must be keyed to specific locations on the site. A good map is a template for identifying microenvironments that are the focus of a complete site assessment.

c) The pre-measurement walk-through is a good opportunity for technicians to make **preliminary observations on the locations and movements of site occupants.** Numbers of persons, types of occupant, and activities can be linked to locations and noted directly on copies of site maps while the technicians are identifying magnetic-field sources.

d) Based on preliminary site information, you should **finalize the definition of the minimum data** set required to define the microenvironments and ultimately make decisions about where, when, and how to make focussed measurements. This step can eliminate or add data elements before the activity-pattern protocol is implemented.

Interview and Questionnaire Protocols. The discussion below offers you the tradeoffs between techniques, guiding you in selecting protocol elements.

Interview/questionnaire versus observation: Interview and questionnaire protocols are useful under a variety of different conditions. They work better than direct observation under the following conditions:

- When activity patterns are not readily observable (e.g., if they are distributed in time and space so that observation is difficult) or the costs of making observations are too high.
- When occupants and/or informants can give accurate reports about activity patterns at the level of detail required.
- When the burden of providing data by being interviewed or filling out a self-administered questionnaire is not too high.

Informants versus occupants as sources of data: In selecting information sources, you will need to assess the distribution of knowledge about activity patterns and the willingness or availability of persons to make reports. Problems arise if these characteristics do not reside in the same persons. An **informant-based protocol** works well where such persons are in a good position to observe others' activity patterns (e.g., foremen or supervisors in some industrial settings, office managers in some office settings) and they will take the time to report via interview or questionnaire. These reports can be improved by first giving informants instructions about what information is needed so they can prepare to respond by making selected observations. **Occupant-based protocols** are those in which each occupant (or a sample of occupants) reports on his or her own activity patterns. This type of data collection is required if no one qualifies as an informant about other people's activities, or if the activities are effectively unobservable except by those doing them. In borderline cases, the choice may be made in relation to cost (using informants is usually cheaper in environments with many occupants) and to the nature of the minimum data set. For example, if very rough information about activities and locations will suffice, then an informant-based protocol may work well even in environment where activities are distributed over many locations.

<u>Interview versus self-administered questionnaire</u>: This choice also depends on several factors:

- The number of persons who will be solicited for reports on activity patterns.
- Whether the questions to be asked require an interviewer to explain the meaning and intent of the investigators.
- In protocols with many respondents, whether interviews or questionnaires offer a better opportunity to achieve a high rate of quality response at a reasonable cost. (Interviews require manpower resources for execution, while questionnaires require a much more structured design and risk a lower response rate.)

An interview-based protocol works well where a small number of interviews will suffice (e.g., when informants can be used effectively, and where the presence of an interviewer helps to clarify the interpretation of questions and to make sure that the responses are recorded in a standardized fashion). Questionnaires can be used effectively for large numbers of occupants when each occupant is the most valid source of information on his or her own activities and when the questions can be framed so that no "interpreter" is necessary to guarantee understanding. In general, it requires more care to construct an acceptable questionnaire than to produce an acceptable interview protocol.

<u>Constructing questions about activity patterns</u>: Below are guidelines for constructing questions about activity patterns for the purpose of defining microenvironments and

determining the locations of focussed measurements. These guidelines apply equally to questionnaire and interview protocols; however, note that presence of an interviewer allows greater liberty in the phrasing of questions and recording of responses.

a) **Use a map to guide questions about locations.** A good site map that shows areas in sufficient detail on a convenient scale is an indispensable tool for asking questions about the location of occupants, activities, and sources. A site map provides: 1) a visual aid for asking questions that require reference to location, and 2) a form for recording locational information about numbers of persons, activities, and types of field sources. When necessary, tentative microenvironmental boundaries may be drawn in to focus questions on areas that may be chosen as sites for further field measurements.

b) **Specify temporal frames as clearly as possible.** The **temporal frame** refers to the period of time that the respondent should use as a basis for answering questions about activity patterns. Examples of such frames are "today", "yesterday", "within the last 24 hours", "on the night shift", "on a typical day", "on an average day within the last month", etc. The terms "typical" and "average" ask the respondent to aggregate over a large number of observations and experiences. This kind of mental operation is especially subject to uncertainty and bias in reporting in environments where there is no predictable routine. Frames like "yesterday" or "today" capitalize on fresh memories of recent events, but may fail to represent the average or typical day. Many different frames may be used in the same interview or questionnaire, but they must be clearly distinguished for each series of questions, and great care must be taken to ensure that the subjects understand any shift in frame. Questions about the **durations of occupancy or of activities** can be directed to different levels of detail. You could include:

- a binary yes/no response about locations, activities, or sources during the reference period,
- estimates of the duration of time associated with activity patterns,
- approximate placement of activities and locations on intervals of a time line, and
- estimated begin- and end-times for specific activities and locations.

Avoid asking questions that lead to a spurious sense of accuracy, e.g., asking for exact numbers of minutes instead of asking for a more realistic broad interval of time.

c) **Decide whose activity patterns need to be evaluated.** About whom should one ask questions? A crude typology of persons, based on length of stay in an environment, is sometimes useful: **occupants**, defined as persons whose normal stay in the environment exceeds some threshold duration per period of time; **casual users**, non-occupants who visit the environment frequently but don't stay for long periods of time; and **drop-ins and passers-by**. Which groups to select depends on the goals of the study, but we suggest asking the following questions:

- Is the general purpose of the environment for the use of casual occupants (such as patrons of a restaurant, members of a church)?
- Does the purpose of the study specify that the casual occupants or passers-by are of interest?
- Is the anticipated magnetic-field environment significantly different than that which the casual occupants or passers-by might experience upon occasion?

If the answer is no to all these questions, then these non-occupants need not be considered in the activity-pattern data collection.

Also of potential importance are **classifications of persons by function** (e.g., job or occupation) and **groupings of persons** (e.g., students in a classroom) who have more or less the same activity patterns. Some rules of thumb for question construction include the following:

- If a classification of persons by function or type is highly correlated with activity patterns, use the classification scheme as a basis for asking questions about groups of persons.
- Ask, as appropriate, about the activities of a sample of specific persons (e.g., a small number of children in each grade level) rather than asking about the activity patterns of an aggregate (e.g., all first-graders).

d) **Consider alternative ways of framing questions about activity patterns, and choose frames that best fit the purpose of the study and the environmental conditions.** The alternatives we have in mind here are distinguished by how a series of questions about activity patterns is begun.

- **Person-focused questions** begin by identifying a person or group of persons and following up with questions on where such persons spend their time, what they do, and whether or not use of EMF sources is involved.

- **Location-focused questions** begin by identifying a location, possibly using a map of the environment, and following up with questions about who spends time there, whether or not sources are located there, and what activities take place there.

- **Activity-focused questions** begin by identifying activities and follow up with questions about who does them, where they take place, and whether or not a source is involved.

- **Source-focused questions** begin by identifying magnetic-field sources, and follow up with questions about where the sources are located, and who uses them or stays near them.

Location-focused questions are likely to be the first choice for the class of protocols for environment-specific magnetic-field measurements because the goal is to help make decisions about where, when, and how to make focussed magnetic-field measurements. Other question frames may be appropriate in particular circumstances: e.g., person-focused questions in an environment with few persons and locations, or source-focused questions in an environment where the sources are few in number and easy to identify in advance. Additional questions about persons (e.g., their age, gender, job title, whether or not they are occupants or casual users, etc.) are particularly easy to incorporate in person-focused questionnaires or interview protocols. To the extent that persons, locations, activities, and sources cluster in time, all question frames will yield approximately the same information about activity patterns.

e) **Within the constraints of time and budget, use standard survey techniques of questionnaire development and administration.** Pretest the questions using a small sample of subjects like those who will be asked activity-pattern questions in the actual study. (The pretest helps to assess subject burden, including cognitive demands of the interview or questionnaire task, and to determine ways to cut the number of questions and make questions easier to answer.) Prepare written interviewer instructions and conduct training sessions with interviewers. (This step helps to promote a uniform administration of an interview according to the standards specified by the investigator.) Train field workers in how to make appointments and get cooperation from potential subjects.

f) **Simulate the process of planning the focussed measurements using information provided by pre-tested versions of questionnaires and/or interview protocols.** In other words, imagine the kinds of information that will be obtained by administering a specific activity-pattern interview or questionnaire and determine whether it provides a minimum data set for making decisions about additional measurements.

> *P.S. An informant-based interview was designed for activity-pattern data collection in the Daycare Pilot Study, because the site informant, the teacher, clearly was more capable than the occupants (pre-schoolers) in providing the needed information. Observation was not possible because the class was not to be disrupted. Two methods of questioning the site-informant were tested: 1) person-based questions, and 2) location-based questions. The informant found it substantially easier to respond to questions about each location and who occupied it.*
>
> *During this study, the questions had been designed to gather data on all occupants, including "casual" occupants such as parents dropping in or the occasional repairman. The volume of the questionning became onerous, and the "casual" occupant data provided little incremental benefit. It was determined that, unless casual occupants are an integral part of the environment's activity's (such as the patrons of a store), and/or unless the investigator has a purpose for the casual occupant information, this data need not be gathered.*

Observer-Based Activity-pattern Protocols. An observer-based protocol should be considered when some or all of the following conditions fit the circumstances of a study:

- The cost of having a dedicated observer can be accommodated within the budget for the study;
- The task of making observations in various locations is feasible, given the physical structure of the environment and the time constraints of the protocol;
- Administration of an interview or distribution of a self-administered questionnaire would disrupt normal activities of the occupants; and/or
- The sample of time dedicated to making observations is representative of activity patterns during "typical" periods (i.e., it is not necessary to ask an occupant or informant to average over a longer period of time).

As with interview and questionnaire protocols, an observer protocol can focus on persons, activities, locations, or sources as a primary interest. For most circumstances, the most appropriate first focus will be selected locations or sources. An observer protocol of this kind has four parts: 1) a specification of the locations or sources (including mobile sources) that should be observed; 2) what events the observer should observe and record; 3) when and for how long such observations should be made; and 4) how observations should be recorded.

a) **Use a site map to identify sources and locations for observation.** The site map should locate boundaries of the observation area precisely. These boundaries should define microenvironments that may be the focus for further EMF measurements, depending on the results of preliminary EMF "sniffing" and activity-pattern observations.

b) **Identify what to observe by reference to the minimal data set for making decisions about focussed measurements.** It is very important to decide what information is required in advance. In many cases, requirements can be limited to counts of occupants in a given location, whether a particular kind of equipment was used, and the duration of various activities or source uses. On the other hand, some types of assessment may require precise observations on the position of the human body (e.g., standing, sitting, bending over, etc.) while operating equipment.

c) **Make the forms for recording observations easy to use.** Where possible, pre-code activity, location, occupant type, and source categories so that the observer can record information by checking boxes rather than writing words. Bind the pages for easy access, and choose a size that balances portability with ease of recording. If exceptions to the activity-pattern coding conventions occur frequently, leave plenty of room for notes and comments. Insist that the observer record the begin- and end-time for observations at fixed locations.

d) **Prepare written instructions for observers or subjects.** Written instructions are critical for observer protocol and in the training of observers. The instructions should include the following elements:

- definitions of activity-pattern codes, where necessary;
- the windows of time during which observations should be made at each designated location (e.g., day shift from 10 AM to noon, at night, during particular activities;
- how to choose an unobtrusive location from which to make observations; and
- if necessary, questions that the observer should ask occupants prior to making observations.

e) **Pre-test** the main components of an observer protocol under conditions that approximate those encountered in actual assessments.

3.3.4 Examples of Data-collection Tools

Based on preliminary testing in pilot studies (see Appendix B) and considerations of feasibility, we believe that standardized interviews with informants concerning activity patterns in the various microenvironments provide a flexible and reliable tool for activity-pattern assessment in most environments. This methodology is relative inexpensive to implement, and it can be modified as an occupant interview or self-administered questionnaire when an informant is not available. The examples shown below may be condensed or lengthened, depending on the need for additional information about persons.

Pre-Site-Visit Questionnaire. As noted above, advance contacts are a useful preliminary to the observations made during a site visit. Appendix C.2 shows a self-administered questionnaire that has been field tested for pre-site-visit data collection at commercial and industrial sites. This particular questionnaire focuses on pertinent characteristics of the facility and labor force. A protocol for the administration and retrieval of such a questionnaire should include the following steps: 1) identification of a person who can provide the requested information; 2) questionnaire mail-out with a cover letter requesting the information and indicating why it is needed; 3) follow-up prior to the site visit to encourage completion and return.

Informant/Occupant Interview Protocol. Appendix C.5 is an interview protocol that is designed to provide an account of activity patterns on locations that are predesignated on a site map. In terms of the distinctions introduced earlier in this section, this protocol is interviewer-administered, location-focused, and employs an "average day" time frame for most of the questions. The locations are described as "rooms" but this term could be replaced by another word for environments lacking wall partitions. The person to be interviewed is an occupant of the location or an informant and the strategy of the interview is as follows:

a) Identify the location and make sure that the informant/occupant understands which location is the focus of the question.

b) Ask about the number of each four types of persons who use the space on an "average day, week, or month" - occupants of the space, regular users who aren't occupants, casual users, and passers-by. (Omit questions about casual users and passers-by if you have determined that the information is not necessary.)

c) Identify the names of each occupant (regular user, casual user) and ask about:

- their characteristics (e.g., age, sex, occupation)
- the time they spend in the location on an average day
- whether or not they operate equipment (which is indicated on the site map)
- and if so, for how long
- for infrequent users, focus questions on numbers and use of equipment.

> *P.S. The interview protocol shown in Appendix C.5 was used in the Daycare Center pilot study. In that study, detailed information was desired about the students' and teachers' activities within the space. More importantly, the site informant had the time available for a more arduous interview. Nevertheless, the questioning became somewhat tedious. In the Grocery Outlet, the site informant's available time was substantially limited. Therefore, the short form discussed below was used, in spite of the fact that more detailed information may have been desirable.*

Informant/Occupant Interview Protocol, Short Form. Appendix C.6 is a short interview protocol for use with local informants or occupants. It is location-based and relies on pre-designated map locations as keys for the questions. The time frame is chosen to be an "average day." In this case, the informant is asked to make aggregate judgements without reference to particular named persons;

- How often is the location occupied?
- When occupied, how many people use it?
- When occupied, how often is equipment in use?

A General Reference for Questionnaire/Interview Protocol Construction. The Survey Kit edited by Arlene Fink (Fink (1995)) is a series of nine small books on aspects of survey methodology that are relevant for activity-pattern assessment in EMF studies. The titles include:

The Survey Handbook
How to Ask Survey Questions
How to Conduct Self-Administered and Mail Surveys
How to Conduct Interviews by Telephone and in Person
How to Sample in Surveys
How to Analyze Survey Data
How to Design Surveys
How to Measure Survey Reliability and Validity
How to Report on Surveys.

3.4 Gathering Non-magnetic-field Data

The rationale for gathering other information about the environment and its sources is that it may provide additional insight into the characteristics of magnetic-field exposure. These data may also help to define the microenvironments and determine the appropriate times to perform the focused measurements. Several research projects have included non-magnetic-field statistics in their protocols and reports. For example, in the 1000 Homes Study (Zaffanella (1993)), statistics were reported about the type of water connection, which is an indicator of possible ground currents.

You will find several opportunities to collect this additional data. During preliminary contacts, (e.g., early telephone meetings or in the facility questionnaire), the site contact may be requested to provide basic site information. (Early site-data-collection was discussed in Section 2 to assist in developing the basic study strategy.) These data may be documented for reference and clarification during the site visits, and included in the final reports where applicable.

You can also gather non-magnetic-field data during the initial site visit. Specific forms may be designed to collect non-magnetic-field data (see Appendix C.7, for example). Use this opportunity to make observations and to question the informant about any of the information gathered.

Finally, throughout the field work, continue to note observations that might shed further light on the magnetic-field characteristics of the environment. Have site description forms or field notes available to document additional observations. Also be aware of and document any change in conditions from what you were originally told or observed, and inquire about the frequency or normality of those changes.

What information is appropriate or helpful will depend on the expected study product. Some relevant categories of non-magnetic-field data are discussed in the sections following.

3.4.1 Describing the Site

Document site characteristics to which elevated magnetic fields, or certain characteristics of magnetic fields, might be related. Examples include:

- age of environment
- type of building construction (steel frame, wood frame, slab on grade, etc.)
- physical dimensions
- number of building floors, and which are of interest
- date and extent of any remodeling
- weather conditions during study (temperature, humidity, precipitation)
- wiring type (Romex, conduit or knob and tube)
- type of grounding
- type of heating
- possible changes in the future to structure or building use
- uses of the site.

3.4.2 Documenting Additional Source Information

Source details will provide insight about the characteristics and magnitude of the magnetic fields produced by that source. You may gather this information from name-plate data, manufacturer's instructions, observations, or informant interview. Such information includes:

- type of motors
- size of motors
- size of step-down transformers
- equipment voltage
- equipment wattage
- equipment frequency (including dc) of electric devices
- manufacturer and model number
- physical dimensions
- typical operating status (Always On, Cycling, Turned On and Off, etc).

3.4.3 Documenting Utility Facilities and Power Source Data

You can gather utility information to some extent through observation, but ultimately, you must contact the utility to determine information such as line loads. Load information may be imperative in studies focusing on the utility contribution to total magnetic fields. If the utility facilities are not a significant contributor to site magnetic fields, and if time resources are limited, utility contact may not be warranted. Information useful about the utilities includes:

- voltage of nearby utility facilities
- types of transformers, capacitors, switches, etc.
- wiring configuration of each circuit (delta, horizontal, triangular, underground)
- distance of distribution wiring from the substation
- loads on the utility facilities — either loads concurrent with study or average and peak load information
- operational characteristics (i.e., hydro dependency; type of customers on line)

- wire code: Wertheimer-Leeper code or other wire-code classification scheme
- magnitude of site-supply voltage, peak power, current levels
- frequency (including dc) of power supply
- possible future changes to the electrical parameters.

3.4.4 Additional Information about the Occupants

Section 3.3 addressed the collection of data about the occupant activity patterns. Specific information about each occupant or group of occupants may provide insight about occupant patterns beyond the location data otherwise collected. This data can also be used for stratification in modeling group exposures by time-weighted-average (TWA) or other methods. Additional occupant information includes:

- job descriptions
- ages
- gender
- physical position (sitting, standing, supine).

3.4.5 Documentation of Non-magnetic-field Data

If your study is relatively simple, basic field notes may suffice for non-magnetic-field data collection. Pre-designed forms, such as the Pre-Site-Visit Questionnaire and the Source Identification Sketch and Data Sheet (Appendices C-2 and C-4) not only supply "boxes" for the data input, but also encourage the researcher to perform a complete survey. Where feasible, a good sketch of the conditions provides excellent locational documentation. The sketch should include room dimensions, equipment shapes and/or dimensions and numbers and types of occupants in the room. Photographs and videotapes, as discussed below, provide an excellent method of supplemental documentation.

3.4.6 Taking Photographs and Videos

We suggest that you take photographs or videotape the site, creating a permanent documentation of the conditions of the site and the locations of the occupants at a given point in time. Such record-keeping is highly valuable when you review the data and compile a report: it fills in many holes of even the best-taken field notes.

Still photos and videotapes have different advantages and disadvantages. Videotaping allows you to provide a simultaneous audio description of the area being taped, and puts the relative locations of the film subjects into clear perspective. Still photos are more readily accessible, and easily sharable; they can more easily be reviewed for reference and can be duplicated for inclusion in reports. Still equipment is also more portable and less expensive.

If practical, take photographs or videotape as you perform the magnetic-field measurements, so that the activities during measurements are documented. (With a limited technical staff, this will be difficult.) Be careful to log the location of each photograph, including the time, the exposure number, the position of the photographer, and the photograph subject. Take multiple photos of any given subject so that it is viewed in more than one perspective, and to ensure that at least one quality image is produced. A sample photograph log is shown in Appendix C.8.

If possible, use a camera with time-stamping features. Time stamps or time/date stamps further document the chronicling of events at the site, and make it easier to keep the handful of loose photographs in order.

3.5 Planning the Focused Magnetic-field Data Collection

In Section 2.7, we discussed the development of the measurement strategy as the decision-making plan by which you ultimately decide where, when, and what type of magnetic-field data will be collected. Through the steps of Section 2 and to this point in Section 3 you have gathered information and taken broad measurements to characterize the site. The preliminary data includes:

- Physical characteristics of the site
- Source locations and characteristics
- Activity patterns
- Project resources.

This section shows you how to systematically compile and analyze that preliminary information to determine the set of quality, exposure-relevant measurements that will comprise the substance of the reported magnetic-field data.

A measurement plan aims to finalize the following decisions:

- **Locations of measurements:** Determine where measurements should be performed in order to gain the most information about the environment characteristics with respect to occupant exposure.
- **Timing of measurements:** Determine a time representative of typical use and activity, taking into account times convenient to the site occupants for measurement, and taking into account the operational characteristics of the environment's sources.
- **Temporal measurements:** Consider whether you anticipate that temporal measurements will provide valuable information about magnetic-field variability over time.
- **Measurement Sampling Rates:** Determine sampling rates that will allow you to collect the field parameter of interest (e.g., frequency, variance).

This section formalizes a process that many investigators use instinctively in choosing their measurement plan and determining the need for special measurements. By formalizing the process and building in careful planning, you can best optimize the limited project resources in the following areas:

- **Time Savings:** The project resources allow time for a limited number of measurements. Those performed will be a set selected to best describe the environment with respect to the exposure of occupants.

- **Database Optimization:** Selecting a limited set of well-planned, exposure-relevant measurements will create a more manageable database. This is particularly true if waveform capture is performed, creating vast quantities of data.
- **Instrumentation Optimization:** By pre-determining the most exposure-relevant set of measurements, project instrumentation can be optimized to be used for spot and/or temporal measurements of appropriate length to fulfill the study needs.

Below we outline a step-by-step process for systematically making those decisions. This outline has been specifically designed for individually read spot measurements, but could be adjusted to pertain to field mapping.

3.5.1 Defining the Microenvironment Boundaries

Microenvironments are a basis for stratifying the environment to more clearly describe magnetic-field exposure. As we noted in Section 2.7.1, the microenvironment has been defined as follows:

> ***A portion of the environment and/or subenvironment defined by the homogeneity of occupancy or use and the homogeneity of the magnetic-field variability.***

Microenvironment boundaries have also been graphically described as a transparency overlay of the environment's sources and the activity locations. **When defining these boundaries, remember that this is a subjective process, limited by the accuracy and completeness of the source and activity information. Perfection is not required for this planning method to substantially enhance the exposure relevance of the data collection.** Also note that, for the sake of ease, you may consider the microenvironments to be mutually exclusive and mutually exhaustive.

Here are the steps to follow in defining the microenvironment boundaries:

1. Perform source identification (Section 3.2 provides further description):

   a. Identify the locations of magnetic-field sources.

b. Determine the approximate level of magnitude of fields created by each source.

c. Determine the type of spatial and temporal variability of the fields created by each source.

d. Note the approximate area of "influence" of the source by drawing its outline on a source map. (Figure 3.2a provides a sample sketch.)

2. Gather activity-pattern data (see Section 3.3).

   a. Identify the locations of occupants.

   b. Identify the numbers of occupants.

   c. Identify the length of time spent in any given area by the occupants.

   d. Designate those areas of activity on a site sketch. (See Figure 3.2b for a sample.)

3. Develop a sketch of microenvironment boundaries by outlining the areas of homogeneous use and homogeneous magnetic-field variability (the "overlay" of the sketches created in Step #1 and Step #2). (See Figure 3.2c for a sample sketch.)

4. Identify each microenvironment with a name appropriate to its use, occupants, or sources, such as: "Lisa's Desk"; "Kitchen Table"; "At Photocopier."

FIGURE 3.2

Sample Illustration of Overlay of Sources and Activity Patterns

FIGURE 3.2a: SOURCE IDENTIFICATION (w/areas of influence)

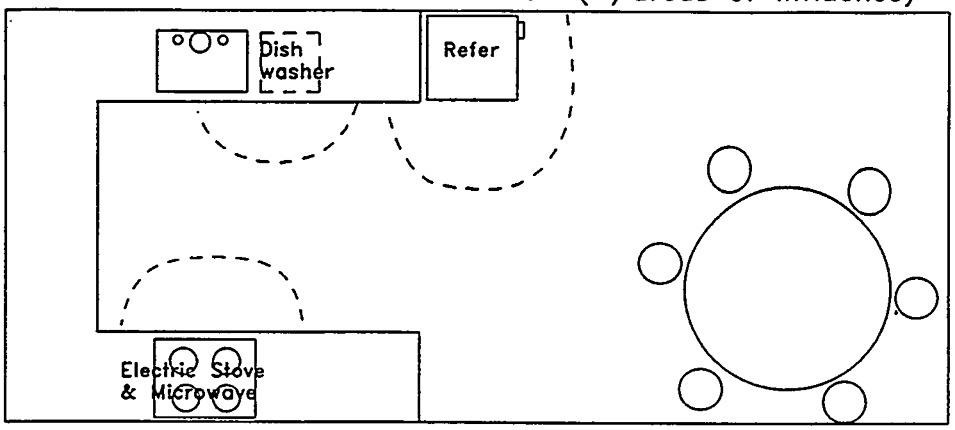


FIGURE 3.2b: ACTIVITY PATTERN LOCATIONS

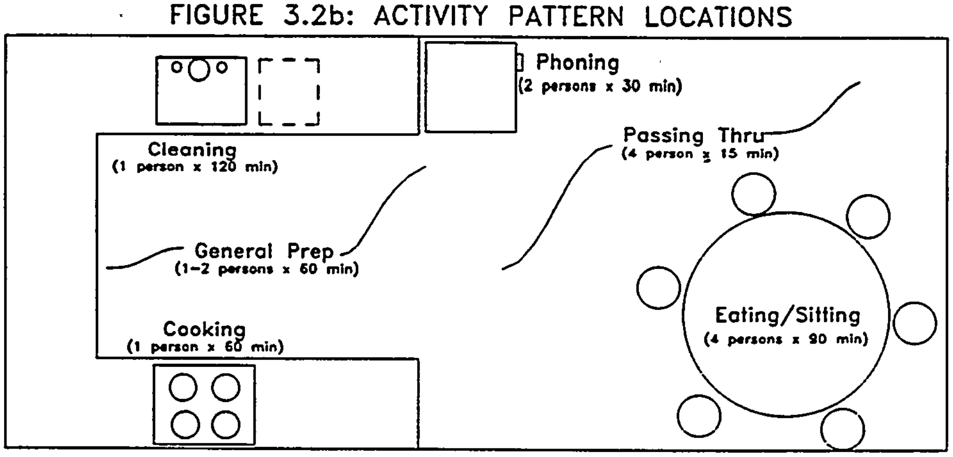
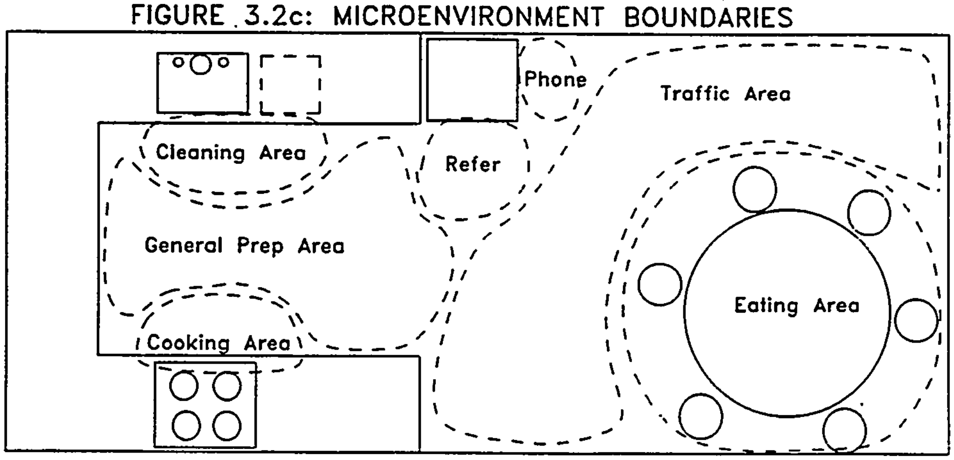


FIGURE 3.2c: MICROENVIRONMENT BOUNDARIES



Technically, you can carry out Steps #1 and #2 independently. In practice, however, it is helpful and normal to have a basic idea of the locations of sources while gathering information about activity patterns, and vice versa. The **interdependency of these two steps** is particularly important when you use an informant interview or questionnaire to gather activity-pattern data. Section 3.3 noted that an informant may better provide information about the relevant activity patterns if the locations of sources, and/or preliminary boundaries of microenvironments, are the basis of the questions presented.

Reversely, it helps to direct source identification to relevant sources by first understanding activity patterns; for example, a locked HVAC room that is rarely visited need not be studied in depth when performing the source identification. Preliminary activity indications are available from the following:

- Reviewing the pre-visit questionnaire responses,
- Observing area activities during initial walk-through and subsequent field work, and
- Making educated assumptions about activity patterns (e.g., "the desk chair within an office is the primary site of activity within that office," or "significant time is spent lying on the bed within a bedroom").

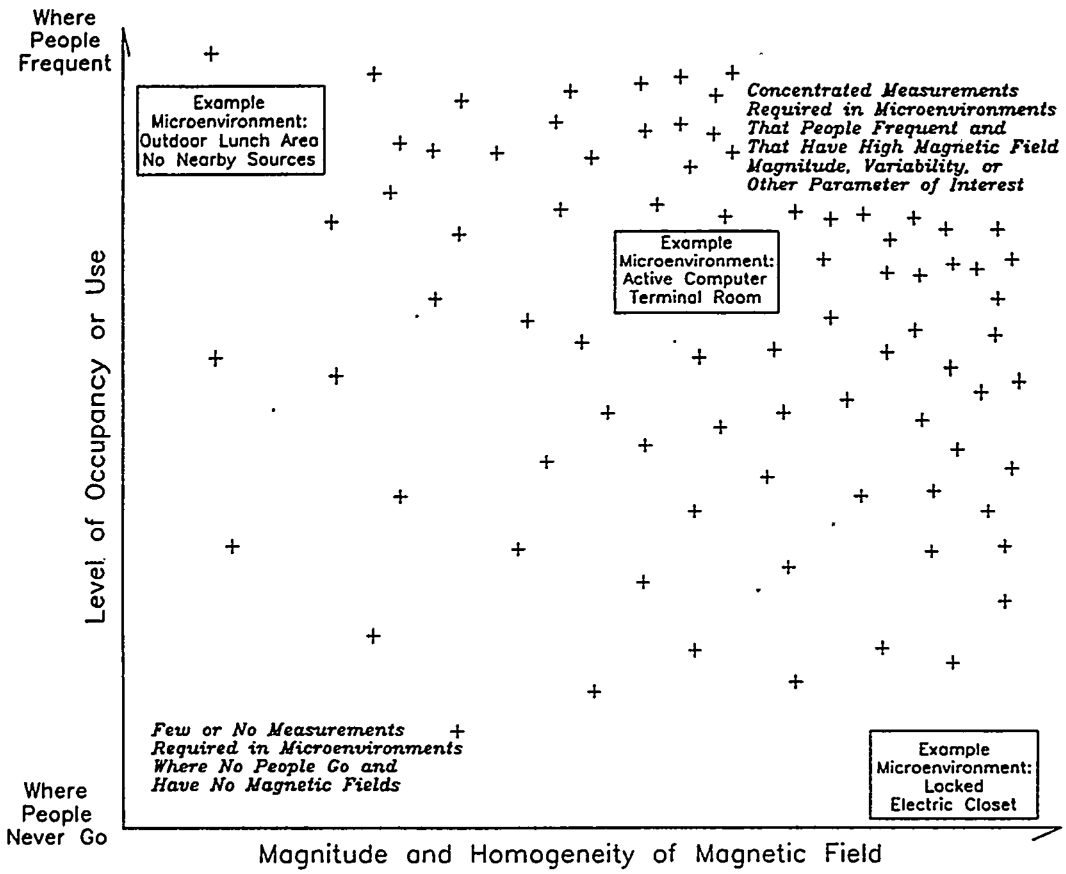
You can use the informant's responses to questions about the preliminary microenvironments to adjust and finalize the microenvironment boundaries, to better understand the source use, and to include in the focussed weighting process, as described below.

P.S. Defining the microenvironments for the Daycare Center and Grocery Outlet pilot studies proved straightforward. Activity pattern data was gathered in informant interviews, and merged with source information gathered in walk-throughs, measurements, and interviewing. Defining the microenvironments in the Metal Fabrication Plant proved more challenging. Like many industrial environments, the sources also defined workstations: i.e., a welding workstation involved a welder, and a lathe defined a specific machining station. However, in this facility, both the sources and the worker locations were portable and unpredictable. Few generalizations could be made about worker location or the sources in use (or their locations) at any given time. Therefore, the microenvironment boundaries in much of the plant were defined as follows: As much source information was gathered during the initial visit as possible. Exploratory measurements of sources operating were performed, and sources not operating were documented. Rough plans for focused measurements were made, to be based on the locations of the workers on the measurement day, making the assumption that the measurement day would be a typical workday. On the measurement day, each worker was approached, briefly questioned about his/her activities at that workstation, his/her uses of the workstation sources, and his/her typical position. Based on this conversation, the microenvironment boundaries were instantaneously defined and the focussed measurements performed. The responses of each worker were later verified with the site informant to ensure the information gathered was, in general, "typical".

3.5.2 Weighting the Microenvironments for Assessment

The purpose of weighting the microenvironments is to determine how much project effort (i.e., the relative number of measurements) should be given to each microenvironment, based on the study goals and project resources. Weighting will optimize the data collection so that the measurements performed are those that create the clearest picture of the magnetic-field environment. There is no need to perform measurements in "vacant" microenvironments or in an occupied microenvironment with no measurable magnetic field. Figure 3.3 illustrates conceptually where the data collection should be focused:

FIGURE 3.3
CONCEPTUAL ILLUSTRATION OF WEIGHTING THE DATA-COLLECTION EFFORTS



The weighting process is a qualitative product of several factors:

- the occupancy of each microenvironment
- the microenvironment's relative physical size
- the relative magnitude (or other parameter) of magn microenvironment
- the spatial variability of the magnetic field.

Do not attempt to base the weighting on purely quantitative parameters, weighted-average of occupancy or on the relative square footage of the microenvironment. Such objective weighting can skew too great a portion of the total of measurements to collecting unnecessary information. (For example, based on a time weighting, one third or more of all measurements in a home would be performed in the bed.)

Appendix C.9 shows a sample form that may be used to weight the microenvironments. This form suggests an eight-step process, as follows:

1. List the identified microenvironments.

2. Note the sources contributing to the magnetic fields within the microenvironment. Identify the predominant source.

3. Transpose the activity-pattern data to the decision matrix in the form of hours per week, per person-type, or other unit.

4. Determine the intensity of usage. This can quantitatively be described by the percentage of total person-hours, or by a qualitative rating, based on the activity-pattern information (i.e., 1 through 5).

5. Determine the relative physical size of the microenvironment with respect to all other microenvironments. In most cases a qualitative rating (Small, Medium, Large) is sufficient.

6. Determine the spatial variability of the magnetic-field magnitude. The spatial variability will depend on the sources affecting the microenvironment. (See Section 3.2.3 for more detail.) In the decision matrix, assign a qualitative rating (i.e., High, Medium, Low).

7. Determine a focus rating for the microenvironment based on relative usage and variability (Sharp, Average, Wide). A "sharp focus" rating would indicate that, based on the total time spent in each area and the presence of sources, a greater weighting for measurements should be given; a wide focus would indicate that fewer points would be necessary to characterize the environment; and an average focus would be the middle point.

8. Review the focus rating and the physical size to weight the microenvironment and select the appropriate number of samples in each microenvironment, as described below.

You may adjust the decision matrix based on the individual study goals. For example, if a protocol is threshold-based, no measurements need be performed in microenvironments where the technician is confidant that the threshold is never exceeded. If a certain occupant group is the focus of a study, its presence in a microenvironment should carry more (or all) weight with respect to the activity-pattern considerations.

In addition, when time is limited, identical or nearly identical microenvironments need not all be characterized. For example, if two identical machines are set up to be run by two operators in very similar manners, effort need be spent in characterizing only one of the two workspaces.

3.5.3 Determining the Number of Measurements to Perform

The total number of focus measurements performed should depend on the goal of the study, the nature of the fields, and the study's resources.. Collection rate will vary with each technical team, with instrumentation, and with the field parameter set selected for measurement. Our experience has shown that, after all other setup, preliminary information gathering, and data collection has been completed, a team can perform approximately 60-100 waveform capture spot measurements in an hour, using a standard setup.

Next, estimate the total number of measurements you plan on performing. If you intend to perform a series of different types of measurements, estimate a total sample size for each type, based on your understanding of the time and resources available.

Finally, determine the approximate number of measurements to be performed in each microenvironment. Obviously, the greatest number of samples should be assigned to the large environment requiring a sharp focus, and the least number to the small environment requiring a wide focus, such that the total sample size will be used. However, assigning a number of samples to each microenvironment is somewhat subjective as well. The technician should review those initial assignments and make the subjective determination as to whether the number of samples assigned is adequate (or over-adequate) to properly characterize the microenvironment.

P.S. A written decision matrix was used the Daycare Center pilot study to the weight of the microenvironments and to determine the number of focussed measurements to perform. The investigators reviewed the following information:

a) sources
b) occupants and activity patterns
c) number and sizes of the microenvironments
d) variability of magnetic-field magnitude within the microenvironments
e) the time allocated for measurements by the facility management
f) resources available for the study (such as time, manpower and instrumentation)

It was determined that time allowed measurements at approximately 80 locations. This quantity was considered sufficient for a quality analysis, based on the small size of the space. The technicians reviewed the source and activity information to subjectively determine the number of data points to be measured in each microenvironment, based on the goal of a total sample size of 80 points. The completed matrix is shown in Figure 3.4.

In small studies, such a formal decision-making process may not be necessary if an experienced investigator understands the data collection requirements simply based on rhetorical data. However, when a decision matrix was not used in the Grocery Store pilot study, more relevant exposure points were left unmeasured.

FIGURE 3.4
SPOT MEASUREMENT LOCATION DECISION MATRIX
USED IN DAYCARE CENTER PILOT STUDY

PROJECT Daycare Center SUBENVIRONMENT Classroom DATE 8/29/95

Microenvironment #	Microenvironment Description	Source number(s) from Initial Walkthru Data Sheet	Time Spent in Microenvironment (Note name of Persons and/or Groups): 4 Staff	28 Kids				Total person-hours spent in micro-environment	% of total person hours at site	Size of Micro-environment (S/M/L) small med large	Variability of MF magnuitude (L/M/H) low medium high	Focus (S/N/W) sharp normal wide	No. of Samples
			Estimate hours/wk for each occupant. If microenvironment is just passed thru, indicate "P"										
1	Electric Panel Area	9	4 × .5/d	28 × 1/d				30 h/d	12%	M	H	S	6
2	Floor Play/Reading		4 × 1/d	28 × 1.5/d				46 h/d	18%	L	M	N	8
3	Entrance		2 × .8/d	28 × .1/d				4.5/d	2%	M	L	W	2
4	Tape Player Area	10	3 × .5/d	1 × 2/d				3.5/d	1.5%	S	H	W	2
5	Bookshelf Area		4 × 1h/d	28 × 1.5/d				46 h/d	18%	L	M	N	6-8
6	Tables		4 × 1h/d	28 × 1.5/d				46 h/d	18%	L	L	W	6
7	Telephone/Radio		2 × 1.5/d	4 × 2/d 20 × .6/d				23 h/d	9%	S	L	N	3
8	Nap Area		4 × 1/d	28 × 1.5/d				46 h/d	18%	L	L	W	6
9	Kitchen Counter	1/2	1 × 2/d	O				2 h/d	1%	S	H	S	4
10	Copier/Fridge	3/4	2 × 15/wk	O				.5 h/w	~	S	H	N	3
11	Child Restroom		2 × .1/d	28 × .2/d				6 h/d	2%	S	L	W	2
12	Adult Restroom		4 × .3/d	O				1.1 h/d	1%	M	M	W	3

3.5.4 Determining Where to Perform Each Measurement Within a Microenvironment

A single spot measurement provides no information about the spatial variability of the magnetic fields in the environment. A series of spot measurements in a well-designed measurement plan can provide spatial and even temporal information.

You should select the patterns, or locations of measurements, within a microenvironment to best characterize the range of exposure experienced by the microenvironment's occupants. Many measurement protocols call for measurements to be based on specified distances from sources, (such as 6-, 12-, and 24-inches), regardless of the occupant's position with respect to the source. Some require a similar set of three measurements be taken in the direction of activity. While such a protocol provides further information about source characterization, measurements may consequently be made that provide little or no indication of an occupant's exposure (i.e., measurements are performed "where people never go," as illustrated in Figure 3.3). For each microenvironment, you should determine a rational set of locations in which the range of magnetic fields to which the occupant is exposed will be measured, while not compromising safety or work productivity. Some guidelines are found below in Table 3.7.

TABLE 3.7
GUIDELINES FOR LOCATIONS OF MEASUREMENT WITHIN THE MICROENVIRONMENT

EXAMPLES	CHARACTERISTICS	SELECTION OF MEASUREMENT LOCATIONS
Workstations or Other Stationary Locations: e.g., desk area, bed, at sewing machine	Long occupancy in relatively stationary position. Possibly high variability of fields from point sources. Sharp focus.	Five-point "X" pattern; center point in the approximate location of stationary occupant, with four points to the front, back, right, and left of the occupant, encompassing the bulk of his area of movement. If the location is characterized by a point source, one axis of the star should be in the direction of the source.
Workstations Where Safety and/or Disruption Are Factors: e.g., as at an active welding machine	Stationary position relative to source. High variability of fields from point sources. Sharp focus.	This may require that the occupant continue working during measurement. Set the five-point "X" pattern such that the center point is as near as possible to the occupant, with four points to the right-front, left-front, right-rear, left-rear, to avoid disruption and safety concerns.
Large Areas: e.g., conference table, restaurant dining table area, production floor area away from equipment	Uniform fields, occupied by people for varying lengths of time. Wide or medium focus.	Select a sample of occupancy points (such as chairs) <u>or</u> Perform measurements throughout the microenvironment in a grid pattern <u>or</u> Use a mapping wheel in a continual S-pattern.
Traffic Areas: e.g., hallways, aisleways.	Short occupancies, people moving from one microenvironment to another. Wide focus.	Minimum of two measurements, at least one every ten feet.

Determining the Height at Which to Perform Measurements. The height at which measurements are performed should theoretically be based on the portion of the body tied to any biological mechanisms of the magnetic fields. However, there is presently no biological basis by which to choose the most exposure-relevant height. Further, any such measurement height would vary by the height of the occupant and the position of the occupant (sitting, standing, supine). Widely accepted protocols and standards have suggested that all measurements be performed at a height of either three feet or one meter, presumably representing the center of body mass, for lack of an indication of a more biologically relevant area.

We acknowledge that no revolutionary guidance may be given here, and that three feet/one meter is a reasonable default. In addition, maintaining a single height saves time: not only are most instrument stands and mapping wheels designed to be used most efficiently when a single height is maintained, but, even with hand-held meters, a single-height protocol eliminates the need to determine and document varying measurement heights. However, a variation of heights, or a single height other than standard (three feet/one meter) may be appropriate depending on the goals and resources of the study. Some considerations are as follows:

> Varying height based on position of occupant: If a hand-held meter is being used, and/or time allows, a relevant body part may be selected for height determination (such as center of body mass or chest-height), and the height of each measurement determined individually, based on the position of the occupant, either standing, sitting or supine. The orientation of the meter relative to the body may be dictated as well.
>
> Studies involving children: In an environment where the predominant occupants are children, or if children are the study focus, a height(s) for measurement should be selected that represents their body mass. (For small children, the standard height of one meter is above their heads.) When occupants include both adults and children, you may wish to select the height of each measurement individually, based on the size and position of the primary user of that microenvironment.
>
> Study goals specific to body-part exposure: The study goals may include studying the exposure of certain body parts, or comparing the exposure of certain body parts. For example Sober (1996) performed spot measurements at the head, chest, pelvic area, thighs, knees, arms, hands, and feet.

Varying height based on sources: The technician may find it appropriate, when a microenvironment is dominated by a source at a level other than waist high, to select various heights in order to best characterize exposure within that microenvironment.

3.5.5 Determining the Timing Factors of Measurement

You should schedule the measurement period to coincide with operations and activity of interest in the study, though convenient to the site occupants. For example, school measurements should be performed while school is in session; retail measurements should be performed during the store's open hours. This may be impractical because of scheduling or disruption difficulties. If so, select as similar as possible a "surrogate" time period; the operations of the sources within the environment should represent those anticipated during the period of interest, i.e., lights and equipment should be turned on.

It is usually beneficial to compact the actual performance of spot measurements into as short a time frame as possible. A series of spot measurements is generally regarded as representing a snapshot in time (even though the report clearly states that the measurements were performed between, say 1:00 p.m. and 4:00 p.m.). By limiting the time period during which the measurements are performed, temporal changes in the environment that affect the measurement results are minimized. This is particularly important if a source with diurnal characteristics (such as a transmission line) is a large contributor to the environment's magnetic field. If you wish to describe a particular source's contribution over time, plan to perform *temporal* measurements of that source. This is much more effective than attempting to identify and interpolate the "moving target" background fields behind measurements performed over a time period in which the background is changing.

Typically, successfully expediting the spot measurements requires excellent preparation prior to measurements. For instance, you should:

1) **Plan the locations** of all spot measurements in the environment

2) Place **masking tape** at each measurement location, and label the masking tape to identify the sample

3) Take most **field notes** prior to measurement, and include the data sample labels in the field notes.

4) **Inform the area occupants** of your intentions and answer all questions during your setup rather than during measurements.

On the other hand, some researchers have found it useful to extend the actual act of performing measurements over the length of the time of interest (such an eight-hour shift in a manufacturing plant) in order to have inherently captured exposure information with respect to the time period of interest. Also, many protocols have suggested performing repeat measurements at several locations to identify temporal variability.

The **source operations** will be a substantial factor when determining measurement timing. You must consider the cycles of equipment when designing spot measurements and planning temporal measurements. Pre-determine the protocol for treating source operations. It is frequently part of the measurement protocol that the operations of sources (i.e., lights, equipment) be left in an **"as is" condition** when entering the environment. Some protocols (usually when studying utility contributions to fields) have performed a series of measurements with most sources off, in order to capture background levels from the utilities. Consider repeating measurements in a single location during different operation conditions (such as "ON" and "OFF", to gather temporal data. In all protocols, include in the field notes whether each source is:

- ON (usually on during occupancy)
- OFF (usually off during occupancy)
- INTERMITTENT (i.e., a source turned on for its use, such as a hair dryer)
- RECURRING (i.e., a refrigerator motor cycling on and off).

3.5.6 Planning and Performing Temporal Measurements

The performance of temporal measurements, as well as other special measurements, can require substantial project resources, including instrumentation, manpower, and expanded analysis. However, the validity of single spot measurements for analyzing exposure has long been questioned, and temporal and other measurements will augment your data set characterizing the magnetic-field environment.

Temporal measurements include any measurement or set of measurements designed to capture information about changes over time in magnetic field in a given location. Most frequently, temporal data collection will involve the setup of a recording meter to periodically capture a magnetic-field measurement. The length of the period will depend on the environment use and sources involved, such as the work day or a few cycles of a machine. In general a single instrument set-up will not characterize the temporal characteristics of the entire environment. Before planning the measurements, determine the direct purpose for each setup, for example:

- documenting the diurnal characteristics of a transmission line
- capturing the cycle of a single piece of machinery
- determining the TWA magnetic field at the selected location
- using a series of instruments in various location to get an indication of variation over the environment.

Security is a consideration when planning temporal measurements. The meters must be stationed where they are not in the way and do not hamper the safety of the environment. In addition, you must recognize the risk of theft or disruption of the instruments when left for a period of time.

Selecting Locations for General Temporal Variability. If resources permit, set up several instruments in the environment to get a general indication of temporal variation. Perform a series of exploratory measurements prior to setup to avoid setting an instrument next to a localized source, if this is not desired. Document the locations of the instruments on drawings, and document the relative location of nearby sources.

Period. Select a sample period tied to the purpose of the measurement The length of the work day or school day may be sufficient for a work environment or school. A 24-hour day may be more appropriate to capture the diurnal characteristics of utility facilities. When capturing the temporal characteristics of a piece of equipment, several cycles may be sufficient.

Sample Rate. A rapid sample rate will ensure that more temporal variation is captured. For example, greater maximums and lesser minimum measurements will be recorded, and you may be able to identify more periodic patterns. However the sample rate also linearly increases the volume of data collected. In fact, you may be limited in how much data your instrument can store, based on the factor of the sample rate and period length. Determine the limitations prior to setting up the temporal measurement.

Base your sample rate on the purpose of the temporal measurement. If you simply intend to record the TWA, a slower sample rate is adequate. If you are trying to identify periodic patterns from equipment, the sample rate should be maximized as your instrumentation permits.

Continuous data may be gathered with a digital tape recorder. Certainly with this method, no peaks or other events are missed. The data must be reviewed by hand in order to look for events, patterns, or idiosyncrasies in cycles.

Documenting Source Operational Changes. Perform a series of measurements at one location to gather information on the magnetic-field contributions based on the source's operation. Consider exposure relevancy when selecting the measurement location, but also consider positioning the instrument so that it primarily captures magnetic fields from the source of interest.

Set the length of time for recording based on the cycle of the equipment. If time allows, capture two or more cycles to ensure you have characterized the operation. Set the sample rate to ensure that you capture sufficient samples in the cycle to chart it. Note that in a short cycle (such as a copier making a copy), an instrument with a set sample rate of 1.5 seconds or so is not sufficient to effectively capture the cycle information.

Using Spot Measurements to Provide Temporal Information. Some studies have reported spot measurements that, rather than being a single instantaneous measurement, are a short series of readings (say, one every five seconds for thirty seconds), which are then averaged for reporting purposes. Using a survey- or recording-rms meter, this practice requires additional time, and thus financial resources, which may not be merited for the information it provides. It is perhaps more efficient to determine locations of temporal interest by watching the meter readout for a few extra moments at a location (particularly near sources of temporal interest), and then to plan temporal measurements only in locations where it is justified and where exposure-relevant. (Note however, that the Multiwave System II waveform system may be programmed to perform its "spot" measurements by taking a series such as this. You can thus efficiently gather valuable expanded information at each location, particularly in environments with continually varying sources.)

For a general indication of temporal variability in a simple spot-measurement study, return to some of the measurement locations later in your field work, and repeat the spot measurement.

3.5.7 Planning and Performing DC Measurements

The inclusion of dc measurements allows that both dc magnetic-field data and ac-to-dc orientation be reported. This may be appropriate if dc power sources are present, or when the collection of dc data is a project goal. DC spot measurements are obviously simple and appropriate to include in the measurement plan when using waveform capture instrumentation. Additionally, the simultaneous ac and dc measurement with a waveform capture system ensures accurate relative measurement of orientation, which has been suggested as a biologically relevant field parameter. If this parameter is of importance to your study, we discourage the performing of measurements with separate ac-rms and dc meters.

If dc measurements are included in your protocol, Bowman (Bowman (1992), pages 303-1 to 303-2) describes a protocol for performing five measurements in an "X" pattern in a given subenvironment: one in the center of the area, and four additional measurements 5-10 feet from the central point along the x- and y-axes. The five measurements will provide a better indication of the range of dc field than will a single measurement that might be substantially perturbed by a nearby object. Also, performing an additional dc measurement outside the site away from structures will provide a better indication of the area's unperturbed dc fields.

3.5.8 Planning Transient Measurements

The performance of transient measurements is most likely to be a valuable use of project resources under two conditions: 1) when substantial transients are suspected, such as in a welding environment, or 2) when a specific purpose of the study is to collect information on transients. Measurement of transient magnetic fields is the most complex of all magnetic-field measurements. All of the guidance given earlier in this document concerning mission, focus, and resources must be applied since there are an infinite set of "transient" conditions, which could be defined for any given study. Discussed here are some considerations when including transient measurements in your study. Because of the infinite set of transient conditions and the complexity of measurement, guidelines for performing the measurements are beyond the scope of this document.

Usually the goal of transient capture is to quantify the time course changes that take place in a temporal sample interval. Performance requires long-term setup of equipment pre-programmed to capture the desired transient events. Waveform capture may adequately serve this purpose if the device is "triggered" in advance of the point in time in which the transient event occurs. Therefore, pre-planning to have appropriate trigger circuits available must take place before arriving on the site. Questions to be resolved in advance are:

- Does the mission require the knowledge of peak fields?
- Within what time span?
- With what rise times to peak?
- With what settling time to "steady-state?"

- Is polarity important?
- Do the resources fit the mission?
- Does the search coil have the required bandwidth?
- Does the recording device have sufficient dynamic range, especially if dB/dt sensing is used?

The study goals and resources will govern the extent of transient measurements appropriate. If the environment includes a wide range of expected transient sources, each dominating microenvironments, multiple transient monitoring sites may be required to fulfill the study goals. Under other conditions and goals, a simple small spatial sampling may be appropriate to ensure that apparently small temporal variability is not confounded with superimposed low-magnitude but high-frequency transients (much greater than the fundamental frequency).

For transient measurements to be practical, measurement time spans should be separated in a manner analogous to frequency bands, with consideration for data storage space conservation. For rise time between 80 milliseconds and 80 microseconds (ELF bandwidth detectors), data storage would be accommodated by the system used for waveform capture of the ELF band. The capture of waveforms with rise times in the microsecond range or faster should only be attempted by those truly expert in high frequency measurements.

3.5.9 Guidelines for Instrument Handling and Orientation When Performing the Data Collection

Whether performing spot, temporal, or other measurements, the handling of the instrumentation will affect the quality of the data and ease of data analysis. Some guidelines for instrument handling are as follows:

Coil Location. Prior to performing measurements, determine where the sensors are within the instrument, so that it may be placed in the appropriate locations for measurement based on the sensors, rather than on the instrument casing.

Instrument Orientation. The relevance of instrument orientation should be considered prior to performing measurements. One of two protocols may be adopted: 1) selecting an x,y grid for the environment and performing the measurements with the coils consistently in the same orientation, or 2) consistently pointing the meter in the direction of sources. The choice will depend on how the measurements will be analyzed, and whether an x,y grid is being used for location reporting in the study. The z-axis is normally considered vertical, and should generally be maintained for all measurements for either of the above protocols. The x- and y- axes can be determined based on suggestions from Section 3.1.3, but you must understand the orientation of each coil within the meter to correlate the meter x- and y-axes with the environment x- and y-axes.

If you perform simultaneous measurements with two instruments to capture, for example, ac-to-dc orientation, then the relative orientation of both meters is critical. (However, we recommend that any such relative metric be captured using a single instrument or setup, such as a waveform capture system.)

Stability. Instruments with a frequency range including ultra-low-frequency ("ULF") fields will capture a ULF measurement if the sensors move through the dc field. It is therefore important to hold the instrument as still as possible when performing each measurement.

Using a **monopod or tripod stand** will enhance the stability of the instrument and alleviate this problem. It can also reduce the uncertainty in determining the relative location, height, and orientation of each measurement. However, the use of a tripod will hinder efficiency during the performance of a series of spot measurements. If using a stand, be sure it is of non-conductive materials.

Proximity to Other Materials. Keep the instrument away from ferromagnetic or conductive materials that are part of the technician's setup, such as a belt or a metal yardstick. IEEE Standard 664-1994 (IEEE 1994) recommends that non-permanent conductive or magnetic materials be kept a distance from the meter equal to at least three times the size of the object.

Recording the Magnetic-field Reading. Whether using a single-axis or three-axis meter, wait until the meter "settles in" to a consistent reading (e.g., after you have stopped moving) to record the measurement. Also, document whether you are reporting the maximum field or rms, as they can differ by a factor of up to 44%, depending on the polarization of the field.

SECTION 4: DATA MANAGEMENT, ANALYSIS, REPORTING AND QUALITY ASSURANCE

4.1 Data-Management Guidelines

Data-management methods are integral to all parts of the study. They help ensure that the collected data are maintained in an efficient manner. A data-management plan will include the following: protocols for documenting the measurement data: conventions for naming or labelling all data; structures for organizing the data for analysis; plans for maintaining the integrity of the data; and a quality assurance plan. Data management in a simple, individual analysis may simply require marking and saving the data so it is readily retrievable and understandable. A complex, multi-site study might require maintaining records of procedures used throughout the study and linking the information from instrumentation data records, field notes, and questionnaires into a format that may be queried for more complex analysis.

4.1.1 Documentation of Measurements

Field notes or forms should include the following information about each measurement:

- Location (either x,y, location or relative location)
- Microenvironment
- Time and date of measurement
- Magnetic-field reading.

When the instrument in use is recording the time, data, and magnetic-field reading, it may be acceptable to manually record this information only periodically, say every five or ten samples. These partial notes will assist in data review and quality assurance steps.

Use **sketches or maps** to document the locations of each spot measurement and any profile measurements. An x-y grid overlaid on the sketch or map prior to the visit will increase the sketch accuracy. Use a separate sketch for each floor level.

Waveforms from oscilloscopes or other meters, should be photographed, printed, or stored digitally.

When performing measurements in each microenvironment, document whether the sources are ON or OFF.

4.1.2 File- and Form-naming Conventions

The data-management plan may require two levels of identification with linkage between them:

1) identifiers for the data-collection tools (i.e., the data files, data-collection forms, instrumentation, field notes, photographs, and sketches), and

2) sample identification.

Data-collection Tools. File names should be unique descriptive names that unambiguously link the data file to the sample. They can include such information as date, site type, site identifier (if one has been chosen), or locations; numbers or initials for any of this information is acceptable. The Windows 95 use of file names beyond eight characters substantially broadens the choices of descriptive names for some software.

Example: EMDEX data file in metal fabrication plant:

	date	site type	site identifier
0601IN12:	**0601**	**IN**	**12**

(Note that four-digit dates as shown in this example should not be used where data collection spans multiple years.)

It is helpful to design the file-naming convention to take advantage of the normal sorting features of the operating system. For example, Windows displays filenames in alphabetical order by default. Numerals employed as part of the filename should be padded with zeros if required to maintain a consistent order (e.g., otherwise 11 will appear before 2, etc.). Additionally, place the more significant portions of the file name to the left where they will be used earlier in the collation. In this way, the operating system will, by default, present the data files in a coherent manner.

Each form used for data collection should be uniquely named as well. The project data from the various media can be linked by including a unique site identifier, such as a location number or measurement date, in the names of all associated files and forms. In a larger study, it may be helpful to print sets of stickers to affix to the instruments, data disks, and field forms to ensure unique, linked names.

Example: For the metal fabrication plant, use the site type/identifier **IN12** on all forms and files.

Consider including the serial number of the instrumentation used to gather magnetic-field (or other physical) data in the data-file name. In the event that trouble is later found with the instrument, the data from that instrument will be easily identified for a scrutiny of its quality. (Some instrumentation software automatically records the instrumentation serial number in the data files.)

A naming convention can also be developed if confidentiality of the data is required. In a multi-site study, such as an exposure assessment of homes or schools, the participants (i.e., the homeowner or school administrator) will frequently desire that the magnetic-field data not be specifically associated with the site. The site can be given a unique confidential identifier to link all associated data.

Use a camera or video-camera with time- and date-stamping capabilities to capture the site and events in pictures. A photograph log, such as that shown in Appendix C.8, should be used to document the time and location of each shot. After development, each photograph should be marked on the back with an identifier tying it to the photograph log.

Example: Use the study date plus the photograph number **0601-1**
or the site type/site identifier plus the photograph number **IN12-1**

Sample Identification. At a minimum, the time and location for each measurement or sample should be recorded. Data collected and saved by most instrumentation software is marked by the sample number; frequently the data is time-stamped as well. It is important that, within the field notes, each sample number be linked to a location. Samples should be identified by subenvironment (e.g., "bedroom"), the microenvironment ("in bed"), and the specific location in one the following forms:

- by location relative to a uniquely identified source
  e.g., 36" from the front of the microwave
- by an x,y coordinate
- by careful notation on the site sketch.

Using objective descriptions of the locations will streamline the identification process, clarify the data, and allow compilation of the data by location type. Particularly in larger studies, it may be helpful to codify the location descriptions, by codifying the sources, source types, subenvironments, and/or microenvironments. Such codification would allow efficient analysis of the magnetic-field data by source type, by subenvironment, or by microenvironment.

In addition to marking the data by location, you may choose to also mark it by time or by environment condition (i.e., source operating on, off). Even if the instrumentation records the sample time, recording times in the field notes proves helpful when deciphering errors or inconsistencies in the notes.

If a time-series of measurements is collected, the use of the "event mark" feature on many instruments can considerably enhance the accuracy of assigning the measurements to categories (i.e., when a transition occurs). Since the event mark is directly associated with the measurements, the mark will indicate the exact measurement and time where the transition occurs. A clock time recorded in the field notes may only be accurate to the nearest minute.

4.1.3 Data Organization for Analysis and Use

Succinct, complete data-collection forms and well-labeled field notes are key to organizing the collected data. In the most basic of studies, organizational requirements may simply include clean field notes with links to data files by name.

For larger studies, building a relational database will allow the data to be organized such that information is linked. This will provide flexibility and allow the data to be stratified in many ways for analysis.

Two types of data must be formatted for input into a computer database: measurement data which are already in a digital form, and the non-magnetic-field information from the field notes. In order to build a database, you will have to codify the field notes for input.

Information which could be codified includes:

- type of environment
- magnetic-field sources
- job or occupant classifications
- activities performed
- age of occupant
- dimensions of environment
- instrumentation
- environment conditions
- date of survey
- time of survey.

Time is typically used to link data for data analysis. Therefore, you must synchronize all data-collection tools, including: the internal clocks of instrumentation, computers, and cameras; the watches worn by technicians; and the effective clock used by the utility for the reporting of any utility load data.

Data-collection tracking may be helpful in a large multi-site study to monitor progress and ensure that the sampling goals are being met. For example, a state-wide school measurement study might have the goals to include percentages of rural and urban schools, of middle schools and high schools, and to include a certain number of industrial arts, home economics, and film classrooms. Setting up a simple database by which the collection of this information is recorded as the study progresses will allow the recruiting and focus to adjust to the remaining needs of the study. It will also allow accurate progress reporting to the sponsors.

4.1.4 Maintenance and Security of the Data

Obviously, ensuring that no data are lost is a primary concern of a data-management plan. Safeguarding data may be accomplished at three points: downloading, archiving, and auditing.

Downloading. Download all software data immediately upon completion of collection, and preferably while still at the site. Develop clear instructions for downloading, including instructions for naming the data files. This practice will ensure that the technicians leave the site with the data secure, and also provides an opportunity for the technicians to review the data in case of any ambiguities.

Archiving. Make backup copies of all data files immediately upon downloading, and clearly mark the files with the file name and date. A backup protocol may be written specifically for this task. In simple projects, you may not need to backup hard data, such as field notes or questionnaires, but be sure to make copies before mailing or shipping these forms to the project sponsor or to project headquarters for further analysis. Requiring that the field technicians maintain copies of both paper forms and magnetic media will protect against a crisis in the event of mail loss, and will allow the technicians to respond to questions or clarifications from the sponsor or headquarters.

The Audit Trail. During the quality assurance reviews of the data, it may be necessary to make manual changes to the collected data. An audit trail acknowledging these changes should be developed so that the changes are verifiable and remediable.

4.1.5 Contributing Data to the RAPID EMF Measurement Database

The EMF Measurements Database is a project sponsored by the EMF RAPID Program to make electric and magnetic-field measurement data more generally available. Data contributed or available to the Database is put into a standard format and then made available, either on the Internet or in hardcopy. The Database's web site can be found at <http://www.emf-data.ord>.

In providing a data set to the Database, one should keep in mind the importance of providing accurate documentation about the data, in addition to the data itself. Data alone are of little value, wince an outsider will understand little of what is necessary to correctly analyze the data.

Information on what is necessary to contribute a data set to the Database can be found on the web site, or by contacting and requesting a packet from: T. Dan Bracken, Inc., 5415 S.E. Milwaukie Avenue, Portland, OR 97202.

4.2 Data Analysis

Data collection can provide volumes of data, including spot measurements, temporal measurements and field mapping, using a variety of instrumentation collecting various field parameters. The choices for methods of analysis must be made based on the questions the study has been designed to answer, and upon the study resources and parameters. Extensive data analysis can require a substantial portion of the study's financial and time resources.

You may use commercially available database, spreadsheet, or statistical software, or develop a custom program to analyze the study data. Custom programs are also frequently provided with recording instrumentation to provide basic statistical analysis of the recorded data.

Summary measures of magnetic-field measurement should be relative and/or absolute measures understood by the audience, selected as appropriate for the project. Summary measures will be an outcome of three factors:

- the field parameters
- a stratification of the environment or environments
- a statistical relationship.

Field Parameters. A group of field parameters will have been measured, based on a selection process outlined in Section 2.5. When waveform capture is the method used, the waveform will have been recorded; the final selection of field parameters to analyze may be made even after data collection is complete. Because of the lack of an accepted biological mechanism related to magnetic fields, it is preferable that more than one field parameter be selected for analysis.

Stratification. The study data and the environment may be partitioned in one of several ways to provide specific information about the area, group, or time of interest:

- by type of environment (in a multi-site study)
- by subenvironment
- by micro-environment
- by group of microenvironments with similar sources
- by group of microenvironments with similar uses, activity patterns, or occupants
- by other physical characteristic of the environment such as age or construction type
- by time frame.

Of course, summary measures that do not involve a stratification may be reported, such as reporting the maximum ac-rms field measured in the given environment.

Stratifying by microenvironment may not yield statistically valid results because of the small number of measurements performed in any given microenvironment. Nevertheless, these summary measures can still provide an excellent indication of the range of magnetic-field exposures experienced by the occupants of the microenvironment. This can be particularly valuable in a study where the occupants, or others very familiar with the environment, are the study audience.

Statistical Relationship. Any of several statistical descriptors may be used for the data, including:

- minimum
- maximum
- arithmetic mean
- geometric mean
- 95th (or other) percentile
- percent over threshold
- standard deviation
- rates of change (in temporal measurements)
- counts (i.e., of transient events).

Again, the choice of statistics to report will rely on the study purpose. For example:

- if the study is threshold-oriented (i.e., performed for verification of health requirement compliance) then percent above threshold and maximum measures may be of most interest.
- In environments where magnetic fields are predominantly small values, such as in residential environments, measured magnetic fields tend to be distributed log-normally. Therefore the geometric mean may be a better indicator of central tendency for the measurements than the arithmetic mean. In such cases, it may be best to present graphical data in a format with a logarithmic scale.
- Mean and maximum measures are most frequently reported. However, the 95th percentile has been reported in many studies because it provides an indication of the high range of exposure without including outliers.

In all cases, the bio-effects of interest to the researcher should dictate some of the statistical calculations performed.

Expanded Use and Analysis of Data. Beyond reporting on the data collected based on conditions present during the study, the data may be manipulated to provide other interpolated information. Two frequent practices are: 1) modeling the exposure of the occupants of an environment, and 2) modeling the magnetic-field environment based on different set of physical conditions. Though these practices are beyond the scope of this report, they are briefly described below:

Occupant exposure modeling: Using a study strategy based on microenvironments provides an excellent database for performing exposure modeling based on TWA exposure. The field technicians may gather enough activity-pattern data to understand the length of time spent in each microenvironment by an occupant or group of occupants. The magnetic-field data may be analyzed to provide an indication of exposure within each microenvironment. The product of time and magnitude for each microenvironment may be summed to provide a model of total time-integrated exposure. Exposure modeling is the subject of a RAPID Report scheduled for publication in 1998.

Physical or operating condition modeling: Magnetic-field computational programs are commercially available. These can model the magnetic-field environment based on physical and electrical characteristics of current-carrying conductors. Such calculations are typically performed with reference to utility lines and facilities, but the principles may be used in any environment where the geometry and currents of the conductors are known. Input data for these models may be gathered in an environment-specific magnetic-field measurement study and the calculated fields compared with the measurements from the same study.

Because the relationship between electric current and magnetic-field magnitude is linear, simple adjustments may be made to field levels to interpolate between various current levels in small, predictable areas of a study.

4.3 Reporting

Your project report should be a compilation of all effort expended in performing the study, presented in a format appropriate to convey the information gathered to the appropriate party: the sponsor, the participants, and/or outside interests. The format will depend on the audience; on the desired study output; and on how the final data will be used. (See Section 2.1 for the initial discussion of this requirement.)

4.3.1 Information

The report should include information in the following primary areas:

- INTRODUCTION. A clear statement of the purpose of the project, its sponsors, and its audience. A summary of the background of the study. A brief description of the site.
- METHODS. A description of the methods used in the study to: determine the data of interest; collect the magnetic-field and non-magnetic-field data; and analyze and manage the data collected.
- RESULTS. The summary measures of the magnetic-field data. Details of source data, activity data, and other information gathered at the site.
- DISCUSSION. Not required for all reports. May include: a comparison of the study data to that of other studies; a description of how the results answer the questions in the statement of purpose; recommended future actions or further monitoring.

4.3.2 Report Structure

Determine the physical makeup and organization of the report, based on how the final data will be used, as you outlined according to Section 2.1 guidelines. Depending on the study requirements, the report will include a compilation of **descriptions, tables, graphics, and perhaps data sets on electronic media;** together, these characterize the magnetic fields at the site. In a more complete report, it may be appropriate to include a **report abstract, table of contents, and conclusions. Appendices** can be attached that include samples of forms, site photographs, etc. A **reference list** of any outside documentation used in preparation of the report should be included. Results may be reported in: text form, table form, graphical form such as 3-D plots, time graphs, and/or source location maps.

Table 4.1 describes the possible inclusions within each of the primary sections of the report.

> ***P.S.:** The final data of the three pilot studies were to be used to describe the magnetic field characteristics to the site occupants, and to be included in these guidelines. Therefore, clarity to the reader was of most importance in the report structure, and extensive codification—which might be required for a large sampling—was not of issue. Graphics frequently can provide the most clear picture of data and were thus used extensively. Tables were also used to provide a greater range of information (i.e., a series of field parameter information) in a succinct format. The figures and tables can be found throughout Appendix B.*

TABLE 4.1
PROJECT REPORT LAYOUT AND SAMPLE CONTENT: Page 1 of 2

	REPORT SECTION	SUBJECT MATTER	POSSIBLE ILLUSTRATIONS, TABLES, APPENDICES
INTRO	ABSTRACT	Brief summary of purpose, methods, and summary results	
	INTRODUCTION	Project purpose Project background Introductory site description	Site map Photos of the site
METHODS	SITE SELECTION	For multi-site reports: discussion of sample selection	
	INSTRUMENTATION	Trade names of instrumentation Technical information on instrumentation Instrumentation settings Time synchronization methods Calibration and operation verification methods	Calibration reports Photos of the instrumentation in use
	MEASUREMENT PROTOCOLS	Time and date of measurement period Persons performing the measurements Summary of the measurement protocol Reference to other protocols or standards observed Description of field parameters collected Methods for selection of measurement locations Quality assurance steps taken	Sample of forms used Maps of measurement locations
	METHODS FOR COLLECTION OF ACTIVITY-PATTERN AND OTHER NON-MAGNETIC-FIELD DATA	Names of data sources, such as site contact or utility personnel Quality assurance steps taken	Sample of forms used Samples of outside data used, such as wiring maps
	ANALYTICAL APPROACH	Sampling strategy Selection of field parameters for measurement Definitions of summary measures Evaluation criteria Methods of special analysis such as computer modeling Quality assurance steps taken	Stratification tables
	DATA-MANAGEMENT METHODS	Description of database structure Downloading and archiving methods Quality assurance steps taken	

TABLE 4.1
PROJECT REPORT LAYOUT AND SAMPLE CONTENT: Page 2 of 2

RESULTS	NON-MAGNETIC FIELD DATA	SOURCES	Discussion of identified sources Locations of sources Source classification Operational status Manufacturers' information Motor size, power requirements, frequency, etc.	Source location map Power facility map
		ACTIVITIES	Locations of people General description of use of the space Numbers of occupants Categories of occupants ("casual" users versus regular, job description, age, sex etc.) Brief description of results (i.e., which major source areas are frequented by people)	Activity location map
		SITE DETAILS	Classification of environment Age of environment Magnitude of supply voltage, peak power, current levels Structure type Possible changes in future to structure or electrical parameters Weather conditions during study	
	MAGNETIC-FIELD DATA		Magnetic-field summary measures	Summary measures in tabular form Lateral profiles from sources 3-D representations of area data Maps with measurement data
DISCUSSION	DISCUSSION		Study limitations Mitigation measures Suggestions for future monitoring Comparison of collected data with results from other studies Comparison of data with industry guidelines, standards, or thresholds	
	CONCLUSION		Summary of study results	

4.3.3 Participant's Report

Frequently, the participating environment's representatives (the site contacts, informants, or others) are not the recipient of the final report, as with multi-site assessments. It is then appropriate to provide an abbreviated version of the data to the site contact. This summary may include, in a format readily understood by individuals less familiar with magnetic-field physics, the following items:

- a discussion of the purpose and methods of the study;
- summary measures of the data collected, and definitions of the summary measures;
- a comparison of the site data with data collected study-wide;
- a comparison of the site data with data collected in previously published studies;
- pamphlets, articles, or references to sources for more information about exposure; research or studies similar to the subject study; and
- a letter of thanks for the site's participation in the study.

4.3.4 Tailoring the Reports for the Audience

Whether you are preparing the primary report or a participant's report, it is important to remember the makeup, interests, and technical capabilities of the audience. You must gear the report language and difficulty of sentence structure to that group which will be using the information. Additionally, you must acknowledge how much of the report the audience will actually read, and how much effort they will put into absorbing the information. If a substantial part of the audience may simply flip to the table and graphs (or if the tables/graphs could possibly be reproduced outside of the report), it is imperative that the tables and graphs be designed and labeled to stand alone, and that they convey a summary of the report information.

Also recognize, particularly in a public or published document, that your audience may include a range of readers with various technical qualifications and interests. In order to accommodate the broader audience in a report targeted to a more sophisticated reader, consider including:

- a glossary of terms used in the text
- definitions of terms within the text, as possible
- background information in an appendix, or references to background information, such as magnetic-field fundamentals or a summary of the purpose of magnetic-field research.

4.4 Quality Assurance Methods

A quality assurance plan seeks to ensure that the data collected and reported are valid and consistent. You should develop this plan during the study planning process.

Quality assurance steps can and should be specified for each phase of the study. For example, checklists may be developed for use when gathering the non-magnetic-field data to ensure completeness; calibration verification steps may be planned prior to measurements to ensure instrument accuracy; and backup protocols may be developed for the data-downloading phases to ensure data preservation. General rules for inclusion in the quality assurance plan, applicable to many study phases, are described below.

4.4.1 Minimizing Subjectivity Throughout the Project

Given the infinite number of differences in sources and activity patterns between and within environments, performing an assessment of an environment will involve much subjectivity, and much of the detailed measurement planning may take place in the field upon site review. Nevertheless, you can minimize the measurement subjectivity and thus enhance the quality of the data. This can be accomplished in the following tasks.

- Produce a written protocol.
- Use standard, succinct data-collection forms (see Appendix C for samples).
- Collect objective data.

4.4.2 Developing Forms and Checklists to Assure Completeness and Consistency

Encourage the technician to follow the planned processes, to gather and document the expected data information, and to ensure the completeness and consistency of data by developing succinct data-collection forms and checklists. Such forms will compel the technician to "fill in the blanks" and "check all the boxes," verifying that all requested study steps have been performed before leaving the site. Checklists can be developed as follows:

- A protocol checklist can outline step-by-step the tasks in the data-collection protocol.
- A field-kit checklist will itemize the instrumentation and supplies required for the study, ensuring that the technician arrives in the field fully equipped.
- An equipment initialization and usage checklist will direct the technicians less familiar with the equipment's settings and uses by describing the step-by-step procedures.
- A data-management checklist can be developed to detail the steps required for downloading, inspecting and backing up the magnetic-field data.

As discussed in Section 3.1.4, you may develop forms for each step of the data collection, including source identification, activity-pattern data collection, non-magnetic-field data collection, and the magnetic-field data collection. Sample forms are shown in Appendix C.

4.4.3 Ensuring Technicians have the Appropriate Expertise to Perform Data Collection

The technicians performing measurements in the field should be trained in the use of the project instrumentation. They should also have a reasonable understanding of magnetic-field physics, so that field decisions can be intelligently made, and ambiguities in the data will be more evident. If such expertise is not available, you must plan a program to sufficiently train those who you have selected to perform the data collection. Ensure also that outsiders providing base information (such as utility or facility information) are qualified to provide accurate information. A good communication system should exist among technicians, and between the home office and the field technicians.

4.4.4 Ensuring the Accuracy of the Study Instrumentation

Ensuring instrumentation accuracy is a most critical piece of the quality assurance plan. It involves periodic calibration verification, regular function verification, user training, and documentation of the instrumentation used in the study.

Calibration Verification. The calibration of all study instrumentation should be verified regularly. At a minimum, the instruments' calibration should be verified according to the manufacturer's recommended schedule, and when dropped or otherwise affected. Set a calibration schedule for longer-term projects, with a verification of perhaps every month. Calibration procedures have been defined in IEEE Standard 644-1994.

For rms meters, or for waveform capture meters with rms readouts, the verification can be a simple process within a reasonable tolerance. Using a commercially available magnetic-field-producing coil, check the calibration in each of the three axes, and test the meter in perhaps three field ranges. The meter may be sent to the manufacturer on periodic basis (e.g., yearly, if recommended) for a thorough check under controlled conditions.

Function Verification. Verify the function of each instrument prior to each data-collection day. With most rms meters, a typical problem is that a coil can become disconnected or damaged. In this case, that directional coil will simply display a measurement of 0.0 mG, even near a source. A quick operational check of each coil will identify such a problem. The power capacity of the instrumentation should be determined during the functional check also, either by verifying sufficient capacity or recharging or changing a battery. You can monitor the instrument function in the field, where possible, by observing data collection in all of the instrument's sensors.

User Training. Ensure that the instrumentation is being used properly, by training the technicians on the specific equipment before they use it. The training also gives you the opportunity to verify that like instrumentation is operating identically.

Document the Instrumentation Used. Document, in the field notes, the serial number or other identifier of the instrumentation used for each phase of the study. Even with a properly implemented function verification and calibration plan, the risk exists that an instrument will malfunction without the technician's knowledge. By carefully identifying the data tied to a given instrument, suspect data can be easy identified in the event of malfunction, and either replicated or removed from the database. Keep a calibration log on each instrument so that potentially bad information can be identified.

4.4.5 Collecting Duplicate Information

Duplicating the recording of data using varied formats creates a backup that can be used to authenticate and clarify the data. Sample methods are as follows:

- Take photographs or videos of the site and sources, in addition to drawing field sketches.
- Document the locations or sources, people, and measurements on sketches, in addition to using a written description or code identifier in the field notes.
- During data collection by the instrumentation, note the measurements in the field notes. This allows an easier review of the information of the data in the field, allowing more complete in-field identification of data discrepancies, unidentified sources, etc.
- Write the time and date of a measurement in the field notes, even though the instrumentation is collecting this data.

4.4.6 Clearly Identifying All Information

Each piece of data collected should be clearly labeled. For dataset information, this requires that each form, data file, photograph, etc. be marked with an identifier indicating its data set. File-naming conventions are discussed more thoroughly in Section 4.1, Data Management Guidelines. For each individual sample, ensure that the time, location, orientation, instrument settings and environmental conditions have been documented.

4.4.7 Inspecting and Analyzing Data in a Timely Manner

No two environments are alike. Therefore, even with the best of intentions and most the objective field notes and forms, data ambiguities will arise that will require recollection of events in the field. Timely review and analysis of the data is imperative.

Inspect the collected data to ensure its validity and consistency. An immediate overview often will show discrepancies, missing information, and an indication as to whether the measurements "make sense." Steps in the quality assurance plan may include the following:

- Review the data-collection forms to assure that all requested data has been documented.
- Review the site data to identify areas of elevated conditions that might indicate unforeseen sources or conditions.
- Check temporal data sets to see that they "make sense," (i.e., twenty-four hour recordings should show a cycle based on the use of sources nearby; "straight lines" in the data may indicate an instrument malfunction).

While excellent documentation and immediate inspection should eliminate most data errors and ambiguities, analyzing the data in a timely manner is also important. Timely analysis provides a continued opportunity to tap into the recollections of the field technicians, if necessary, and to return to the study site for data clarifications while the environment is in relatively the same condition as during the study period.

4.4.8 Backing Up Everything

Develop a plan to backup all forms of data. Instrumentation should be downloaded as soon as possible, and transferred to two sets of media (i.e., your computer hard drive and floppy disks). Copies of hard data should be made prior to mailing them anywhere.

4.4.9 Performing Pilot Studies

If possible, test the planned protocol and instrumentation before the study by performing one or more pilot studies. Pilot studies will help pinpoint subjectivity in the protocols and any ambiguities in the forms and checklists. They will provide an indication of the time requirements of the study. They will also give the technicians the opportunity to test the instrumentation and identify any differences in default settings. **Pilot studies are a particularly important quality assurance step in broad data-collection projects where protocol consistency is important, and for studies when the technicians are less familiar with the instrumentation.**

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APPENDIX A.1: LITERATURE REVIEW OF MEASUREMENT STUDIES

In order to gather information about previously used methods for environment measurements, a literature search was performed. The literature search included published articles and project abstracts for studies that involved magnetic-field measurements specific to environments or sources, hereafter described as area measurements. Studies involving only personal exposure recording (PEM) were not included in the review. The purpose of identifying similar past studies was a) to draw upon the study designs for development of the environment-specific measurement guidelines, and b) to provide a list of studies similar in purpose, environment focus, and selected instrumentation that may be referred to when a developing a measurement plan.

The literature review was not exhaustive. Rather, a representative set of studies was identified to provide information about the factors considered in previous study designs. This review went beyond the breadth of environment characterization studies. It included source characterization studies and personal exposure (PE) assessments augmented by area measurements. Such related studies lend insight to the aspects important to designing an environment characterization study, such as source identification and exposure-relevance.

In order to perform the review, data about each study was collected in a format shown in Table A.1 at the end of this section. An identified study was included if the available report or abstract contained sufficient facts to define the study protocol and purpose. Seventy-five studies were included in the review. A summary of each study review is included as Table A.2. The reader may refer to this table to identify the studies with the features discussed below.

Features of the studies may be summarized as follows:

A.1.1 Study Purpose

The inherent objective of most magnetic-field measurements is to provide information with respect to magnetic-field exposure. The most direct method of exposure assessment is to perform personal exposure measurements (PEM), where a subject wears instrumentation that gathers and stores magnetic-field data over a period of time. Area measurements act as a surrogate for, or expand upon, PE information. The purpose of most studies involving area measurements may be described in one or more of five broad categories: environment characterization, source characterization, exposure assessment, methods validation (for environment or source characterization or exposure assessment) and data collection for epidemiological studies.

- **Environment Characterization (28 of the studies reviewed):** Measurements were performed for the purpose of characterizing the magnetic fields in a specific environment. Sub-purposes within this group include a health-hazard evaluation request, verifying suspected high magnetic-field levels in a particular industry, or the collection of magnetic-field data with respect to an environment group. A few of the studies were designed to specifically identify the contributions of a particular source to the selected environment, such as contribution from power lines.

- **Source characterization (15 studies):** Information was gathered about the magnetic-field characteristics of a particular group of sources. These studies were performed in either a laboratory setting or in the source's typical environment. Measurement protocols were designed to capture the characteristics of the source magnetic fields, disregarding the background environment. In many of these studies, the relevance of the measurements to exposure was not a factor. Rather, the measurement locations were selected solely based on distance from the source.

- **Exposure Assessment (12 studies):** These studies were performed to characterize the magnetic-field exposure of an individual or group of individuals in a specific environment. Measurements at the locations which the individuals occupy are of primary importance for exposure assessment. Some of these studies included PEM, augmented by area measurements. In other studies, the area measurements were performed as a surrogate measure of exposure assessment.

- **Methods validation (9 studies):** The purpose of nine studies reviewed was to validate or compare methods of environment characterization or exposure assessment, including modeling. Exposure data were gathered using one or more methods, and the results of the collection or modeling were compared to determine the similarities between methods.

- **Epidemiology (10 studies):** Area measurements have been frequently used as a surrogate measure of exposure in epidemiological studies. In each of the ten epidemiological studies reviewed, one or more exposure metrics was calculated for comparison with specific health risks.

A.1.2 Environments

Research on the health effects of magnetic-field exposure has focused substantially on home exposures and on elevated exposures in occupational settings. These environments have therefore been the subject of many magnetic-field studies performed over the past twenty years. In addition to the numerous published reports of home measurements, utilities have performed tens of thousands of home measurements nationwide at the requests of customers. The following environment groups were included in the studies reviewed:

Environment Group	Number of Studies
Residential	27
School	6
Transportation and Communication	9
Medical Services	3
Agricultural	0
Industrial	14
Commercial Office	11
Trade & Services	4
Electric Utility	13

A.1.3 Sources of Interest

Several studies have focused on the magnetic-field characterization of specific equipment. As stated above, source characterization was the primary purpose of fifteen of the studies reviewed. Utility facilities (distribution lines, transmission lines, and substations), have been the subject of many area measurement programs. Other sources of interest have included: a) industrial equipment, b) home appliances, and c) non-home sources to which children or other members of the public might be exposed.

The following sources were characterized in the literature reviewed:

- Infant incubators and heating beds
- Sewing machines and cutters
- MRI human exposure room
- Naval communications equipment
- Home appliances
- Cellular telephones and battery packs
- Arcade video games
- Industrial induction heaters
- Arc-welding equipment
- VDT's
- Plasma cutters
- Electric furnaces
- Jigsaws
- Utility distribution lines
- Utility transmission lines
- Substations

A.1.4 Instrumentation

Magnetic-field instrumentation has developed over the past twenty years with the expanding demand for further information about exposure. Before 1990, virtually all studies were performed with a single-axis, non-recording survey meter. In a few cases, researchers developed homemade instruments to gather three-axis data or frequency information. Since then, lightweight, three-axis recording instruments and waveform capture systems have become commercially available, expanding the researchers' sources of practical instrumentation. The instrumentation used in the studies reviewed included the following:

- **Single-axis survey meters (28 studies):** Single-axis meters generally are handheld devices with a digital or analog display that uses a single coil or loop to measure the field in one direction. The researchers reported either the maximum magnetic field, found by rotating the coil to locate the orientation of the fields or by measuring consecutively in three orthogonal directions and calculating the resultant field from the square root of the sum of the squares of the three readings.

- **Three-axis recording instruments (33 studies):** These instruments involve three orthogonally located coils that simultaneously measure the magnetic flux density. The resultant magnetic field is internally calculated, and the resultant and, in some meters, each of the three axis measurements are recorded. The measurements may be performed at a time interval specified by the user and stored in memory. These meters were popularized by use in PEM (in which the subject wore the recording instrument over a period of time). They also may be used in the following modes: as a survey meter for spot measurements or source detection, as a long term fixed-site recorder, and in conjunction with a mapping wheel for area data collection.

- **Three-axis survey meters (3 studies):** These meters operate in the same manner as the three-axis recording instruments, but are not equipped to store data. They have recently become commercially available as an inexpensive survey device—more user-friendly than their single-axis predecessors.

- **Multiwave System (9 studies):** The Multiwave System II (and its predecessor the Multiwave System) is the waveform capture system presently commercially available. The system digitizes and stores analog waveforms from a triaxial fluxgate magnetometer, and will compute a wide range of magnetic-field parameters based on the waveform information.

- **Spectrum and waveform analyzers (14 studies):** In order to capture waveforms, researchers have used such equipment as oscilloscopes, spectrum analyzers, and FFT analyzers in conjunction with magnetic-field probes and coils. Data collected by the Multiwave System can be analyzed to provide a spectral composition of the waveform.

- **Mapping capabilities (13 studies):** Mapping wheels have been used in conjunction with three-axis recording instruments. The instrument is attached to a wheel and mounting platform which sends a trigger pulse to record a measurement at specified distance intervals. The instrument maintains a record of the location of each measurement so that the magnetic-field data can be spatially analyzed.

A.1.5 Activity-pattern Considerations

The seventy-five studies were reviewed to determine the extent to which information about the activity patterns of environment occupants was gathered for consideration in the measurement plan. Because most magnetic-field research has stemmed from the concern about health risks, activity patterns are inherently factored into the study design; even with no additional review of activity patterns specific to the subject environment, most studies involve measurements in areas of expected occupancy (for example, a "center of bedroom" measurement). A few studies included no consideration; for example, power-line magnetic fields were characterized by performing lateral profiles under the lines, away from any occupied areas (Feero (1989)). The following methods of obtaining activity information were observed:

- **Interviews and questionnaires (11 studies):** Subject or informant interviews provided activity-pattern data that were used to determine the locations for measurement. The extent of this information ranged from determining rooms "frequently occupied" by the subject, to discussing with a worker his/her normal position at a specific worksite.

- **Worker Location Determination (15 studies):** The researcher determined the "worker location," either by interview or visual determination, and selected the measurement locations accordingly.

- **Focus on exposure of body parts (5 studies):** Measurements were taken at specific body part locations, either with or without the subject present. This meant that the researcher had to gather information about the body position prior to his/her measurements..

- **Personal exposure measurements (17 studies):** The activities of the person who is being assessed are, by default, a component of PEM. In ten of the studies, the researchers used questionnaires or other means to gather activity-pattern data. However, in seven of seventeen studies involving PEM, no other activity information was gathered to determine the locations for augmenting area measurements.

- **No activity-pattern data collection (32 studies):** No activity-pattern data specific to the study were gathered to facilitate the selection of measurement locations, and no PEMs were performed.

A.1.6 Area and Spatial Variation Data-collection Methods

The most commonly used method of collecting magnetic-field data in area measurements is the point-in-time or "spot" measurement of magnetic-field magnitude, in the frequency bandwidth dictated by the instrumentation in use. Most of the studies reviewed used more than one technique to gather information, in order that spatial variation, temporal variation, exposure relevance, and or frequency information could be assessed.

The following methods were used for collecting area data and information about spatial variability:

- **Point-in-time or "spot" measurements (48 studies):** Spot measurements were performed at selected locations in the environment.

- **Exploratory measurements for source detection (5 studies):** A handheld survey meter was used to investigate areas of elevated fields to determine the field sources.

- **Peripheral profiles (9 studies):** Measurements were taken in series around subject buildings to capture information about external sources. A survey meter or a mapping wheel and recording meter was used.

- **Lateral and parallel profiles (9 studies):** Measurements were taken in a path perpendicular and/or parallel to power lines to characterize the magnetic-field falloff with distance from the lines. A survey meter or a mapping wheel and recording meter was used.

- **Area Mapping (5 studies):** With the use of a mapping wheel, magnetic-field magnitude was recorded, together with the corresponding location of measurement. Using three-dimensional interpolation, the data were graphed for spatial analysis of the fields over the measured area.

- **Spot measurements at sources (12 studies):** Spot measurements were performed at a series of specified distances from a source to characterize the spatial variation of the magnetic fields produced by that source.

- **"Walk around" data collection (4 studies):** Health hazard evaluators use the practice of "walking around" to collect data, which involves using a handheld recording meter to pass through worksites and search for sources, while using the recording feature of the instrument to collect the data about the environment and worker exposure. Other than with notes or event markers, the magnetic-field data are not sufficiently linked to location data to provide any summary measures.

- **Personal exposure measurements (17 studies):** While PEM captures spatial information as the meter wearer changes location, information about the locations must be collected using time-diaries or other methods.

A.1.7 Temporal Variation

Magnetic fields vary over time. However, before recording meters were developed, it was arduous to capture information about the temporal variation of fields. It has more recently been a factor in most study designs. Temporal variation was factored into the reviewed study protocols as follows:

- **Operational variation (12 studies):** Measurements were repeated under various operating scenarios, such as power on/off, or vehicles accelerating, maintaining speed, and decelerating.

- **Spot-measurement repetition (6 studies):** Spot measurements were repeated in the same locations at various times of day or seasons to determine diurnal or seasonal variation.

- **Long-term measurements (27 studies):** Data was gathered at a fixed site for 24 hours (or other selected period) at a sample rate selected by the researcher.

- **Averaged "spot" measurements (3 studies):** Reported "spot" measurements were in fact the average of measurements repeated over a very short time (i.e., recording at a fixed site every second for 30 seconds).

- **Continuous data collection (3 studies):** A digital tape recorder was used to continuously gather digitized waveform data, which could later be reviewed for temporal variations not evident from other sampling methods.

- **Transient-data collection (5 studies):** Instrumentation was set to be triggered by and record magnetic-field events outside the parameter thresholds set by the user.

- **Personal exposure measurements (17 studies):** Temporal variation specific to the subject, rather than to the environment, is gathered in PEM.

- **No consideration (18 studies):** Only spot measurements at a single point-in-time were performed in eighteen of the studies reviewed.

A.1.8 Frequency

By far the majority of magnetic-field studies performed report the magnetic-field magnitude based on the frequency response of the handheld instrument used for measurement. However, other methods and instrumentation were used in at least forty-one of the studies reviewed to gather expanded frequency information. These methods included:

- Very-Low-Frequency (VLF) measurements with VLF instrumentation (3 studies)
- Multiwave System waveform capture (10 studies)
- Measurement of the harmonic component with the EMDEX II meter (6 studies)
- Use of the flat and linear modes of a single-axis meter to estimate harmonic content (4 studies)
- Use of oscilloscopes, spectrum analyzers, and FFT analyzers (14 studies)
- Use of an added adaptor to capture the third harmonic (2 studies)
- Measurement of the static field using a magnetometer (4 studies).

A.1.9 Measurement Literature Discussion

The evolution of magnetic-field measurement protocols has been driven by: a) the expanding interest in exposure assessment, b) new hypotheses of biological mechanisms, and c) the commercial availability of more practical instrumentation. Instrumentation is now available to capture nearly all aspects of magnetic fields in an environment. However the quantity of data produced in such an exhaustive measurement protocol would be unmanageable. As can be seen from the literature reviewed, even in the early studies, a clear study purpose helps to focus the study design. The consideration of activity patterns in the measurement plan will help assure the exposure relevance of the data collected, as the list of parameters for measurement continues to expand.

TABLE A.1
FORMAT FOR SUMMARIZING AREA MEASUREMENT STUDIES REVIEWED

REFERENCE	author, year
CITATION	author, title, journal, date (more than one if related to same study)
STUDY PURPOSE	environment characterization, source characterization exposure assessment, methods validation, epidemiology
ENVIRONMENT	residential, school, transportation & communication medical services, agricultural, industrial commercial office, trade & services, electric utility (no environment if source characterization not specific to an environment)
SOURCES OF INTEREST	source which recieves specific focus in study, i.e., power lines, appliances
DATA-COLLECTION METHODS	spot measurements, long-term, PEM
INSTRUMENTATION	manufacturer, model
SAMPLE SIZE	number and types of units (environments, sources, subjects, etc.)
LOCATIONS OF MEASUREMENTS	i.e., center of all rooms, at locations of all workstations
HEIGHT	height above ground or floor of measurements, if consistent
ACTIVITY-PATTERN DATA COLLECTED	methods of recording activity pattern data specific to the study
TEMPORAL COLLECTION	methods by which temporal data is collected
FREQUENCY SPECTRUM	bandwidths measured, and methods of capturing frequency information
FIELD PARAMETERS MEASURED	units of data collected, i.e., rms values of magnetic flux density recorded shape of signal and frequency analysis (another instrument?)
EXPOSURE METRICS REPORTED	units of data reported
COMMENTS	

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 1 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
1	Anger (1994)	Source characterization	Medical Services	Incubators Heating beds	Combinova MFM 10	Spot Signal shape Frequency	bed height	Operational	Wave shape, frequency analysis
2	Anger and Carlsson (1995)	Exposure assessment	Transportation -rail engines		Radians Innova BMM3 EMDEX Lite (PE) Spectrum analyzer	PE Spot	PE, otherwise unknown	PE	Harmonic contribution
3	Banks et al. (1995)	Exposure assessment (main study: NCI/CCG Case Study)	Residential		Unknown	"Spot" 1 sec x 30 Long-term: 24-hour and 2-wk DC spots	No	Season/diurnal 7 visits/yr Long-term	Unknown
4	Barroetavena (1994)	Environment characterization	Industrial -pulp/paper mills		Holaday 3600-02	Spot	Interview to determine employee locations	No	No
5	Berglund and Mild (1992)	Exposure assessment	Commercial offices		Radians Innova Sydkraft-1-axis	Long-term	Unknown	Intermittency Purpose of study	No
6	Berisha et al. (1995)	Environment characterization	Transportation -electric vehicles		Single axis, including DC FFT Analyzer	Unknown	In seats	Operational: accelerate, decelerate	FFT
7	Bowman (1988)	Exposure assessment	Industrial Residential Retail Offices Electric utility		EFM 113	Spot	Measurements taken as close to worker as possible	No	No
8	Bracken (1994)	Exposure assessment	Residential		EMDEX 100 EMDEX-C EMDEX II	Spot Long-term PE	Only found "frequently occupied" rooms	Long-term	No
9	Breysse et al. (1994)	Exposure assessment	Commercial office		Monitor 42B1	Spot for source ID PE was focus	Yes: at work locations. No apparent interview	PE	No
10	Bullough et al. (1995)	Environment characterization	Medical services -neonatal unit		EMDEX II	Spot	Discussed work locations w/workers	Two times of day	No
11	Caola et al. (1983)	Environment characterization Source characterization	Residential	500-kV transmission lines	EFM 110	Lateral profiles Spots	No	No	No

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 2 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
12	Davanipour et al. (1995)	Exposure assessment	Industrial -garment factory	Sewing machines	Combinova MFM 10	Spot	Measured at body parts	No	No
13	Delpizzo et al. (1991)	Methods: environment characterization	Residential		3-axis MFD meter	Long-term	No	Diurnal purpose of study	No
14	Dietrich et al. (1993)	Environment characterization	Transportation: electric vehicles		EMDEX II Multiwave System Digital tape recorder	Spot Long-term Continuous	Unknown	Operational Transients	Waveform capture
15	Dietrich et al. (1995a)	Environment characterization	Electric utility	Transmission distrib systems	Multiwave System II	Long-term	In general area of workers	Long-term	Waveform capture
16	Dietrich et al. (1995b)	Source characterization (transients)	Medical Services	MRI human exposure room	Triaxial field sensor and oscilloscope	Waveform acquisition	No	Capture transients	Digitized waveforms
17	Dlugosz et al. (1989)	Methods: Environment char	Residential neighborhood	Power lines	EFM 113	Spot	No	Repeated for several days	No
18	Dovan et al. (1993)	Environment characterization (repeating study)	Residential		EMDEX 100	Long-term "Spot" (5 sec ave)	No	Purpose of study. Long-term, 5 sec spot	No
19	Enk and Martin (1984)	Environment characterization, Source characterization	Residential Commercial Office Trade & Services	Naval com-munications facilities	Single-axis probe Signal wave analyzer	Spot	No	Measured at time room normally occupied	Various bandwidths
20	Feero et al. (1989)	Source characterization (measure vs predict)		Substations Transmission lines	EFM 111 EFM 112 Monitor 42A	Spot Lateral profiles	No	Prior to and after construction	No
21	Feero and Dietrich (1994)	Environment characterization	Transportation -electric railroad		Multiwave system Digital tape recorder EMDEX (PE)	Long-term Continuous (tape) PE	No	Long-term Digital tape	Waveform capture
22	Fenster et al. (1995)	Environment characterization	Transportation - aircraft		Combinova MFM 100 Comb FD1 and FD2 Teslatronics 70 HP spectrum analyzer	Spot, others unknown	"taken at distances consistent w/ proper human factors"	Operational	Yes
23	Feychting and Ahlbom (1992)	Epidemiology	Residential	Power lines	Sydkraft (3-axis)	Spot PE	No	PE	No
24	Gauger (1985)	Source characterization	Residential	Appliances	Single-axis probes	Spot	No	No	No

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 3 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
25	Grainger and Preece (1995)	Source characterization		Distribution systems, Substations	Emdex II Emdex Lite	Peripheral profiles Long-term reference	No	Reference meter set up	Recorded broadband and harmonic
26	Guttman et al. (1993)	Environment characterization Transient data	Residential		MF sensors, oscilloscopes digital tape recorder, etc.	Continuous wave data	Unknown	Transient occurrences	Yes
27	Hammond (1994)	Epidemiology	Industrial		Unknown	Assume spot	At listed devices and selected work areas. Each asked how much time spent at devices.	Unknown	Unknown
28	Hansen et al. (1995)	Exposure assessment	Industrial -garment factories	Sewing machines	Multiwave II EMDEX II Magnetometer & oscilloscope	Spot waveform Long-term on oscilloscope Spot site survey PE	Grid of measurements of body position	200-second samples to determine duty cycles	Waveform capture
29	Harvey and Scheer (1993)	Source characterization		Distribution wiring	Unknown	Long-term (1 hr)	No	Long-term	60-Hz fund and total harmonic thru 15th
30	Hayashi et al. (1989)	Environment characterization	Electric utility -substations		Single-axis coil: rms FFT analyzer	Spots (profiles) of all harmonics	No	No	Harmonic content
31	Hogue (1995)	Exposure assessment (Environment Characterization)	Offices Residential		EMDEX II EMDEX Lite Linda	Spot Mapping PE	At work: determined where spend 10% of time spent	Repetitions of spot measurements, non-consecutive PE days	No
32	Holte and Kim (1995)	Source characterization Modelling		Transmission lines	Multiwave EMDEX	Profiles	No	No	Waveform capture, THD
33	Holte et al. (1995)	Source characterization		Distribution lines	Multiwave EMDEX	Long-term, Mid-term EMDEX , sh tm Multiwave	No	Long-term Mid-term	Waveform capture, THD

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 4 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
34	Johnson (1991)	Source identification/ characterization	Offices Schools Industrial Electric Utility		STAR VANA 1- axis probes Harmonic satellite adaptor	Lateral profiles Peripheral profiles Inside walkthru Long-term	No	24-hour recordings at temporally variable sources	No
35	Karady et al. (1993)	Environment characterization	Transportation -electric vehicles		Unknown AC and DC	Unknown	No	Operational	DC, harmonics
36	Kaune et al. (1987)	Epidemiology	Residential		4-probe data acquisition system, flat & linear, RMS	Spot 24-hour	Determined most occupied room n/i kitchen and bedr	24-hour	Harmonic content via flat & linear response
37	Kaune and Zaffanella (1994)	Methods investigation: for historical exposure assessment	Residential		STAR VANA AMEX (PE)	Peripheral profile 24-hour PE	In all rooms where subject >1 hr/day. At location if known, or center.	24-hour day, Measured in two seasons	No
38	Kaune et al. (1994)	Methodology development for spots or 24-hours as surrogates	Residential Schools		EMDEX-C AMEX (PE)	Spot Long-term PE	In rooms where >15 min/wk, at spots where spent time	24-hour bedr Spots at norm/low power	No
39	Kaune et al. (1995)	Environment characterization	Transportation -electric trolley system		Multiwave System II EMDEX II EMDEX Lite	Spot (Multiwave) Long-term (EMDEX)	Unknown	Long-term	Waveform capture
40	Kavet et al. (1992)	Methods: Exposure assessment	Residential		EPRI EMDEX EFM 113 Monitor 42A	Long-term Spot Lateral profile PE	No	Long-term	No
41	Koontz (1992)	Methods: Exposure assessment	Residential		EMDEX AMEX (PE)	Spot Long-term (96 hr)	No	PE Long-term Different seasons	No
42	Linde and Hansson Mild (1995)	Source characterization		Cellular telephones and battery packs	EMDEX II Bell 640 Gauss meter for DC Tektronix current probe	Spot Current pulse on oscilloscope	No	Current pulses	DC

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 5 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
43	Linde et al. (1995)	Exposure assessment	Transportation -electric locomotive driving compart		EMDEX Lite Radians Innova Le Croy oscilloscope w/FFT	Spot PE Frequency content	PE in breast pocket, otherwise unknown	PE	Frequency content
44	London et al. (1991)	Epidemiology	Residential		EMDEX IREQ Bartington fluxgate EFM 113	Spot 24-hour DC spot	Outdoor areas where child spent time	24-hour	Harmonic content via flat & linear response
45	Lovsund et al. (1982)	Environment characterization	Industrial	Sources specifically measured	Bell 610Z	"points selected to obtain closest possible impression of MFs to which workers are exposed"	Unknown	Unknown	Yes
46	Malkin and Moss (1994)	Environment characterization (Health-hazard evaluation)	Industrial -telephone central office facility		EMDEX II AMEX Holaday ELF and VLF Transient capturing instrumentation	Spot "walk around" Long-term (AMEX) PE Transient capture	Unknwon	Long-term	ELF and VLF Waveforms in transient capture
47	Methner (1995)	Methods: Environment characterization: ranking of industries by magnitude	Industrial		EMDEX II	Walk-around	Emphasis on worksites are areas that workers occupy	No	Gathered broadband and harmonic
48	Moss (1993)	Environment characterization (Health-hazards evaluation)	Commercial offices		EMDEX (spot and PE) AMEX (6-hour)	Walk-around PE Long-term (6-hr)	EWAO: effective area occupancy methods, at head (30% of office is where time spent)	PE Long-term	No
49	Moss and Booher (1994)	Environment characterization (Health-hazard evaluation request)	Industrial -steel refinery, ladle refinery & electrogalvanizing lines		EMDEX II Holaday 3600-01 Holaday 3600-02 Holaday HI-3624 Magnetic field profiler (ERM)	Walk-around PE Spot ELF and VLF Mapping	designed to survey worker's actual exposure while they worked	some PE	VLF fields w/ Holaday instrument and profiler
50	National Cancer Institute (1990)	Epidemiology	Residential School		Unknown	Spot 24-hour PE	Unknown	24-hour	Unknown

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
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	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
51	Ouattara et al. (1994)	Source characterization		Transmission lines Substations	EMDEX-C	Lateral profiles Periphery profiles around substations	No	No	No
52	Ouattara and Miller (1995)	Source characterization	Residential Commercial office	Distribution lines	EMDEX II	Long-term Line loads	No	Purpose was daily/season trends	No
53	Paz et al. (1994)	Exposure assessment	Retail -video arcade	Video games	Walker Scientific ELF-60D	Spot	At head, chest, hands, lower extremity	Operational	No
54	Peralta et al. (1995)	Environment characterization	Electric utility -hydroelectric station		Unknown, for mapping and transient measurements	Mapping PE Transients	Mapped workplaces	PE	Unknown
55	Perry et al. (1981)	Epidemiology	Residential		Polytek FB-100	Spot	No	No	No
56	Preece et al. (1995)	Environment characterization Source characterization methodology for exposure assessment	Residential	Appliances	EMDEX II EMDEX Lite Holaday HI-3624	Spot 24-hour PE	No	24-hour	Gathered broadband and harmonic for some measurements
57	Preston-Martin(1995)	Epidemiology	Residential		STAR EMDEX Others unknown	Spot 24-hour Profile DC	No	24-hour	DC, harmonic content via flat and linear response
58	Rosenthal et al. (1991)	Environment characterization	Industrial -plants of semiconductor devices		EFM 120	Spot	Measurements taken in employee position where stationary	No	Checked for >60 Hz w/ bandpass filter
59	Salzberg et al. (1992)	Epidemiology	Melbourne streets		Gaus Maus	Spot	No	No	No
60	Savitz et al. (1988)	Epidemiology	Residential		EFM 111 EFM 113	Spot	Measured in any room occupied by subject >1 hr/day, per questionnaire	Low/high power	No
61	Severson et al. (1988)	Epidemiology	Residential		EFM 111	Spot	No	Low/high power	No

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 7 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
62	Silva et al. (1988)	Environment characterization	Residential, church, school, office, motel	Appliances also measured	EFM 113	Spot 24-hour	Included locations frequently occupied. Measured at body reference height (head, chest, belt)	No	Harmonic content via flat and linear response
63	Silva et al. (1995)	Source characterization discussion	Schools		EMDEX II EMDEX Lite	Spot Sniff Long-term Profiles	No	Long-term	No
64	Soldatchenkov et al. (1995)	Environment characterization	Commercial office	Power plant contribution	HI-3624	Spot	No	Operational	No
65	Stuchly and Lecuyer (1985)	Source characterization	Industrial	Induction heating	Narda 8616 monitor Sm ferrite loop w/antenna OnoSokki FFT analyzer HP Spectrum Analyzer	Spot	Measured at head, chest, waist, knees	Operational	Looked at field strength in various frequency ranges
66	Stuchly and Lecuyer (1989)	Exposure assessment Source characterization	Industrial	Arc welding	Self-made coil w/FFT analyzer EFM 112	Spot	Head, chest, waist, gonads, leg, hand	No	RMS values at various frequencies
67	Sun et al. (1994)	Environment characterization	Schools		Field Star 1000 VANA	Mapping Spots Sniff	No	No	No
68	Tell (1990)	Source characterization		VDT's	HI-3600-01 HI-3600-02 Analog and oscilloscope	Spot Frequency	No	No	ELF,VLF, RF, measured fly-back frequency
69	Thansandote et al. (1995)	Source characterization (transients of typical work equipment)		Welding machines, plasma cutters, jigsaws electric furnace	Magnetic field sensor and HP digitizing oscilloscope	Transient	In locations of human exposure	Transients	Frequency content to 2 MHz
70	Tofani and D'Amore (1991)	Source characterization (frequency domain)		VDT's	EMCO 7604 coil antenna and HP spectrum analyzer	Spot	No	No	ELF and VLF harmonic contributions
71	Wenzl (1994)	Exposure assessment	Industrial -automotive -uranium enrichment		Handheld Instrument PE instrument	Sniff PE	PE primary. Spots only to explore source details	PE	Unknown

TABLE A-2: AREA AND SOURCE MEASUREMENT LITERATURE REVIEW
SHEET 8 OF 8

	AUTHOR	STUDY PURPOSE	ENVIRONMENT	SOURCES OF INTEREST	INSTRUMENTS	DATA COLLECTION	ACTIVITY PATTERNS CONSIDERED?	TEMPORAL ASSESSMENT?	FREQUENCY INFO GATHERED?
72	Wenzl (1995)	Exposure assessment	Transportation -railway maintainance		PE monitor Multiwave System II	Waveform spots PE (on investigator)	"93 typical rail maintenance worksites"	No	Waveform capture
73	Wong and Sastre (1995)	Data collection	Residential, near power lines		Multiwave System	Spot Long-term	No	Long-term at homes	Waveform capture
74	Wong et al. (1993)	Environment characterization	Electric utility -substation		Field Star 1000 EMDEX-C	Spot Mapping	No	No	Transients and RI also reviewed
75	Zaffanella (1993)	Source characterization Environment characterization	Residential		STAR VANA Satellite for harmonics	Spot Spots at appliances Lateral profile Peripheral profile 24-hour	No	24-hour	180-Hz THD

APPENDIX A.2: MEASUREMENT PROTOCOLS AND GUIDELINES

Several of the reports included in Table A.2 include detailed descriptions of the protocols used for magnetic-field data collection, including instrument specifications and measurement methods. Complete protocols and sample data forms can be found in the full study reports.

The following protocols and guidelines were written for a broader audience than a single study. These protocols may be drawn upon for methods, techniques and considerations when developing an environment-specific measurement plan:

A-2.1 Guidelines

Exposure Assessment for Electric and Magnetic Fields (Patterson (1992)): Defines exposure assessment with respect to EMF, and describes methods of exposure assessment, including the use of surrogate measures, models, and monitoring.

Magnetic Field Sources in Residences: Measurement, Detection and Options (Johnson (1994)): Describes measurement techniques, source detection, and potential management strategies for source inherent to residences.

Measurement of Power Frequency Magnetic Fields Away from Power Lines (IEEE (1990)): Describes the instrumentation and calibration considerations and measurement techniques for residential and occupational environments.

Exposure Assessment for Power Frequency Magnetic Fields and Its Application to Epidemiological Studies (Bracken (1993)): Describes strategies and considerations for designing EMF exposure assessments in any environment.

Manual for Assessing Electric and Magnetic Field Exposures (Bowman (1992)): A collection of methods for assessing workplace exposure, documented by contributing investigators. Assembled as a reference source for use by others (industrial hygienists, engineers, etc.) in tailoring a measurement plan for a specific study.

A.2.2 Protocols

Test Methods for Video Display Units (MPR (1990)): The Swedish standards for VDU emissions.

PG&E Magnetic Field Measurement Protocol for Schools (PG&E (1992)): For use within the utility for school-requested measurement surveys. Details a structured spot measurement protocol for comparable data collection and an unstructured component for measurement locations requested by the customer.

California Protocol for Measuring 60 Hz Magnetic Fields in Residences (Yost (1992)): Details a spot measurement protocol for the purpose of comparing or ranking different residences with respect to magnetic fields.

A protocol for Spot Measurements of Residential Power Frequency Magnetic Fields (IEEE (1992)): Describes a structured protocol for residential measurements for comparable data collection, and unstructured guidelines for responding to the occupant's inquiries.

Power Frequency Magnetic Fields: A Protocol for Conducting Spot Measurements in Residential Settings (N.E.M.P.G. (1994)): For use by utility representatives in customer-requested surveys, describes a structured protocol for residential measurements for comparable data collection, and unstructured guidelines for responding to customer needs. Similar to (IEEE 1992).

A.2.3 Standards

IEEE Standard Procedures for Measurements of Power Frequency Electric and Magnetic Fields from AC Power Lines (IEEE (1994)): Describes the instrumentation, calibration and measurement techniques for the characterization of power-line fields.

APPENDIX A.3: ACTIVITY-PATTERN LITERATURE REVIEW

A.3.1 Literature Search Procedures

Activity-pattern information is important to the assurance of exposure-relevant magnetic-field data collection. However, to date, little information has been available regarding the application of activity-pattern data in EMF exposure assessment and measurement design. Research literature pertaining to the characterization of activity patterns in exposure studies was accessed in several ways. First, documents generated by projects done at the Survey Research Center, University of California, were used to identify the locations and activities investigated in large-scale surveys of potential exposure to air pollution. Second, we conducted a literature search on library databases using keywords such as "activity pattern," "activity pattern surveys," and "microenvironments" alone and in combination with "EMF." Third, we contacted experts in hazard appraisal to learn how activity-pattern assessments are done in field studies.

A.3.2 Activity Patterns and Microenvironments: Conceptual Models

The "microenvironment" is a portion of an environment that is homogeneous with respect to a specific set of characteristics. The minimal specification of a microenvironment includes information about its location in space and its type—i.e., its generic purpose or use. Additional elements that could be included to distinguish one microenvironment from another are size and shape, what is contained therein, and whether or not the basic character of environment changes over time. The concept of activity pattern pertains to where people spend their time (the location aspect), how much time they spend in particular locations (the temporal aspect), and what they are doing in a location at a particular time (the behavioral aspect). The simplest conceptual model for linking the microenvironment and the activity pattern is a matrix that cross-classifies a minimal classification of microenvironments (types of places) with a minimal classification of activity patterns (being in a place doing something). The nature of these minimal classifications and the extent to which it is necessary to describe location/activity combinations in more detail depend on the purpose of an investigation.

In our review of available materials, we considered three kinds of exposure methodologies for which classifications of microenvironments and activity patterns are relevant:

a) selection of microenvironments for detailed assessment;

b) indirect assessment of personal or group exposure by integrating exposure levels and exposure times over microenvironments; and

c) direct PE measurement.

In each case, the following questions are relevant.

- How are microenvironments defined and classified? How broad or narrow are the classifications? Is precise location within a microenvironment a focus of measurement?
- How are activities defined and classified? Is the activity classification equivalent to a location classification? Are activities that are directly related to exposure identified and recorded?
- How are persons defined and classified? In particular, are persons identified by occupational title and/or duties?

A.3.3 Review of Selected Source Materials

California Air Resources Board Activity Surveys (Wiley (1991a) and Wiley (1991b)). The reports describe the results of two telephone surveys of California residents conducted between October 1987 and February 1990. The first survey interviewed a sample of 1,762 persons 12- years-old or older. The second survey (N=1,200) focused on the activity and location patterns of children under 12, based on interviews with adult informants. Both surveys used a time-diary method based on open-ended questions for eliciting the activities and locations of respondents in a 24-hour period prior to interview. A large number of microenvironments (called "locations" in these reports) and activities were identified and coded in each study. The approximately 60 location codes used in the two studies included home environments (rooms and outdoor locations), workplaces (office and plant), school and child care locations, stores and shopping places, and in-transit locations. The classification of activities is even more extensive, with over 115 distinct codes grouped into 10 major classifications. [Lists of locations identified can be found in Table 3.1 page 31a of the adult report (Wiley (1991a)) and Table 2.4, page 26c of the children's report (Wiley (1991b)). The activity coding scheme is found in Appendix A of each report.] The surveys also collected data on responses to direct questions about air pollution exposures (e.g., gas: stoves and heaters on: tobacco smoking: use of hair spray) and asked a series of questions about characteristics of the respondents (e.g., age, gender, race/ethnicity, and occupation).

Microenvironmental methods of exposure assessment. The Washington Urban Scale Study used the microenvironmental monitoring approach to the measurement of exposure to carbon monoxide and related pollutants (Duan (1985)). The purpose of this research was to link microenvironment type (MET) to activity data based on time diaries for a single day. METs were defined as microenvironments of a similar nature with respect to potential or measured air pollution exposures. The METs were identified as parking, public transportation, private car, pedestrian, shops, offices, and others (mainly home). The diary reports were merged with microenvironment monitoring data on pollution concentrations (ppm) to generate indirect measures of exposure that could be compared with data collected via personal monitoring. Although exposure was generally overestimated by this indirect approach, there were significant correlations between direct and indirect measures. Subsequent reports in this series document refinements in statistical and data analytic procedures. A recent article by Navidi and Lurman (1995) follows the same microenvironmental monitoring approach to estimating exposure to pollutants. The investigators consider the relation between indirect and direct exposure estimates via simulation studies using statistical models that incorporate various sources of measurement error. The classification of microenvironments was crude, making use of only three categories: home, school, and outdoors. The distributions of time spent in these microenvironments was taken from the survey data described in Wiley et al. (1991b).

Activity system models. Silva, Zaffanella, and Hummon (1985) develop a version of indirect assessment for estimating human exposure to 60-Hz electric fields. The "activity systems model" combines descriptions of the physical geography of an area, characterization of the electrical environment (e.g., power line locations and design parameters), and the trajectory of human activities in space and time. The model computes electric-field exposure by integrating Rover physical space of the product of time spent at a location and the equivalent field strength at that location. The model makes use of modifiers for exposure called "activity factors" which adjust point exposures according to the specific circumstances (e.g., whether or not the subject is wearing workboots, is standing on wet grass, etc.).

Health Hazard Evaluation. An interview with Eugene Moss of The National Institute for Occupational Safety and Health (NIOSH) and a review of a sample protocol for evaluation of EMF exposures provided information about the microenvironment and activity definitions used in health hazard evaluations. In this context, it is clear that both activities and microenvironments are more precisely defined than in the types of studies reviewed above (i.e., locations within rooms and movement of persons relative to those locations versus time spent in a general category of location such as office or school). The intent is to measure overlap between locations of exposure sources and locations of people with specific jobs in the same microenvironment. Such protocols typically involve developing detailed floor plans and maps and monitoring the activities and positions of persons in relation to EMF sources located on a floor plan.

A.3.4 Activity-pattern Literature Discussion

Large-scale population-based exposure studies like those done in the air pollution field use broad microenvironment types (which may be independently assessed for exposure) and time diaries or recall surveys to determine how much time persons spend in such environments and what they are doing there. Health hazard assessment (particularly for occupational exposures) tends to define locations and activities much more precisely (e.g., within x meters from source, or standing, sitting, bending over). In the latter case, the distinctions made to define regions of the microenvironment are often based on where sources are known to be located. What are called "activity patterns" in this context are really indicators of where persons are in relation to sources.

These can be measured by direct observation (e.g., watching someone operate a machine), time diaries, or recall surveys.

This review of limited research literature on activity patterns in exposure assessment warrants several tentative conclusions. First, most of the published work on activity patterns in relation to exposure deals with air pollution and indirect methods of assessment. In this work, the sources of exposure tend to be diffuse and the microenvironmental categories appropriately quite broad. With some exceptions such as power line characterizations, it is likely that EMF exposure studies will typically deal with more localized sources of exposure and correspondingly smaller and more circumscribed microenvironments. Second, in most cases, the term "activity pattern" is really used as a synonym for time spent in pre-designated locations with potential for exposure. Exceptions are: the "activity systems model" where corrections are applied for body position, dress, and specific and changeable environmental factors; and studies of air pollution exposure which incorporate level of physical exertion as an indicator of exposure. The information required to delineate microenvironments and activities depends largely on the purpose of an investigation and the actual structure of the environment and the human use of it.

APPENDIX A.4: REVIEW OF MAGNETIC-FIELD PARAMETERS AND POSSIBLE HEALTH IMPACTS

An important consideration in the selection of the specific magnetic-field parameters to be characterized in any given study is the known or suspected capability of those parameters to affect human health in some manner. At present, evidence for such impact comes primarily from three sources. These are:

1) rigorous laboratory studies that show EM field effects on specific health-related biological endpoints,

2) more subjective laboratory research dealing with interaction mechanisms between electromagnetic fields and biologic systems, and

3) government-approved medical devices that employ EM fields for human clinical treatment and therapy.

Included in source 1) are epidemiology studies that show correlation between disease and a specific aspect of EM field exposure.

A.4.1 Laboratory and Epidemiology Studies

IIT Research Institute (IITRI) compiled a tabulation of rigorous studies reporting EMF bioeffects as published in the open literature during the period 1990 through early 1995. The criteria used to select references in this tabulation were the biological relevance of the experimental endpoints examined and the strength of the study. A study was considered relevant if its biological endpoints were related to cancer or other adverse health effects. Study strength was evaluated on the basis of the adequacy of group size for good statistical analysis, the magnitude of the effect(s) reported, and the reproducibility of the effect(s). The primary reasons for excluding citations were lack of relevance to disease-related endpoints, inadequate group size, and/or failure to provide sufficient experimental detail to allow characterization of exposure conditions. The tabulation also excluded studies involving only sinusoidal 50/60-Hz fields, as these frequencies provide the basis for the bulk of the EMF health effects studies published to date, and their inclusion as relevant metrics in any exposure assessment program is assumed.

The studies cited in the tabulation report exposure frequencies ranging from 0.8 Hz to 180 Hz. Three of the studies employed square waveforms, while one study employed a 60-Hz, high dB/dt waveform. The balance of the cited studies all used sinusoidal waveforms; none of the tabulated studies employed pulsed or transient waveforms. Two studies used symmetric on/off cycles (of from minutes to hours), while two others varied field coherence. However, most exposures were either continuous or not reported (and assumed continuous). Approximately half of the cited studies either measured, controlled, or canceled the dc magnetic field; in the remaining studies, the dc field was not reported. In only one study was the ac field aligned with the geomagnetic field; in all other studies the ac-field orientation was horizontal, vertical, or unreported.

On the basis of the tabulation, the most relevant magnetic-field parameters with respect to potential human health effects appear to be the field magnitude and its frequency content from dc up to perhaps a few hundred hertz. Other parameters whose importance is hinted at include kilohertz-range frequency content (square-wave content), dB/dt, field intermittency and coherence, and the magnitude of the geomagnetic field and its orientation to the ac field. IITRI researchers note, however, that relatively little hard biological data exists to support the characterization of any of these field parameters. Even for 50/60-Hz, the universe of disease-related endpoints that has been examined is quite small. The IITRI researchers conclude that the state of biological science still has a long way to go before specific conclusions can be drawn about the relationships between various magnetic-field attributes and possible biological system responses or health effects. Hence, even though the physics of magnetic fields and their various metrics are relatively well understood, no clearly definable criteria for the selection of field parameters based on health concerns was established.

A.4.2 Interaction Mechanism Studies

A somewhat subjective and considerably less rigorous approach from the biological standpoint is to select the magnetic-field parameters to be measured on the basis of the various proposed models of electromagnetic-field interaction with biologic systems. A review of interaction mechanisms was described in Guidelines for EMF Source Characterization (Feero (1997)). A second review and analysis of interaction mechanisms was conducted by researchers at Pacific Northwest Laboratories (PNL) as described in a poster presented at the 1995 DOE Contractors' Review Meeting in Palm Springs, CA. The principal interaction models, the metric(s) associated with the models, and the magnetic-field parameters that must be characterized to support the metrics are summarized as follows.

Ion Resonance (parametric or quantum coherence). Ion resonance models hypothesize that certain combinations and relative orientations of the ac- and dc-magnetic fields can set up molecular resonances which can affect the binding of intra- and extra-cellular ions. Proposed metrics for these models are the percent of the subject's body in which resonance conditions exist for a particular ion, and the ratios of the peak and mean ac- and dc-field magnitudes. Magnetic-field parameters that must be measured to support these models include the following:

- the dc-field magnitude (x,y,z axes),
- the ac-field frequency spectrum and temporal variability,
- the ac-field magnitude for each frequency of interest (x,y,z axes), and
- the ac- and dc-field spatial variations.

Note that characterization of temporal variability requires recording over an extended time period, while characterization of spatial variability may require measurements at many locations. For this model, measurements of the ac- and dc-field components must also be coincident so that the relative angle between the ac and dc field can be determined.

Magnetic Moments (radical pairs, magnetosomes). Magnetic-moment models hypothesize that certain characteristics of the ac field can affect the recombination rate of radical pairs or have some influence on molecules or cells that have a naturally occurring magnetic dipole moment (magnetite crystals, magnetosomes). Metrics suggested for these models include the percent of time spent in a field with a magnitude above a threshold value, and the degree of field polarization and/or intermittency. Magnetic-field parameters that may be necessary to characterize in order to support such metrics include:

- the ac-field magnitude (x,y,z axes),
- the ac-field polarization, and
- the ac-field frequency spectrum and temporal variability/intermittency.

Note that determination of field polarization requires information on the phase relationship between the x, y, and z field components.

Coherence. Coherence theory states that cells have and use memory in responding to outside stimuli. Specifically, a stimulus must be present for at least 100ms in order to be "seen" by a cell, and in addition must remain both present and constant (less than 20 to 50% change) for at least 10s or so in order to elicit any cell response. An electromagnetic stimulus that meets these criteria is called a "coherent event." Proponents of this theory indicate that multiple coherent events produce a more sustained response than a single long period of coherence, and that multiple coherent events with changing stimuli produce a still greater response. Suggested metrics for this model include the percent of time spent in "coherent" fields, and the number of coherent events per unit time. Magnetic-field parameters that must be measured to support these metrics include:

- the dc-field magnitude (x,y,z axes),
- the ac-field magnitude (x,y,z,axes),
- the ac-field frequency spectrum and temporal variations, and
- the ac- and dc-field spatial variations.

For this model, temporal field measurements must be taken and compared at intervals of 100ms or less, and over extended time periods, in order to resolve and count coherent events.

Induced Currents. The basic proposition of this hypothesis is that the mechanism of biologic interaction is related to the body current induced by the magnetic field, rather than to the direct action of the field itself. The induced-current interaction mechanism might be an interference with normal physiological currents (ion flows) or through interfering electrical potentials at the membrane, cell, or tissue level. Possible metrics for this model might include current density and evoked electrical potentials. Presumably, the metrics suggested for coherence could also apply. Magnetic-field parameters that determine the amount of current induced in a subject include the following:

- the ac-field magnitude (x,y,z axes),
- the ac-field frequency spectrum,
- the field time-rate-of-change (dB/dt),
- the peak amplitude of dB/dt, and
- the ac-field temporal and spatial variations.

Transients. Transients can be considered as either a direct field interaction mechanism or as a coupling mechanism for induced current. As such, transients may play a role in the magnetic moment, coherence, and induced-current models. It has also been hypothesized that high-frequency, high-amplitude transients may induce micro-shocks or cause cell wall electroporation from induced potentials. Low-frequency transients may be more aptly classified as changes in field state or as field intermittency. Therefore, it should be appropriate in this case to apply the metrics and field parameters associated with the coherence and induced current models. However, mixed- and high-frequency transients may require measurement or characterization of the following parameters:

- the field time-rate-of-change (dB/dt),
- the field peak B and peak dB/dt,
- the transient count,
- the transient pulse burst rate (high-frequency), and
- the transient pulse width (mid-frequency).

For typical high-frequency transients, real-time threshold-triggered transient detection may be suitable to obtain transient counts within ranges of peak values of B and dB/dt.

A.4.3 Clinical Devices

Medical devices for clinical use in the United States are subject to the approval of the Federal Drug Administration (FDA), which requires proof that a device is not only safe but effective as well. A review by Polk (Polk and Postow (1996)) listed three manufacturers of clinical devices that employ magnetic fields for therapy and that had received FDA certification as of March 1994. These companies were Electro-Biology, Inc. (EBI), Ortho-Fix (OF) (formerly American Medical Electronics, Inc.), and OrthoLogic Corp. (OLC). The approved clinical applications of these devices are for the treatment of non-unions (NU) (long-term, unhealed fractures), congenital pseudoarthroses (CP), and failed (spinal) fusions (FF). The biological interaction mechanisms through which these devices function are not fully understood. However, it is generally believed that the fields employed induce currents that stimulate cells involved with growth and healing, and/or that augment the endogenous electrical potentials and currents involved in normal healing processes. Devices from two of the manufacturers use pulsed magnetic fields (PEMFs) of specific waveshapes, while the third uses sine waves with a dc field superimposed. Specifics of the fields are given in the following table.

MFG	USE	WAVE TYPE	FREQ/ RATE	PULSE /BURST	PEAK B	PEAK dB/dt	PULSE RISE/ FALL TIME
EBI	NU/FF	Burst	15/s	20	2 mT	90T/s	200/23us
EBI	CP	Pulse	72/s	N/A	3.5 mT	9.2T/s	.38/4.5ms
OF	NU	Burst	15/s	21	0.4 mT	6.2T/s	65/95us
OF	FF	Burst	1.5/s	100	0.7 mT	10T/s	65/95us
OLC	NU	Sine +DC	15.3 Hz 76.6 Hz	40uT peak-peak ac + 20uT dc			

Another class of FDA certified devices of interest to this discussion are those used for electro-therapy. These instruments utilize capacitive coupling via surface electrodes, rather than inductive coupling, to induce currents in the range of from microamperes to milliamperes.

Approved clinical treatments using these devices include muscle stimulation/relaxation, and pain management. There appear to be literally dozens of manufacturers of electro-therapy equipment. At least one type is known to produce square waves with a 50% duty cycle over a frequency range from 0.1 to 1000 Hz. Other devices also use sine waves. A complete survey of such devices has not been conducted under this effort, but it is likely that many waveform regimes exist.

It seems reasonable to make the argument that if the clinically controlled application of magnetic fields and currents having specific waveshapes have proven beneficial health impact, then it is also possible, if not probable, that uncontrolled exposure to randomly generated background fields may have adverse health implications in some situations. Support for this argument can be found in a review of PEMF therapeutic uses (Bassett (1989)), in which some studies were reported to show either a positive or negative effect on growth or healing depending on the specifics of the applied waveforms. Clinical uses of EMFs would therefore seem to dictate the measurement of a number of magnetic-field parameters, as listed below.

- AC- and dc-field magnitudes (3-axes, coincident)
- AC- and dc-field temporal and spatial variability
- AC-field waveform and frequency spectrum (to at least the mid-kilohertz range)
- Field dB/dt and peak dB/dt
- Transient waveform and count.

APPENDIX A.5: DEVELOPMENT OF THE ENVIRONMENTAL CLASSIFICATIONS

A.5.1 Environmental Classification Table Purpose

The "Environmental Classification Table" is a comprehensive listing of environments where the United States population spends its time. It is logically organized in environmental groups, environments, and subenvironments. Each of the environments has been assigned a unique reference code number that corresponds to, or parallels, Standard Industrial Classification code numbers for establishments. The environments have been categorized into nine groups based on similar uses and similar expected magnetic-field exposures. A listing of subenvironments typical of each environmental group has been included, and the subenvironments have been letter coded.

The table was designed to provide a well-defined road map that would repeatedly lead investigators to the environment or environmental group of interest. It is expected that the investigator who is interested in performing magnetic-field measurements in a specific environment, or subenvironment, will be able to quickly and easily identify that environment and its code number in the Environmental Classification Table. It is also expected that the Environmental Classification Table may be imported into a global database that can be used for future meta-analysis.

A.5.2 Classification Procedures

The criteria for classification were:

- Each environment should be easily categorized.
- The expected magnetic-field exposures within an environment classification should be similar.
- The environments should be occupied by similar groups of people; i.e., shoppers, students, machinists, etc.
- The environments should be used in similar ways; i.e., purchasing, learning, welding, etc.

The objective of the classification process was to reduce the nearly-infinite number of specific environments down to a manageable size. The process began with consideration of the "nominal list of environments" suggested by the Department of Energy. The six suggested environments were:

- Residential environments
- Schools
- Industrial settings (excluding utility industries), e.g., machinery shops, material processing, welding shops
- Commercial settings, e.g., grocery stores, malls, appliance stores, entertainment areas
- Transportation vehicles and stations
- Medical instrument rooms.

Literature search. To fully develop this nominal list, research was performed, literature searches were completed, governmental codes were reviewed, and multi-disciplinary reviews were completed in the following areas:

Environments
Exposure Assessment
Classifications
Employment by Industry
EMF
Demographics
Magnetic Fields
Market Outlook
Magnetic-field Measurements
Job Outlook
Activity Patterns

Searches were completed on each of these subjects through city and county library systems, university library systems, and through our own resource files. Although most of this effort proved fruitless, four particular documents did turn out to be of value:

Standard Industrial Classification Manual (OMB (1987))
Activity Patterns of California Residents (Wiley (1991a))
Study of Children's' Activity Patterns (Wiley (1991b))
Exposure Factors Handbook (US EPA (1989))

Standard Industrial Classification (SIC) Manual. The SIC code ultimately became the cornerstone of the final Environmental Classification Table. The SIC Manual is a numerical listing of establishments, prepared by the United States Government Office of Management and Budget. It includes the thousands of establishments that significantly contribute to the economy of United States industry. It is used extensively by federal, state, and local governments and by industry and industrial organizations for statistical comparisons. Nearly all of the over two-hundred environments that were identified in this project were correlated with business establishments already coded in the SIC Manual. Through discussion, some codes were eliminated, and some others were combined, but the final table has its recognizable roots in the SIC Manual. Since the Manual is an economics-based statistical tool, it did not directly suit the purpose of classifying environments based on magnetic-field exposures. The establishments were reorganized and regrouped, while retaining their numerical codes, into Environmental Groups. In a few instances, where there was not an SIC establishment corresponding to an environment of interest, a listing was created and assigned a unique code number.

The Environmental Classification Table was developed one step beyond the SIC Manual: subenvironments typical of each environmental group were listed. The subenvironments are physical portions of environments, e.g., a classroom is a subenvironment of the university environment. Each environment in an environmental group may include one or more of the subenvironments typical of the environmental group. The subenvironments were assigned unique code letters.

A.5.3 Environmental Classification Table Description

The Environmental Classification Table is attached as Table A.3. The original six environments nominally suggested by the Department of Energy were expanded to nine:

- Residential
- School
- Transportation and Public Utilities (Non-electric)
- Medical Services
- Agricultural
- Industrial
- Commercial Office
- Trade and Service
- Electrical Generation, Transmission, and Distribution.

A tenth group, Non-Classified, was then added. Subenvironments were identified for each environmental group. As many as twenty subenvironments were identified for the industrial group, whereas only seven were identified for the commercial office group. Each subenvironment was assigned an arbitrary but unique code letter. Lastly, the environmental groups were broken-down into 178 specific environments. The environments were coded using the SIC code number corresponding to the establishment most closely representing that environment. In some cases, (e.g., mobile home) where SIC code numbers did not exist, code numbers were assigned from the corresponding SIC group series. The final lists of Environmental Groups, Environments, and Subenvironments have been compiled in a spreadsheet.

The greatest strength of the Environmental Classification Table lies in its completeness. There are very few, if any, environments that have been left out of the table. Also, the table is organized so that even the unfamiliar user will be able to quickly and easily locate any environment. The fact that the Environmental Classification Table was built around the Standard Industrial Classification Manual will make it inherently familiar to many users.

Perhaps the weakest aspect of the Environmental Classification Table is in its compromises. In order to limit the nearly infinite number of environments, many distinct environments were combined. There are no doubt some distinctly individual environments that have lost their identity.

These compromises may give rise to a degree of uncertainty in the investigation. The investigator should include them in his/her uncertainty analysis to determine the impact that compromises in the environmental classification specification may have on the overall investigation.

The table is comprehensive, well-organized, and easy to use. An investigator with an established purpose will quickly and easily locate the environment of interest in the Environmental Classification Table. The codified environment listing will also be provided to the Rapid EMF Measurement Database in order that it may be considered as a method of stratification.

TABLE A.3
ENVIRONMENTAL CLASSIFICATION TABLE
PAGE 1 of 6

Introduction

The Environmental Classification Table is a categorized listing of environments where the United States population spends its time. The environment names and their code numbers are based on the Standard Industrial Classification (SIC) codes, used by government agencies and by trade associations.

Many SIC establishments have been omitted either because they were redundant or of little additional magnetic field interest. A few establishments were added because of their particular exposure interest.

The environments have been categorized into eight groups, based on similar uses and similar expected magnetic field exposures. The grouping is intended to be a logical stratification for use by the researcher in his selection of the appropriate EMF measurement guidelines, and for aiding in EMF database management.

Sub-Environments typical of each group have also been included and codified for the purpose of the EMF RAPID Engineering Project #2. A sub-environment is defined as a physical portion of an environment; for example, a classroom is a sub-environment of the university environment. Depending on the nature of the study, the researcher will need to exercise judgment in the use of the sub-environments. In one instance the university may be the environment of interest, but in another instance the engineering building (a sub-set of the university) might be the environment. In either case, the classroom would most likely be a sub-environment.

An "Other Areas" sub-environment has been included in each Environmental Group. This category has been included to cover hallways, restrooms, and other areas where people come and go but do not spend significant amounts of time. The "Other Area" sub-environment should also be used sparingly in those case where an appropriate sub-environment was inadvertently left off the list.

The very first step in the use of the Environmental Classification Table is to establish the purpose of the investigation. This is especially critical in investigations of environments occupied by both casual and permanent occupants or by both patrons and employees. For example, when investigating a commercial bank, if the investigator is interested in the employees, their Environment will be the "Low Rise Office Building" in the "Commercial Offices" Environmental Group. But, if the investigator is interested in bank patrons, then their Environment will be "Banks, Savings & Loan Offices" in the "Trade and Services" Environmental Group.

The Environmental Groups are:

Home Environment	Places of long term or primary residence. Short term residency such as hotels have been categorized in the Trade and Service Environment.
School Environment	Environments where academic or technical instruction is provided, including day care centers.
Transportation and Communications Environments	Environments of mass transportation and their ancillary facilities, and environments where communications are transmitted and/or received. These are environments which generally include vehicles or are otherwise spread over wide geographic areas.

TABLE A.3
ENVIRONMENTAL CLASSIFICATION TABLE
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Electric Generation, Transmission, and Distribution	Environments occupied exclusively by electric utility workers. These include generating stations, switching stations, substations, overhead and underground transmission and distribution line facilities. Common utility facilities such as offices and warehouses are excluded.
Medical Services Environments	Environments occupied by providers of medical services and their patients. Solely occupational environments such as medical equipment companies or outside testing facilities have been categorized as Industrial Environments.
Agricultural Environments	Locations where agricultural production occurs. In general, an establishment including both fields and structures is considered a single environment.
Industrial Environments	Environments where the production of goods other than agricultural products occurs. Such an environment will include offices and warehousing if these facilities are on site.
Commercial Office Environments	Those establishments with offices which do not generally receive public traffic. Mixed tenant offices, corporate headquarters, and government administration buildings are the most common examples of Commercial Offices. Other examples include: engineering offices, banking administrative offices, and law offices. Minor offices that are within a school, transportation, medical, production, or trade establishment are considered a sub-environment of that establishment.
Trade and Services Environments	Wholesale distribution, retail distribution, and service environments (public and private) where minimal, or no, production occurs. Office facilities which frequently receive public traffic are included here. Examples are: bank branches, stock brokerages, and postal stations.

Environmental Group	Environment	Code Number	Sub-environment Typical of Group	Code Number
Home	Apartment Building	8812	Family Room	a
	Dormitory	8813	Kitchen	b
	Duplex/Town House	8811	Bedroom	c
	Mobile Home	8814	Living Room	d
	Residential Care Center	8360	Laundry Room	e
	Single Family Home	8810	Bathroom	f
			Garage	g
			Shop	h
			Basement	i
			Yard	w
			Office	x
			Common Areas	y
			Other Areas	z
School	Child Day Care Center	8292	Classroom	a
	College & University	8220	Library	b
	Elementary	8250	Gymnasium	c
	Language, Art & Music Schools	8291	Cafeteria	d

TABLE A.3
ENVIRONMENTAL CLASSIFICATION TABLE
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Environmental Group	Environment	Code Number	Sub-environment Typical of Group	Code Number
School (Cont')	Middle	8260	Metal/wood Shop	e
	Secondary	8270	Home Economics	f
	Vocational School	8240	Computer Room	g
			Listening Room	h
			Activity Center	i
			School Yard	j
			Sports Field	k
			Copy Room	s
			Laboratory	t
			Office	x
			Common Areas	y
			Other Areas	z
Transportation and Public Utilities	Airplane	4500	Veh Opertr Area	a
	Automobile	4119	Veh Pasngr Area	b
	Boat/Ship	4400	Ticket Area	c
	Bus	4130	Maintenance Area	d
	Communications Facilities	4800	Baggage Claim	e
	Gas & Sewer Svc Facilities	4900	Studio	f
	Light Rail System	4030	Transmitter	g
	Railroad Train	4010	Switch	h
	Subway System	4020	Repeater	i
			Office	x
			Common Areas	y
			Other Areas	z
Electric Generation, Transmission, and Distribution	Generation Station	4912	Tower	a
	Overhead Distribution Line	4917	Pole	b
	Overhead Transmission Line	4915	Manhole	c
	Substation	4914	Office	x
	Switching Station	4913	Common Areas	y
	Underground Distribution Line	4918	Other Areas	z
	Underground Transmission Line	4916		
Medical Services	Clinical Laboratory	8070	Waiting Room	a
	Dentist's Office	8020	Reception Desk	b
	Doctor's Office	8010	Inspection Room	c
	Hospital	8060	Surgery Room	d
	Nursing Home	8050	Special Care Unit	e
	Optometrist's Office	8042	Ward	f
	Veterinary Hospital	740	Nurses Station	g
			X-ray Room	h
			MRI Area	i
			Laboratory	t
			Office	x
			Common Areas	y
			Other Areas	z
Agricultural	Commercial Fishing Facility	910	Field	a
	Crop Farm	100	Orchard	b
	Fish Hatchery	920	Barn	c
	Forest Products Yard	830	Production Building	d
	Forest Service Facilities	850	Packing Shed	e
	Livestock Ranch	200	Silo	f
	Timber Farm	810	Repair Shop	v
			Office	x

TABLE A.3
ENVIRONMENTAL CLASSIFICATION TABLE
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Environmental Group	Environment	Code Number	Sub-environment Typical of Group	Code Number
Agricultural (Cont')			Common Areas	y
			Other Areas	z
Industrial	Apparel Factory	2300	Mine Shaft	a
	Asphalt Plant	2950	Open Pit	b
	Automotive Repair Shop	7530	Locker Room	c
	Bakery Products Plant	2050	Construction Site	d
	Beverage Distilling/Bottling Plant	2080	Production Area	e
	Bridge & Tunnel Const Sites	1622	Assembly Area	f
	Building Services Facility	7340	Casting Area	g
	Canned/Frozen Food Proc Plant	2030	Welding Area	h
	Chemical & Fertilizer Mine	1470	Machining Area	i
	Chemical Plant	2810	Painting Area	k
	Clay Products Plants	3250	Warehouse	l
	Coal Mine	1200	Shipping Dock	m
	Computer & Office Equip Mfg Plnt	3570	Laboratory	t
	Confectionery Products Plant	2060	Break Room	u
	Dairy Production Plant	2020	Repair Shop	v
	Drug Production Facilities	2830	Yard	w
	Elect & Electronic Eqmt Mfg Plant	3600	Office	x
	Electrical Repair Shop	7620	Common Areas	y
	Fabricated Plastic Products Plant	3080	Other Areas	z
	Fabricated Rubber Products Plant	3000		
	Fat & Oil Production Plants	2070		
	Finishing/Fabricating Mill	2430		
	Furniture Factory	2500		
	Furniture Repair Shop	7640		
	Gas & Sewer Service Facilities	4900		
	Glass Products Plants	3200		
	Grain Processor	2040		
	Highway & Street Const Sites	1610		
	Iron & Steel Foundries	3320		
	Jewelry Repair Shop	7630		
	Leather Products Plant	3100		
	Logging Establishment	2410		
	Machine Manufacturing Plant	3500		
	Meat Production Plant	2010		
	Metal Coating & Plating Plant	3470		
	Metal Fabrication Plant	3400		
	Miscellaneous Mfg Plants	3900		
	Motion Picture Distribution Facility	7820		
	Motion Picture Production Facility	7810		
	Nonferrous Foundry	3360		
	Nonferrous Rolling Mill	3350		
	Nonferrous Smelter	3330		
	Nonresidential Bldg Const Site	1540		
	Oil & Natural Gas Fields	1300		
	Ore Mine	1090		
	Other Food Production Plant	2090		
	Paint Factory	2850		
	Paper Mill	2620		
	Petroleum Pipeline Facilities	4600		
	Petroleum Refinery	2900		

TABLE A.3
ENVIRONMENTAL CLASSIFICATION TABLE
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Environmental Group	Environment	Code Number	Sub-environment Typical of Group	Code Number
Industrial (Cont')	Plastic Production Facilities	2820		
	Printing & Publishing Facilities	2700		
	Pulp Mill	2610		
	Residential Bldg Const Site	1520		
	Sand, Gravel & Quarries	1440		
	Saw Mill	2420		
	Soap Factory	2840		
	Steel Mill	3310		
	Stone Quarry	1410		
	Testing Laboratory	8734		
	Textile Mill	2200		
	Tobacco Production Facility	2100		
	Transportation Equip Mfg Plant	3700		
	Utility (Non-elect) Const Site	1623		
	Welding Repair Shop	7692		
Commercial Office	Low Rise Office Building	6810	Stock Room	a
	High Rise Office Building	6820	Equipment Room	b
			Computer Room	g
			Copy Room	s
			Break Room	u
			Office	x
			Common Areas	y
			Other Areas	z
Trade and Services	Amusement Park	7996	Merchandise Area	a
	Apparel Store	5600	Cash Register Area	b
	Appliance Store	5720	Refrgrted Area	c
	Arcade	7993	Stock Room	d
	Automobile Parking Lot	7520	Production Area	e
	Automotive Rental Lot	7510	Lighted Cnter Area	f
	Fincial, Insur & Real Estate Offices	6000	Lumber Yard	g
	Beauty/Barber Shop	7235	Nursery Center	h
	Bowling Alley	7930	Shipping Area	i
	Building Materials Store	5210	Break Room	u
	Camps & RV Parks	7030	Office	x
	Const Materials Whsl Outlet	5030	Common Areas	y
	Copying & Mailing Shops	7334	Other Areas	z
	Dance Studio	7910		
	Department/Variety Store	5300		
	Eating & Drinking Places	5810		
	Food Store	5400		
	Furniture Store	5710		
	Golf Course	7992		
	Hardware Store	5250		
	Hotels & Motels	7010		
	Insurance Office	6300		
	Laundry & Dry Cleaning Facilities	7210		
	Library	8231		
	Marine & Motor Veh Dealerships	5500		
	Mobile Home Dealership	5270		
	Motion Picture Theater	7830		
	Motor Vehicle Whsl Dealership	5010		
	Museums & Art Galleries	8410		

TABLE A.3
ENVIRONMENTAL CLASSIFICATION TABLE
PAGE 6 of 6

Environmental Group	Environment	Code Number	Sub-environment Typical of Group	Code Number
Trade and Services (Cont')	Nursery	5260		
	Other Retail Store	5900		
	Paint Store	5230		
	Photographic Studio	7220		
	Physical Fitness Facility	7991		
	Professional Equip Whsl Outlet	5040		
	Governmental Service Office	9000		
	Real Estate & Title Offices	6500		
	Religious Establishment	8660		
	Renting & Leasing Stores	7350		
	Rooming & Boarding Houses	7020		
	Shoe Repair Shop	7250		
	Social Service Office	8300		
	Sports & Social Clubs	7997		
	Sports Stadium/Arena	7940		
	Stock Brokerage House	6200		
	Theatrical Playhouse	7920		
	Trucking & Warehouses	4200		
	TV & Computer Stores	5730		
	Video Rental Store	7840		
	Whsl Apparel Outlet	5130		
	Whsl Chemical Products Outlet	5160		
	Whsl Distilled Beverages Outlet	5180		
	Whsl Electrical Goods Outlet	5060		
	Whsl Farm Products Outlet	5150		
	Whsl Furniture Outlet	5020		
	Whsl Grocery Outlet	5140		
	Whsl Machinery Outlet	5080		
	Whsl Metal & Mineral Outlet	5050		
	Whsl Paper Products Outlet	5110		
	Whsl Petroleum Products Outlet	5170		
	Whsl Plumbing Outlet	5070		
	Whsl Sundries Outlet	5120		
Non-Classified		9900		

APPENDIX A.6 CLASSIFICATION OF SOURCES

For the RAPID Program's Guidelines for EMF Source Characterization (Feero (1997)), a relatively simple means for classifiying the general magnetic-field characteristic that may be expected from point sources was developed.

The classification system is based on identifying the source's common name followed by alphanumeric descriptors for a total of 20 characters, followed by a four-digit code box, for example:

UPS-brandxx50kVA208V | 4 | 2 | 3 | 8 |

The first digit of the code box grades the range of magnetic-field magnitudes that may be expected at a point 30 cm (1 ft) in front of the surface of the device. The value of the digit is the power of 10 which, when used in the formula $B \leq .1$ mG x 10^n, would produce the nearest measure of the magnetic field's resultant magnitude. In the above example, the 4 indicates a magnitude greater than 100 mG and less than 1000 mG.

The second digit in the box is a measure of the frequency of the most dominant magnitude. Again, the digits are powers of 10. This time the formula is frequency in **Hz ≤ 10^{k_2}**, where k_2's value produces the nearest measure of the frequency of the most dominant source. In the above example, the 2 indicates the frequency of the dominant source is greater than 10 Hz and less than 100 Hz.

The third digit in the box is a measure of how intermittent the point source may be,. A power of 10 is employed based on an annual cycle being represented by 10^0. Since we keep time in years, months, weeks, days, hours, minutes, seconds, and the inverse of cycles per second, a simple time formula is less useful than tabulation such as given in Table A.4, below. In the above example, the third digit in the box, 3, indicates the point source changes steady state slightly less frequently than every 8 hours.

The fourth digit in the box is a measure of two different attributes, spatial attenuation, and polarization. Table A.5, below, gives the codes for attributes. Thus, the final digit of 8 in the example indicates a source that has a dipole characteristic and has a field that is elliptically polarized.

TABLE A.4

TIME CHANGE CODES FOR POINT SOURCES

Power of 10	A Change in Steady State Occurs Less Frequently Than Once Every....	Simplifying Interpretation of Time Spans
0	Year	Sample at Least Yearly
1.	1.2 Months	Sample at Least Monthly
2	.52 Weeks	Sample at Twice a Week
3	8.76 Hours	Sample at Least Every 8 Hours
4	.876 Hours	Sample at Least Every 50 Minutes
5	5.256 Minutes	Sample at Least Every 5 Minutes
6	.5256 Minutes	Sample at Least Every 30 Seconds
7	3.1536 Seconds	Sample at Least Every 3 Seconds
8	.31536 Seconds	Sample at Least Every .3 Seconds
9	31.536 Milliseconds	On 60-Hz Power System, Sample Every Cycle

TABLE A.5
CODES THAT RATE THE ATTENUATION AND POLARIZATION TO BE EXPECTED

	CODE #									
	0	1	2	3	4	5	6	7	8	9
Unknown	X					X				
1/r		X					X			
1/r			X					X		
1/r				X					X	
Greater than $1/r^3$					X					X
Linear		X	X	X	X					
Elliptical	X					X	X	X	X	X

APPENDIX B.1: SAN FRANCISCO DAYCARE CENTER PILOT STUDY REPORT

MAGNETIC-FIELD ASSESSMENT of a SAN FRANCISCO DAYCARE CENTER

Magnetic Measurements
Kentfield, CA 94914

Study Dates: August 28 and 29, 1995

ABSTRACT

An assessment of magnetic fields in an urban daycare center was performed to document the magnetic fields experienced by teachers and students in an urban daycare facility. The assessment was performed as a pilot study for developing the recommendations for guidelines for environment-specific field measurements. The daycare facility is located in the first floor of a wood frame two-story building, on a busy street used by dc electric buses. Twenty-eight children and four adult staff members regularly occupy the facility. A magnetic-field scoping study was performed using an EMDEX II to verify the locations of sources. External sources of magnetic fields in the facility included electric distribution lines across the street and dc trolley lines above the street. Internal sources included lights, appliances, and non-visible sources inside walls. An interview was performed with the center director to determine the activity patterns of the occupants. Waveform capture measurements were performed using a Multiwave System II® at 65 exposure-relevant locations, selected based on the sources and occupant locations. At the time of the study, the external sources contributed approximately 1.5 mG to the east side of the classroom, falling off to 0.6 mG on the west side. Significant point sources of exposure were the copier in operation, electric panels, and two unidentified in-wall sources. DC field intensity appeared to have been affected by the dc trolley lines. Polarization ranged from 10% to 85%. The greatest areas of total harmonic distortion appeared to be near the fluorescent lighting and electric metering.

INTRODUCTION AND PURPOSE

An assessment of magnetic fields was performed for a daycare center in San Francisco, California. The purpose of the project was to assess the magnetic fields experienced by teachers and students in an urban daycare facility. The project also was to test the recommended guidelines for environment-specific field measurements in a school environment, and to gather environment-specific magnetic-field data for inclusion in the

RAPID EMF Database. Scoping measurements were performed on August 28, 1995; waveform data measurements were performed on August 29, 1995 between 6:00 p.m. and 7:15 p.m.

DESCRIPTION OF THE SITE

A plan of the daycare center and the surrounding area is shown in Figure 1.

The daycare facility is located in an urban environment. The facility is surrounded on the north, west, and south by abutting low-rise residential and commercial buildings. On the east side the facility faces the sidewalk and a busy urban street used by cars and electric buses with an overhead dc trolley line.

The two-story building was originally built in the 1940's of wood frame construction. The first floor was retrofitted for the daycare center in 1990. The daycare facility includes approximately 1025 square feet of interior floor space and an exterior play area of 1971 square feet.

RAPID Environmental Classification: The daycare facility may be classified as

Environmental Group:	*School*
Environment:	*8292: Child Day Care Center*

The environment may be divided into the following classifications of subenvironments:

Subenvironment	Classification
Classroom	a-classroom
Outdoor Play Area	j-schoolyard

INSTRUMENTATION

The instrumentation available for the study included one EMDEX II® magnetic flux density meter, and one Multiwave System II® waveform capture system.

EMDEX II: A hand-held EMDEX II was used as a scoping tool in the source identification process and for performing lateral profiles from the external utility distribution lines. The EMDEX II magnetic flux density meter is manufactured by Enertech Consultants, Inc. of Campbell, CA. The EMDEX II has a range of 0.1 to 3000 mG and a frequency bandwidth of 40 Hz to 800 Hz; it filters for a harmonic component bandwidth of 100 Hz to 800 Hz. It contains three orthogonal magnetic-field sensor coils for measuring the x-, y-, and z- axis components of extremely low frequency magnetic fields. The resultant field is calculated by computing the square root of the sum of the squares of the simultaneous measurements of field magnitude by the three orthogonal coils. Operation verification of the instrument was performed immediately prior to the study. The meter calibration was verified within 60 days of the study.

MULTIWAVE SYSTEM II: The Multiwave System II® was used for the collection of the data collected within the environment and reported in the results of this study. The Multiwave System II® is manufactured by Electric Research and Management, Inc. of State College, PA. The system digitizes and stores analog waveforms from a triaxial Faraday induction coil ac magnetic-field sensor and a triaxial fluxgate magnetometer dc magnetic-field sensor. The waveform capture system was operated with a base frequency of 60-Hz at a rate of 7680 samples/second per active channel. This resulted in 128 digitized samples for each 16.67-ms period of the 60-Hz-based frequency.

INVESTIGATION METHODOLOGY

The magnetic-field assessment was planned and performed using the following protocol:

1. Source Identification: The investigators used three sources of information to locate the magnetic-field sources within the facility. First, a visual inspection was performed of the site, and known or suspected sources were documented on the site plans. Second, "scoping" measurements were performed using an EMDEX II hand-held magnetic flux density meter to identify elevated levels of fields related to non-visible sources. Finally, the study informant (the director of the daycare center), was questioned regarding the identified and other known sources.

2. Activity-pattern Data Collection: Information about the environment's occupants and their locations and activities within the space were gathered so that the measurement plan could be formulated relevant to the occupants' exposures. Upon arrival at the site, the informant provided a general tour to the technicians, explaining the uses of the site. Second, the technicians, simultaneously with the source investigation, performed a visual inspection to select primary areas of activity as they related to sources. This step created the preliminary definitions of the site's "microenvironments," as described in the following paragraph. The third stage involved an extensive interview with the informant to collect detailed activity data in each of the areas of assumed activity.

3. Microenvironment Identification and Measurement Point Selection: A microenvironment may be described as an area within a subenvironment characterized by a homogeneity of activity patterns and a homogeneity of field variability. The task of defining "microenvironments" was to determine the exposure-relevant areas of each subenvironment. The source data and activity-pattern information were analyzed collectively to develop subjective boundaries of the microenvironments. Source information included field magnitude, variability, and other expected field characteristics such as transients or temporal variability. Activity information included occupant types, locations, activities, and use of sources. The microenvironments are identified on Figures 2A and 2B. The investigators reviewed the source and activity information, and based on the study resources, selected 80 locations for further measurement.

4. Magnetic-field Data Collection: "Spot" magnetic-field data was collected at the designated points within each microenvironment using the Multiwave System II® waveform capture system. Waveform samples were made for a period of 16.67 ms at each location. The data was digitized and recorded for later analysis.

The triaxial sensors were positioned with the x,y coordinates parallel to the walls of the environment in the approximate north and west directions, respectively. All measurements were made at an elevation of two feet above the floor, correlating with the approximate chest height of the children. Retrospectively, a more exposure-relevant height approach would be to measure at a height of one meter in those locations primarily frequented by standing adults (such as the kitchen counter/phone area).

In order to determine the contribution of magnetic fields from the external utilities, a series of ac-rms measurements was taken in a profile perpendicular to the utility distribution lines across the street. At this time, the main electrical switch was opened to assure that the measured fields were from external sources.

RESULTS

Sources of Magnetic Fields

External Utilities**:** The electric service enters the building in the southeast corner of the building's second floor at a height of approximately 20 feet. It is fed by the service conductors running perpendicular to the street. Both the secondary circuit and 12-kV primary circuit are mounted on crossarms on wood poles and run along the east side of the street, approximately 69 feet from the building face, as shown in Figure 1. The secondary circuit is in a twisted-wire configuration and is approximately 23 feet off the ground. The primary circuit is constructed in a horizontal configuration approximately 28 feet off the ground.

DC trolley lines for the electric bus system are strung on both sides and in the center of the street, at a height of approximately 18 feet.

Internal Sources: Sources of magnetic fields found internal to the site were wiring, lighting, and appliances typical of a school environment. The lighting and appliances are considered "point" sources and fall off with distance at a rate of approximately $1/d^3$. Thus, these sources contributed to the exposure of occupants only in the immediate vicinity of the source. They included the following:

CLASSROOM SOURCES	OPERATIONAL STATUS (DURING SCHOOL HOURS)	SCOPING MEASUREMENT AT 12"/24" FROM SOURCE
Fluorescent Lighting	Usually on	7.1 / 1.1 mG
Electric Panel	Always on, variable current	4.0 / 2.3 mG
Microwave	On only with use	23 / 2.3 mG
Refrigerator	Always on, intermittent	0.6 / 0.6 mG
Copier	On only with use	2.6 / 0.5 mG
Tape player transformer	Always on	9.8 / 2.0 mG
Telephone/Transformer	Always on	8.2 / 1.1 mG
Clock radio	Always on	1.4 / 1.3 mG
Ceiling Fan	On only with use	0.7 / 0.6 mG

In two locations, non-visible sources produced magnetic fields. These magnetic fields fell of at a rate of 1/d and $1/d^2$. Like the utility distribution lines, these sources may be considered "distributed" sources. The areas included:

CLASSROOM SOURCES	APPARENT OPERATIONAL STATUS
Source inside south wall, appears to be internal wiring carrying minor net current	Usually on, variable current

OUTSIDE PLAY AREA SOURCES	APPARENT OPERATIONAL STATUS
Unknown source in contiguous building in northeast corner of play structure area; possibly wiring or underground plumbing	Presume always on, variable current

Uses of the Site

Occupants: Twenty-eight children between the ages of 2 and 5 years old and four adult staff occupy the environment five days per week, eight to eleven hours per day. Most areas are used by all children, and used by the children in similar enough ways that the children may be generally considered a homogeneous group for the purposes of this study. The four staff members had different responsibilities; therefore, their activities were reported individually.

Casual, or infrequent occupants of the environment include parents dropping off children and occasional service people, such as repairmen or meter readers. Because the primary use of the space is for the full-time occupants, and because the magnetic-field exposure was found to be similar to exposures found casually in everyday life, the casual occupants were not considered in the study.

Location and activities: The activities in each microenvironment are documented in Table 1:

TABLE 1: ACTIVITY-PATTERN SUMMARY

MICROENVIRONMENT		PRIMARY SOURCES	STAFF	CHILDREN	SOURCE DEPEND ON USE
1	Electric Panel Area	Electric panel, meters	All for 1/2 hr/day (reading time)	All for one hr/day, primarily floor play	no
2	Floor Play/Reading Area	External wiring, electric panel	4 x 2 hour/day, often near panel	28 x 3 hour/day floor play & reading	no
3	Entrance Area	External wiring	4 x 15 min/day thru travel	28 x 10 min/day thru travel	no
4	Tape Player Area	Transformer	3 x 1.5 hr/day	1 x 2 hour/day playing tapes	no
5	Bookshelf Area	None	4 x 10 min/day	28 x 30 min/day	no
6	Table Area	None	4 x 1 hour/day working w/ children	28 x 1.5 hr/day sitting at desks	no
7	Telephone/Radio Area	Clock radio, telephone	2 x 1.5 hr/day use of phone	20 x 10 min/day 2 x 2 hr/day	no
8	Nap Area	None	4 x 15 min/day thru travel	24 x 30 min /day napping and travel	no
9	Kitchen Counter Area	Microwave, phone transformer	All, total of 3.75 hr/d. All use mwave and phone	1 min x 28 thru travel	yes, mwave no, phone
10	Copier/Refrigerator Area	Copier, refrigerator	2 use copier for 15 min/wk and use refrigerator	negligible	yes-copier no-frig
11	Child Restroom	Fluorescent light	2 x 5 min day cleaning	28 x 20 min/day using toilets	no
12	Adult Restroom	Ceiling fan, Fluorescent light	4 x 10 min/day, using equip	negligible	yes
13	Outdoor Paved Play Area	None	2 x 2 hour/day supervising outside play	28 x 1 hour/day playing	no
14	Outdoor Play Structure Area	Unknown wiring source	2 x 10 min/day supervising outside play	28 x 1 hour/day playing	no
15	Outdoor Entrance Area	None	2 x 10 min/day supervising & thru travel	28 x 5 min/day thru travel	no

Measurement Results

Waveform-Data Collection: Magnetic-field waveform data were recorded at 53 locations in the classroom subenvironment and at 12 locations in the outdoor play area subenvironment. Measurements for the environment are summarized in Table 2. Note that the sample points were not distributed linearly over the area, nor were they distributed linearly based on the time of exposure of the occupants. The "mean measurement" has therefore been reported here to provide a relative indication of the field parameters, and not to represent a time-weighted-average or a spatial average.

TABLE 2
SUMMARY OF WAVEFORM-DATA COLLECTION

MAGNETIC-FIELD PARAMETER	MEAN MEASUREMENT	MEASUREMENT RANGE	STANDARD DEVIATION
Resultant AC Magnetic Field	0.9 mG	0.4-2.3 mG	0.5 mG
DC Field	466 mG	379-545 mG	34.9 mG
Total Harmonic Distortion AC Field	30%	1.1-60%	9%
Resultant 3rd Harmonic AC field	0.2 mG	0.1-0.5 mG	0.1 mG
Polarization (Axial Ratio)	0.44	.10-.85	0.20
AC Field Parallel to DC	0.4 mG	0.2-1.0 mG	0.2 mG
AC Field Perpendicular to DC	0.8 mG	0.3-2.1 mG	0.4 mG

A summary of the waveform data for each microenvironment is included as Table 3. The raw waveform data and summary data for each sample point are available from Magnetic Measurements if further analysis or review of other field parameters is desired.

The resultant ac-field measurements are shown at the sample locations in Figures 3A and 3B; a graph comparison is shown in Figure 4.

TABLE 3:
SUMMARY OF MEASUREMENTS OF MAGNETIC-FIELD PARAMETERS BY MICROENVIRONMENT

	MICROENVIRONMENT	# OF DATA PTS	MEAN (MAXIMUM)						
			AC FIELDS RMS (mG)	DC FIELDS (mG)	THD AC Field (percent)	POLARIZ-ATION	AC ⊥ DC 60 Hz (mG)	AC ⊥ DC 60 Hz (percent)	AC II DC 60 Hz (mG)
1	Electric Panel Area	6	1.5 (2.3)	518.6 (545.1)	30.0% (51.9%)	0.2 (0.6)	1.2 (2.1)	83.5% (98.5%)	0.6 (1.0)
2	Floor Play/Reading	9	1.4 (1.8)	449.9 (489.6)	29.8% (42.2%)	0.5 (0.8)	1.2 (1.7)	88.0% (96.4%)	0.6 (0.9)
3	Entrance Area	2	1.5 (1.5)	441.5 (444.8)	22.8% (23.8%)	0.7 (0.8)	1.2 (1.3)	79.1% (85.4%)	0.9 (1.0)
4	Tape Player Area	2	1.5 (1.5)	478.3 (479.4)	30.4% (30.8%)	0.2 (0.3)	1.1 (1.3)	81.7% (90.9%)	0.7 (0.9)
5	Bookshelf Area	6	1.2 (1.6)	479.4 (484.6)	22.9% (26.1%)	0.6 (0.7)	1.1 (1.5)	94.4% (98.6%)	0.3 (0.5)
6	Table Area	6	0.9 (1.1)	455.6 (467.1)	28.6% (35.4%)	0.6 (0.7)	0.8 (0.9)	88.8% (92.0%)	0.4 (0.5)
7	Telephone/Radio Area	3	0.7 (0.8)	488.6 (497.7)	32.7% (34.2%)	0.3 (0.3)	0.6 (0.6)	88.3% (93.9%)	0.3 (0.4)
8	Nap Area	5	0.9 (1.2)	488.3 (518.3)	24.4% (29.4%)	0.4 (0.5)	0.8 (0.9)	87.2% (95.0%)	0.4 (0.7)
9	Kitchen Counter/Phone	4	0.8 (1.0)	390.4 (403.1)	35.9% (38.5%)	0.2 (0.3)	0.7 (0.8)	90.2% (97.9%)	0.3 (0.3)
10	Copier/Refrigerator	4	0.8 (0.9)	445.3 (447.8)	33.5% (40.5%)	0.4 (0.7)	0.6 (0.7)	89.8% (94.3%)	0.3 (0.4)
11	Children's Restroom	2	0.6 (0.6)	442.9 (445.7)	44.3% (47.2%)	0.4 (0.4)	0.5 (0.5)	94.5% (94.7%)	0.2 (0.2)
12	Adult Restroom	3	0.5 (0.6)	436.8 (443.8)	48.4% (59.6%)	0.7 (0.8)	0.3 (0.4)	72.4% (73.5%)	0.3 (0.4)
13	Outdoor Paved Play	5	0.5 (0.6)	492.4 (509.5)	32.3% (40.4%)	0.6 (0.8)	0.3 (0.4)	76.5% (81.9%)	0.3 (0.4)
14	Play Structure Area	3	0.6 (1.4)	482.3 (517.2)	28.6% (46.1%)	0.4 (0.7)	0.4 (1.2)	77.3% (82.1%)	0.3 (0.8)
15	Outdoor Entrance Area	1	0.8 (0.8)	492.5 (492.5)	22.0% (22.0%)	0.8 (0.2)	0.6 (0.8)	78.9% (62.7%)	0.5 (0.6)

Lateral Profile Measurements:

Using the EMDEX II handheld meter, broadband and harmonic magnetic-field data were gathered in a profile perpendicular to the utility distribution lines across the street from the daycare facility. The results are shown in Figure 5. External sources apparent from the profile were the utility distribution lines, and a stray current or other source on the trolley lines. Their significant contribution to the background magnetic fields within the daycare center was verified by opening the main switch and finding little change in the background fields. These external sources contributed less harmonic exposure than other sources in the facility: the average total harmonic distortion in the lateral profile was 14%.

The lateral profiles were performed at the same time of day, but at a later date than the interior waveform measurements.

Data Results Summary

A summary discussion of the data collection follows.

Resultant ac magnetic field: The external sources (the utility distribution lines and or the stray current on the trolley lines) appear to have made the greatest contribution to time-weighted-average magnetic-field exposure. This is because their influence affected most of the classroom subenvironment, including areas of regular activity where no other sources contributed significantly to the exposure. During the waveform-data collection, the external sources contributed approximately 1.5 mG at the east side of the classroom, falling off to the west side of the classroom at approximately 0.6 mG.

The measured source that contributed the highest magnitude magnetic field to overall exposure was the copier, which produced a magnetic field of 16.5 mG during operation, approximate six inches away. (This event was captured on the LED readout of the Multiwave, but not recorded.) Other significant sources included the electric panels, the microwave, the non-visible source in the wall on the south side of the classroom, and the non-visible source in the building adjacent to the play structure area. The 110-volt transformers for the phone and tape player produced extremely elevated fields, but these fell off very rapidly with distance, and therefore only minimally affected exposure.

<u>DC Field Intensity:</u> In general, the range of dc fields is as would be expected in environment containing various ferromagnetic materials. The dc fields of greatest magnitude tended to be located on the south side of the environment, while the fields of least magnitude tended to be located on the north side of the environment. This could possibly have been perturbation caused by ferro-magnetic materials in the walls such as plumbing or reinforcing.

It appears that the dc fields were influenced by the dc bus lines, as evidenced by the fact that all dc fields in the X-direction were positive, whereas the fields in the Y-direction were distributed between positive and negative fields. However, the dc fields in the X direction were lowest closest to the bus lines.

<u>Total Harmonic Distortion of AC Fields (THD):</u> The THD is the root-mean-square of the individual harmonic field intensities divided by the intensity of the fundamental 60-Hz field component. It indicates the relative amount of harmonics in a field waveform without regard to frequency. In addition to the THD reported, the waveforms and the absolute values of the harmonic magnetic-field intensities were reviewed.

The frequency spectra throughout the room were unique, and all locations had significant harmonic content as measured by the THD. The THD consisted mainly of odd low-order harmonics. The location of greatest THD was in the restrooms, which was contributed by the fluorescent lights in the lowered ceiling. The microenvironment with the greatest absolute magnitude of harmonics was near the electric panels, which appeared to be contributed by the utility company's electric metering, the telecommunication panels, and/or the alarm system.

<u>Polarization:</u> Power-frequency magnetic fields in the vicinity of multiphase sources with multiple-frequency components is very complex, but for any given frequency, the polarization is, in general elliptical. The degree of elliptical polarization of the 60-Hz frequency component has been expressed by the ratio of the semi-minor axis to the semi-major axis.

Polarization of the 60-Hz component ranged widely from 10% to 85%, and did not appear to be distributed such that any general conclusions could be drawn. The least polarization was found around the electric panels and kichen counter microenvironments. Greater polarization tended to be found in the outdoor play area, bookshelf area, table area, entrance, and adult restroom microenvironments.

<u>AC-DC Relative Orientation</u> (ac field perpendicular to dc): The three-dimensional dc- and ac-magnetic flux density simultaneous measurements were analyzed to compute the orthogonal components of the maximum axis of the 60-Hz field vector with the dc field vector. These have been presented as the magnitude in milliGauss and as a percentage of the maximum axis.

<u>Temporal Variability</u> : Because of instrumentation limitations, and because the facility director requested that no long-term instrumentation be left at the site, no focus was placed on gathering information about temporal variability during the study. The following observations were made based on the data available:

> It can be assumed that magnetic fields from the external sources will vary over the period of a day and by season, as is typical of power-line sources. This was evidenced in the variation in measurements taken nearest the power lines during the spot measurements (approximately 1.5 mG), and the lateral profiles from the power lines performed on another day (approximately 3 mG at the same location). Because these sources affect exposure over a large area of the facility, this temporal variability will effect overall exposure of the occupants. Similar variation may be anticipated in the Electric Panel Area microenvironment, because variation in electric use in the building will effect field magnitude from the electric panels. Long-term measurements (i.e., over a ten-hour day) would help to quantify the variation.
>
> Some of the interior sources will contribute to variability based on their operations. Sources such as the copier, microwave, restroom lights, and fan will vary from "no contribution" to "contributing" as that source is turned on and off. The refrigerator by design will cycle on and off, causing variability over any time period. None of these sources are located in microenvironments regularly occupied by the children.

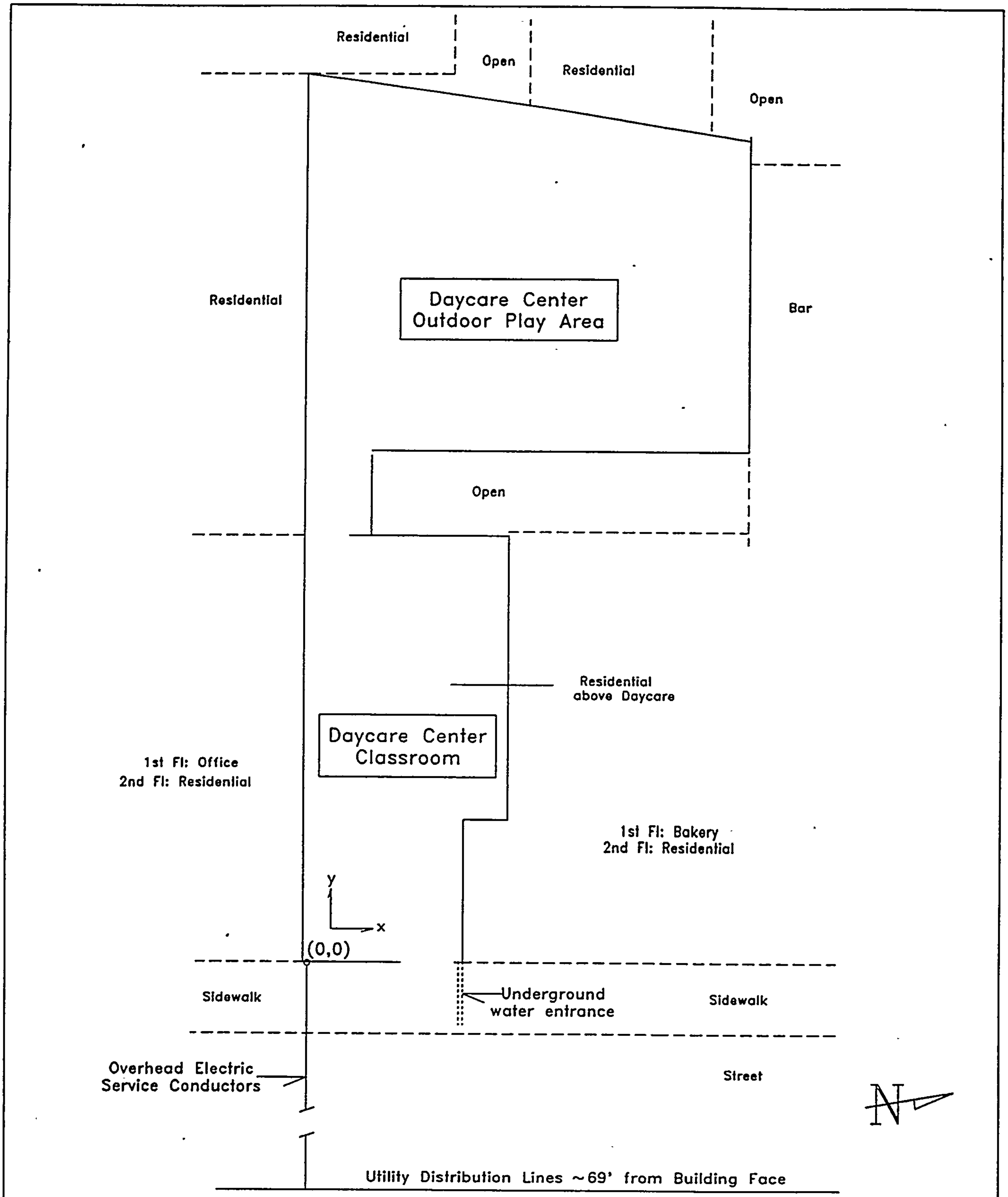


Figure 1: Map of Daycare Center and Surrounding Area

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment Daycare Center, San Francisco, CA

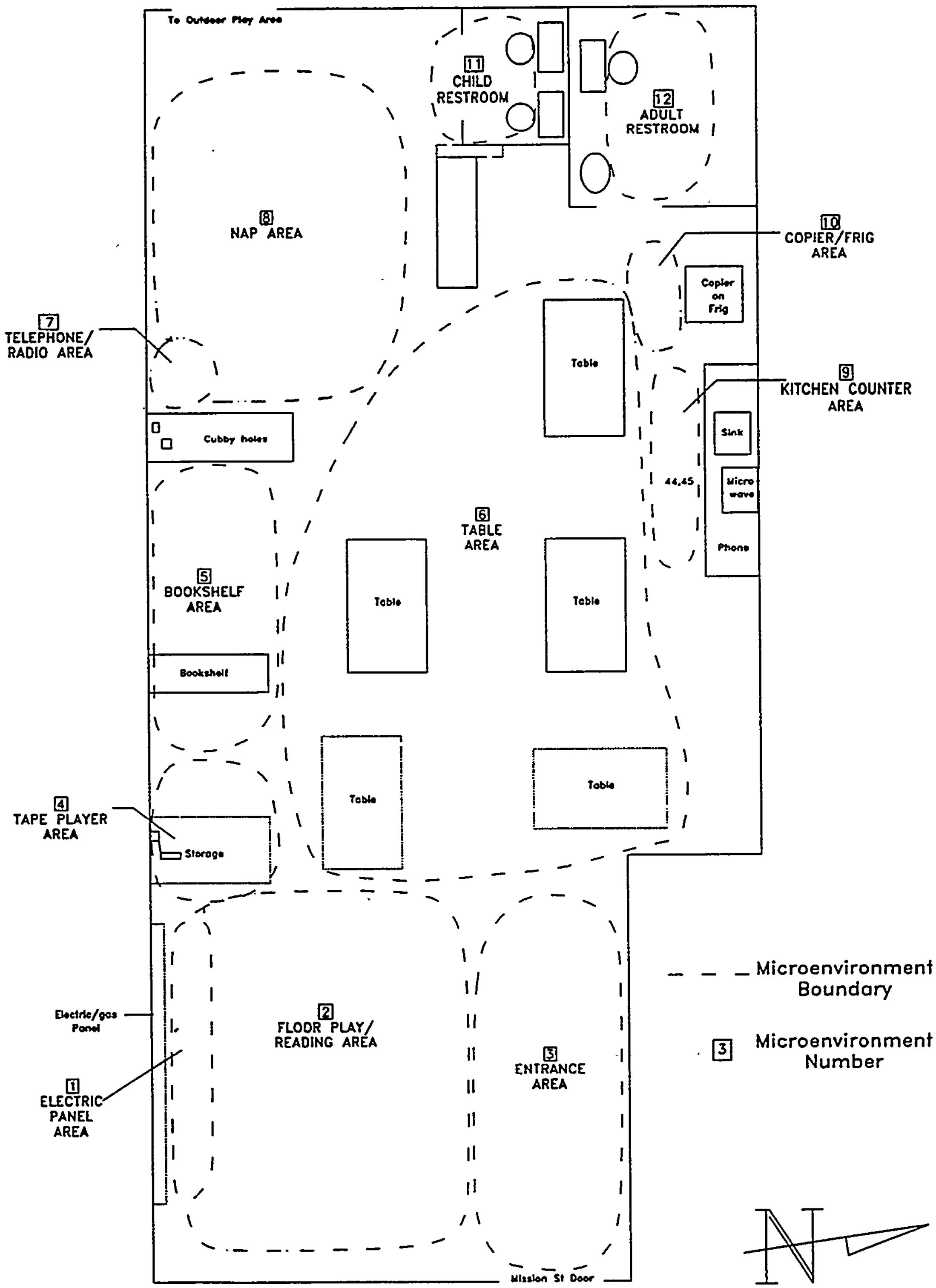


Figure 2A: Locations of Microenvironments in Classroom

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment Daycare Center, San Francisco, CA

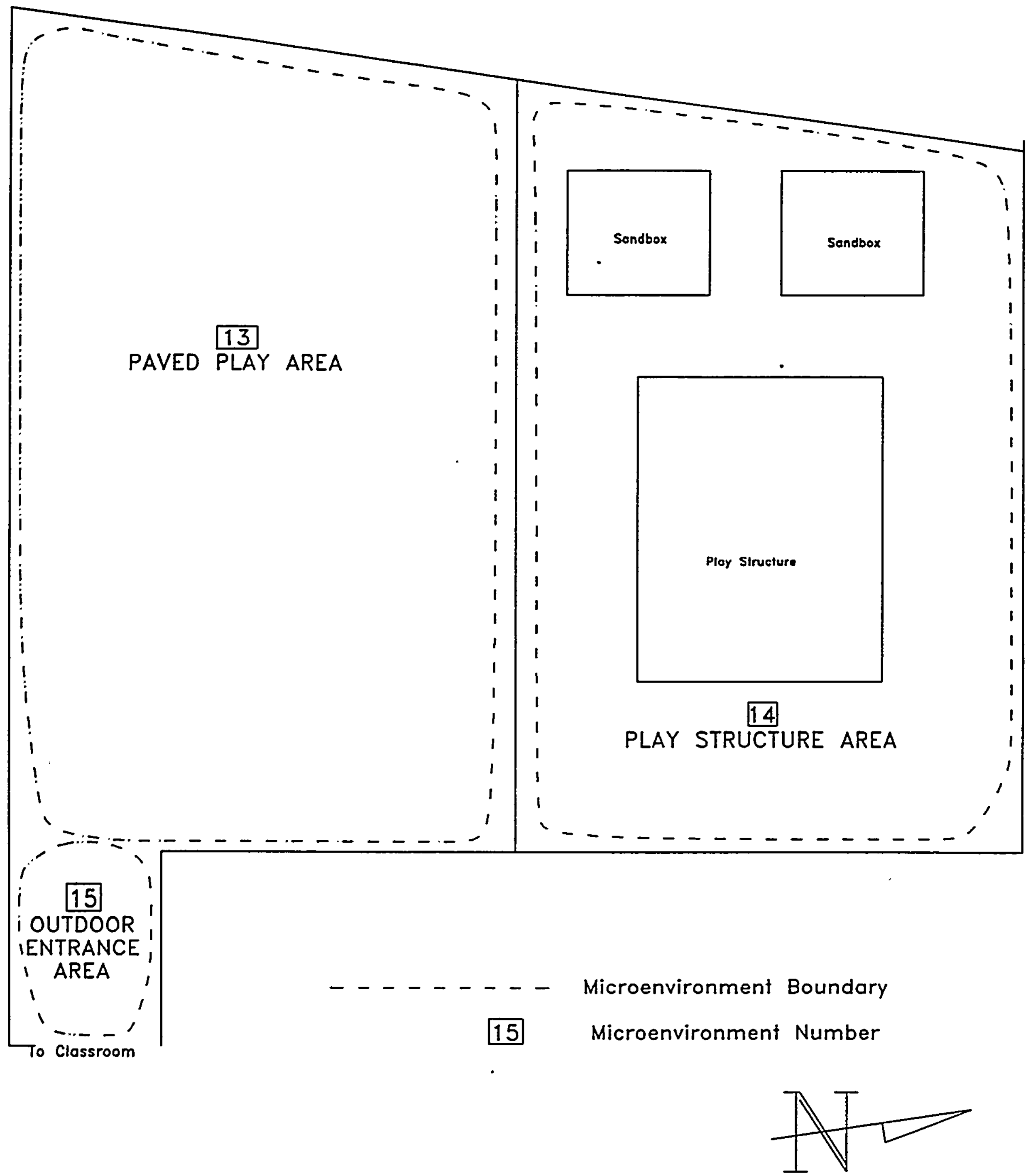


Figure 2B: Locations of Microenvironments in Outdoor Play Area

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment Daycare Center, San Francisco, CA

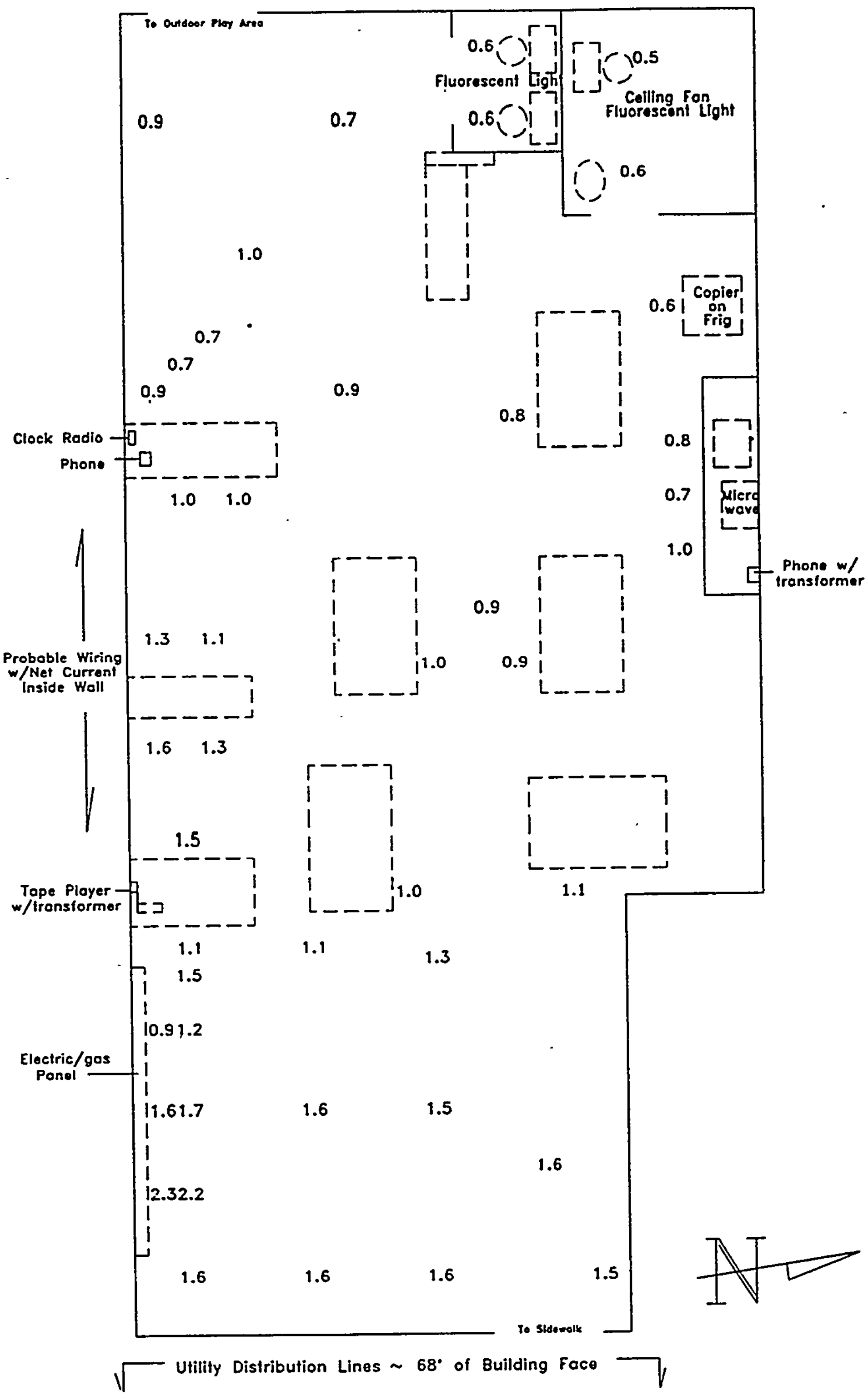


FIGURE 3A: Resultant AC Magnetic Fields and Locations of Sources in Classroom (mG)

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment Daycare Center, San Francisco, CA

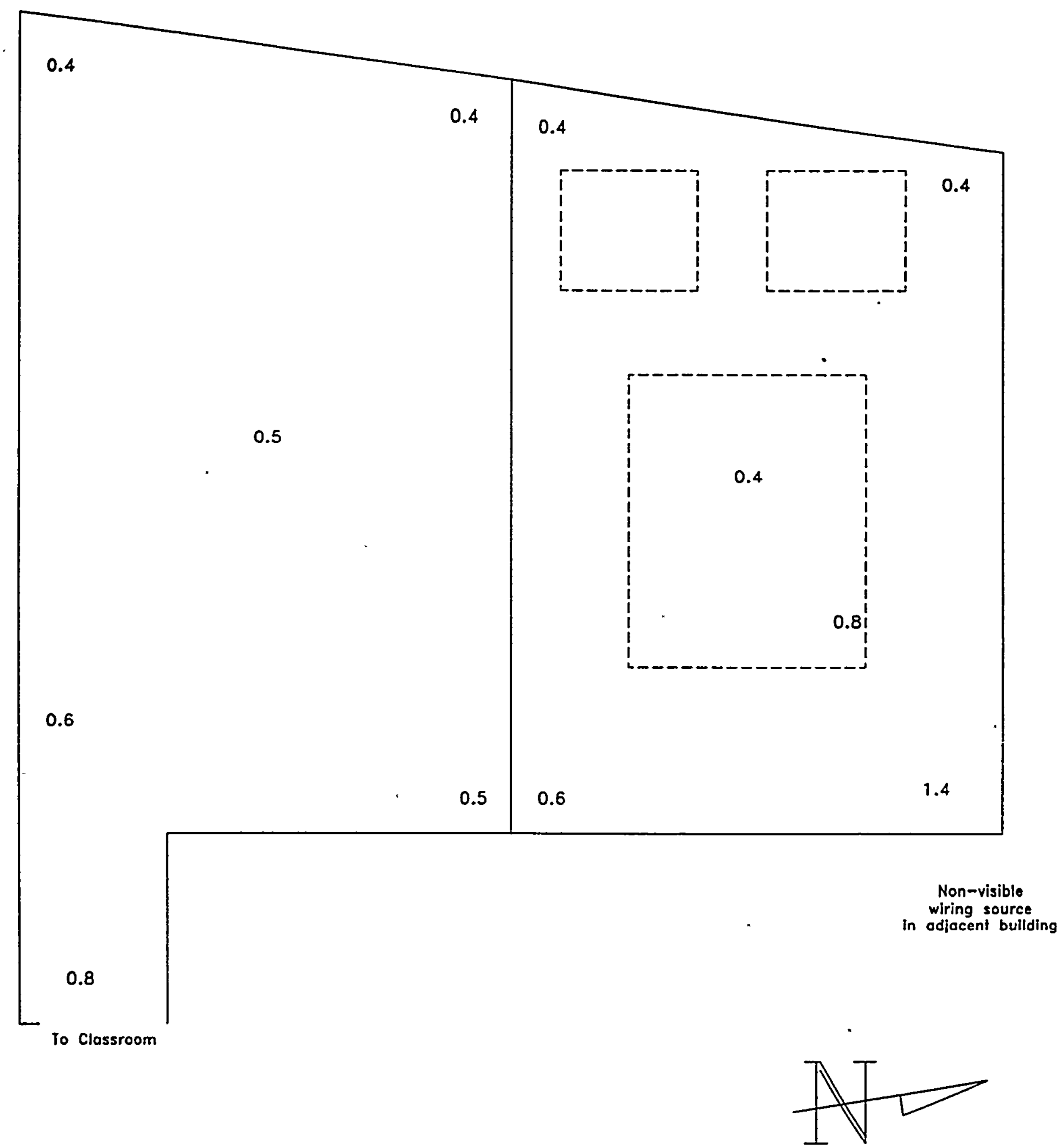


Figure 3B: Resultant AC Magnetic Fields and Locations of Sources in Outdoor Play Area (mG)

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment Daycare Center, San Francisco, CA

Figure 4:
Resultant AC Fields by Microenvironment
Daycare Center Magnetic-field Assessment

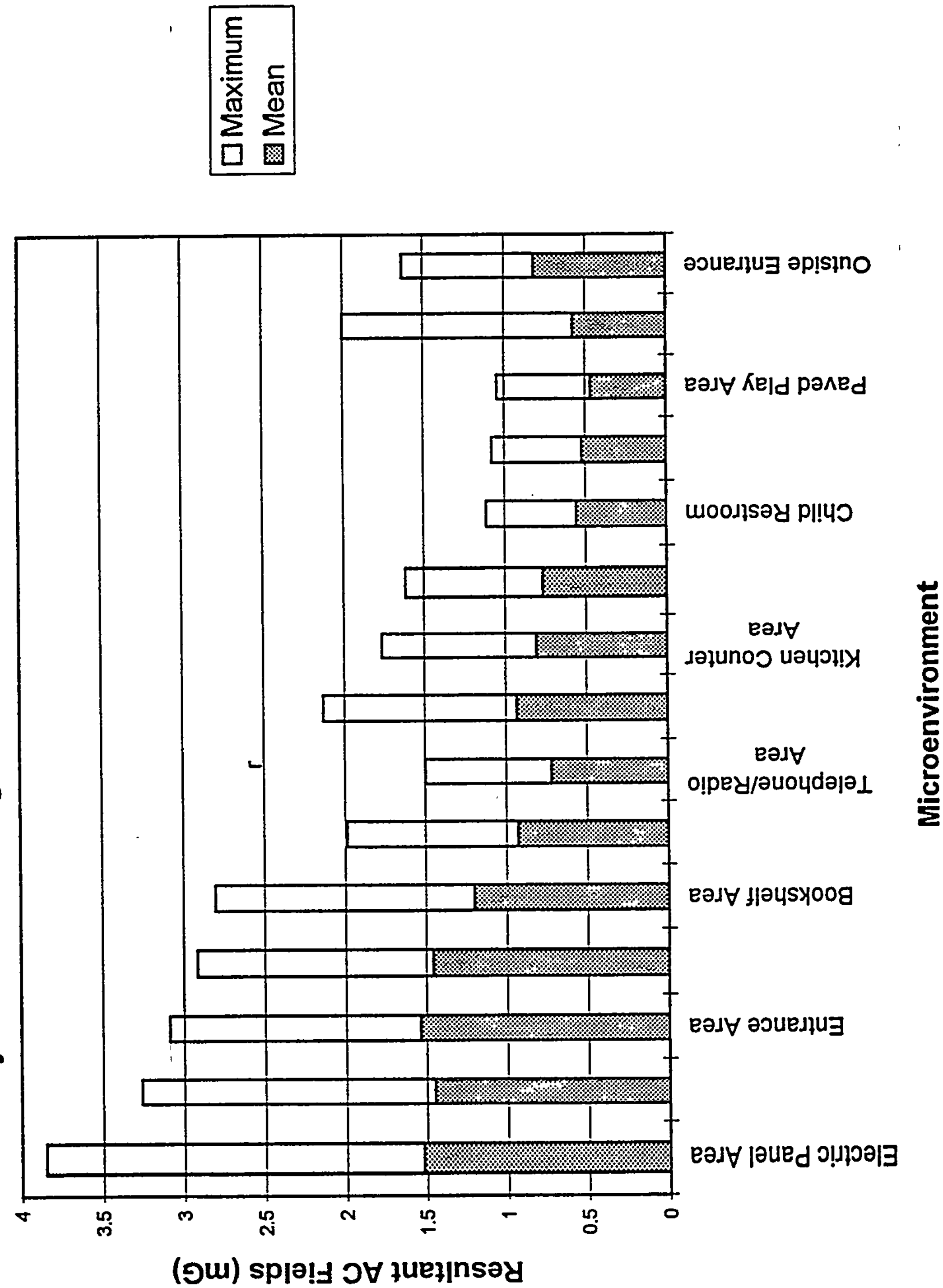
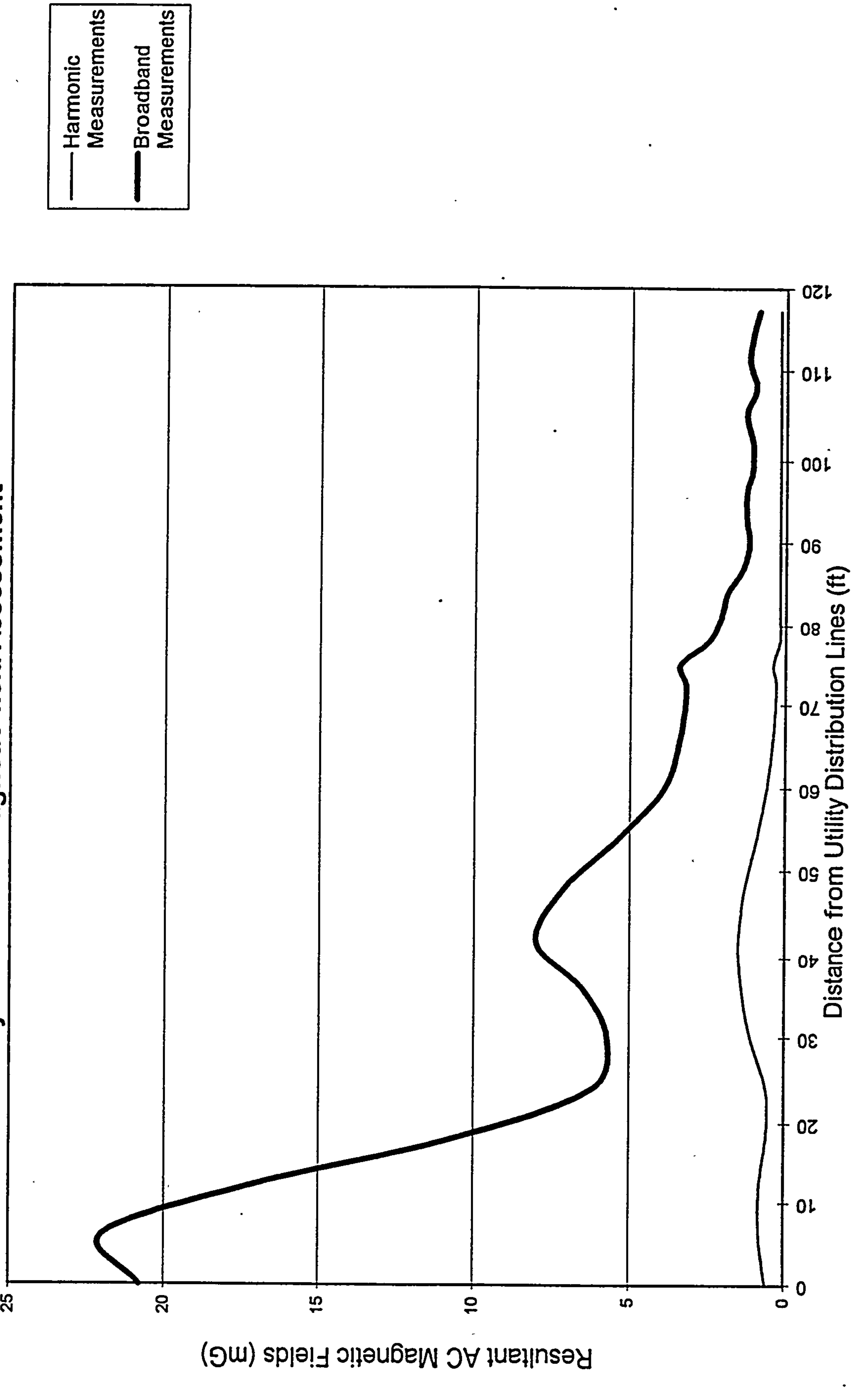


Figure 5:
Lateral Profile of Resultant Magnetic Fields from Utility Distribution Lines (mG)
Daycare Center Magnetic-field Assessment



APPENDIX B.2 METAL FABRICATION PLANT PILOT STUDY REPORT

MARCH METALFAB, INC.
METAL FABRICATION PLANT
MAGNETIC-FIELD ASSESSMENT

Magnetic Measurements
Kentfield, CA 94914

Study Dates: October 2 and 3, 1995

ABSTRACT

A magnetic-field assessment was performed at March Metalfab, Inc., a fabrication facility for large ferrous and non-ferrous metal products. The project was to determine the areas and/or sources of elevated magnetic fields due to operations within in a fabrication plant. The assessment was performed as a pilot study for developing recommendations for environment-specific magnetic-field measurements. Operations in the plant include welding, machining, metal forming, and assembly. Excluding the main offices, most of the work tasks performed at the facility are associated with a specific piece of equipment, and most equipment is portable. Magnetic-field sources include office equipment, welding equipment, hand tools, industrial motors, transformers, subpanels, machining equipment, and shaping equipment. A mapping of the magnetic flux density was performed throughout the facility, and waveform capture measurements were performed at a set of worksites. The areas with the highest magnitudes of fields involved the welding processes and hand-held grinders. The magnetic fields from both of these source types fell off quickly with distance. An apparent net current source in the ceiling of the restroom affected the magnetic-field exposure in a large area. Most resultant dc magnetic fields ranged from 225 mG to 700 mG, with the primary exception being in the vicinity of dc welders. Total harmonic distortion ranged from 3% (near the net current source) to 1126% in the vicinity of a welder. External utilities contributed very little to the magnetic-field exposure within the plant.

INTRODUCTION AND PURPOSE

A study of the characteristics of magnetic fields was performed for the facilities of March Metalfab, Inc. in Hayward, California. The purpose of the project was to determine the areas and/or sources of elevated magnetic fields due to operations within in a fabrication plant. The project also pilot-tested the recommended guidelines for environment-specific field measurements in an industrial setting, and collected environment specific magnetic-field data for inclusion in the RAPID EMF Measurement Database. Measurements were performed on October 2 and 3, 1995.

DESCRIPTION OF THE SITE

The March Metalfab, Inc. facility is a fabrication facility for large ferrous and non-ferrous metal products. Operations within the plant include welding, machining, metal forming, and assembly. The production and administrative offices are also located at the facility. A layout of the facility is shown in Figure 1.

March Metalfab, Inc. is considered a "job shop"; the company performs specific metal fabrication projects at the request of a customer. Projects range in physical size from tabletop work to room-size vessels and steel structures. Therefore, the area, the equipment, the employees and the processes required to perform a fabrication project are designed to change with each project, from day to day, and in many cases within a day. Almost all equipment is on wheels or is easily moved with a fork lift.

Physical Site: The facility was built in 1971, and includes 55,000 square feet of floor space on one level. A 37,500-square-foot yard is used for assembly, fabrication, receiving, and storage. The main plant is of steel frame construction with sheet metal siding on a reinforced concrete slab on grade. Employee parking is outside of the main plant area. In the surrounding vicinity of March Metalfab are modern low-rise industrial buildings. The weather conditions at the site were hot, dry, and clear during the study.

RAPID Environmental Classification: The March Metalfab facility may be classified as:

Environmental Group:	*Industrial*
Environment:	*3400: Metal Fabrication*

The environment may be divided into the following classifications of subenvironments:

Subenvironment	Classification
Main Office	x-Office
Non-ferrous Fabrication*	e-Production
Machine/Small Parts Shop	i-Machining Area
Break Room	u-Break Room
Welding Area	h-Welding Area
Manufacturing & Prep*	e-Production
Manufacturing & Assembly*	e-Production
Yard	w-Yard
Maintenance Shop	v-Repair Shop
Layout Room	x-Office
Restroom	c-Locker Room
Quality Control Office	x-Office

*Welding is a significant activity in Non-ferrous Fabrication, Manufacturing & Assembly, and the Manufacturing & Prep subenvironments.

INSTRUMENTATION

The instrumentation available for the subject study included one Field Star® 1000 magnetic flux density meter, two Multiwave System II® waveform capture systems, and two EMDEX II® magnetic flux density meters.

Field Star® 1000: The Field Star® 1000 was used for the performance of the area mapping of ac magnetic fields. The Field Star® 1000 is manufactured by Dexsil Corporation of Hamden, Connecticut. The Field Star 1000 has a range of 0.04 mG to 1000 mG, and is filtered to capture the 60-Hz component of the ac fields only. It contains three orthogonal magnetic-field sensor coils for measuring the x-, y-, and z- axis components of the magnetic fields. The resultant is calculated by computing the square root of the sum of the squares of the simultaneous measurements of field magnitude by the three orthogonal coils. The meter was calibrated within six months of the study, and was verified immediately after the study.

The Field Star® meter was attached to a measurement wheel four feet in circumference. Sensors were set to trigger a recorded measurement by the instrument every one foot along the wheel's path. Turns in the path were entered and recorded automatically with the field data so that each data point was given a location on the x,y grid of the area measured.

MULTIWAVE SYSTEM II®: The Multiwave System II® was used to collect magnetic-field waveform data at 192 selected locations. The Multiwave System II® is manufactured by Electric Research and Management, Inc. of State College, PA. The instrument digitizes and stores analog waveforms from a triaxial Faraday induction-coil ac-magnetic-field sensor and a triaxial fluxgate magnetometer dc-magnetic-field sensor. The Multiwave System II® was operated with a base frequency of 15-Hz at a rate of 7680 samples/second per active channel. This resulted in 512 digitized samples for each 16.67 ms period of the 60-Hz based frequency.

A stationary Multiwave System II® was also set up near a welding machine in use. The system was programmed to record waveform data every minute for a period of 147 minutes. This instrument was operated with a base frequency of 60-Hz.

EMDEX II: A handheld EMDEX II® was used as a scoping tool in the source identification. It was also used to perform a series of measurements over time in an area of suspected net currents. The EMDEX II magnetic flux density meter is manufactured by Enertech Consultants, Inc. of Campbell, CA. The EMDEX II® has a range of 0.1 to 3000 mG and a frequency bandwidth of 40 Hz to 800 Hz; it filters for a harmonic component bandwidth of 100 Hz to 800 Hz. Like the Field Star® 1000, it contains three orthogonal magnetic-field sensor coils for measuring the x-, y-, and z- axis components of extremely low frequency magnetic fields. The resultant is calculated by computing the square root of the sum of the squares of the simultaneous measurements of field magnitude by the three orthogonal coils. The meter calibration was verified within thirty days of the study, and the operation of the three sensor coils was verified immediately prior to the study.

ASSESSMENT METHODS

The magnetic-field assessment was planned and performed using the following study schedule: area mapping, source identification, activity-pattern data collection, and determination of microenvironments were performed on the first visit; waveform capture measurements, long-term measurements, and confirmation of data previously collected were performed on the second visit, the next day.

Area Mapping: The Field Star® 1000 was used to record rms magnetic-field measurements throughout the facility. The meter was attached to a recording wheel at a height of one meter above the floor. The wheel was "driven" by a technician in a pattern through each subenvironment, with particular attention to those areas where employees would spend time on work tasks and in traffic areas. At every 1-foot increment along the path of the wheel, the meter was triggered to record a magnetic flux density measurement and the relative location of that measurement. This data was interpolated into a three-dimensional plot so that the areas of elevated magnetic field could be identified, and to provide an overall picture of the magnetic flux density at the facility.

Source Identification: The technicians used three sources of information to locate and identify the magnetic-field sources within the facility:

1) Upon arrival at the site, the informant (the Operations Superintendant) provided a general tour of the plant, explaining the site manufacturing equipment.

2) A visual inspection was performed of the site. Visible possible sources were identified and documented on the site plans. Upon return to the subenvironment for waveform capture measurements, pertinent information about the source, as available from nameplates or discussions with employees, were documented.

3) The results of the area mapping task were reviewed to identify areas of elevated ac fields. If any area of elevated field did not correspond with a visually identified source, the technicians returned to the site and "scoped out" the source using an EMDEX II® hand-held magnetic flux density meter.

Activity-pattern Data Collection: Activity-pattern data were collected to determine where and near what sources the employees spent their time, so that the magnetic-field measurement plan could be formulated relevant to the occupant's exposure. Like many industrial environments, the many sources also define workstations:; i.e., a welding workstation will involve a welder; a lathe defines a specific machining workstation. However, March Metalfab, Inc. is somewhat unique in the fact that many worker locations and sources are portable and unpredictable. Therefore, few generalizations could be made about worker location. Information about the locations of workers was gathered in six stages:

1) Prior to the measurement dates, the site informant completed a written questionnaire about the employees and their locations within the plant.

2) During the general tour of the site, the informant explained the uses of the equipment and described the types and numbers of occupants in each environment.

3) Simultaneously with the source investigation, the technicians performed a visual inspection to select primary areas of activity as they related to sources.

4) In the moments prior to the waveform capture measurements at a workstation, the individual employee was briefly questioned about his/her typical position while at that workstation, and the typical uses of the workstation sources.

5) Photographs were taken of the employees at their workstations.

6) A post-measurement interview with the informant was performed to verify the responses of the employees, and to confirm or clarify the technicians' observations.

Identification of Microenvironments and Selection of Microenvironments for Waveform Capture Measurement: A microenvironment may be defined by a combination of the locations of sources and the locations of people with respect to the sources. As previously stated, much of the March Metalfab facilities are portable, and both the workers and the sources relocate, depending on the project at hand. Because of the mobility of both the employees and the equipment, many of the microenvironments within the March Metalfab facility could not be permanently defined. The microenvironments could be placed into four categories:

1) Permanent work locations in which specific permanent sources might influence personal exposure.
   Examples: main office work stations, quality control office desks

2) Workstations specifically defined by the portable equipment in use by an employee, independent of the location of the equipment in the facility.
   Examples: grinders, welders

3) Non-work locations or workstations not normally defined by permanent sources.
   Examples: break room seating, restroom stall, welding area office

4) General traffic and work areas within a subenvironment in which portable sources might influence exposure.

With the exception of the Main Office, the goal of the selection of microenvironments for characterization was to assure that a representative set of exposure-relevant microenvironments was measured, with minimal disruption to the workforce. In order to accomplish this, the microenvironments selected were those occupied on the particular date and time of data collection. It was assumed that these selected areas of exposure would be generally representative of microenvironments throughout the plant.

Main Office: A preliminary review of the area mapping and source identification information showed that the main offices contained sources and magnetic-field levels typical of other office environments. Because of this, and because the focus of the study was on exposure in an industrial environment, only four microenvironments in the main office were selected for further study: two permanent work stations, the copier area, and the general traffic area.

The Remainder of the Facility: The goal of the selection of microenvironments for characterization was to assure that a representative set of exposure-relevant microenvironments was measured, with minimal disruption to the workforce. In order to accomplish this, the microenvironments selected were those occupied on the particular date and time of data collection. It was assumed that these selected areas of exposure would be generally representative of microenvironments throughout the plant.

Waveform Capture Measurements: Waveform capture measurements were performed on October 3, 1995 while the facility was in operation. No measurements were performed during the company lunch break.

Measurement points were selected in order to obtain the best possible characterization of the magnetic fields to which workers were exposed. Information from the activity-pattern data collection identified the area of movement for an employee in any given microenvironment. For each microenvironment, a series of points was selected to best include and characterize the range of exposure for the worker. In most microenvironments, measurements were performed in a five-point "X" pattern: one in the approximate "typical" location of the worker, and one each to the left-front, right-front, left-rear and right-rear of the "typical" location. The measurement point pattern generally wasgenerally such that the outlying points were 18 inches from the center point, though this was subjectively determined based on the range of mobility of the worker within the microenvironment and the spatial variation of the magnetic fields. (It is acknowledged that such a series of measurements may not have captured the peak location of exposure. For example, at a machinery workstation or welding workstation, it is likely a front-center measurement may better have indicated the peak exposure. However, the "X" pattern was chosen to maximize safety, minimize disruption, and assure that data could be collected while work was taking place.)

In General Traffic microenvironments, measurements were performed in a grid pattern throughout the area of occupancy in order to gather a representative sample of information about exposures not specific to the use of or proximity to a single piece of equipment.

At all selected locations, measurements were made with the instrument's sensor staff oriented vertically and in line with the facility grid, with the sensors at a height of 1 m (3.3 feet) above the floor.

Temporal-data Collection: From the preliminary information gathered during the initial site tour and area mapping task, two areas of interest with respect to the temporal characteristics of magnetic fields were confirmed: the exposure from welding equipment, and the exposure from an unknown, apparent net current source.

The area mapping data and subsequent scoping indicated a potential net current source which affected exposure primarily in the Layout Department, Restroom, and Quality Control Office. A stationary EMDEX II was deployed in the Layout Department to collect any temporal variation in the magnetic-field magnitude. Every 3.0 seconds for a period of 94 minutes, the instrument recorded the broadband and harmonic components of the ac magnetic flux density. Events during that time involving area sources or activities were not documented.

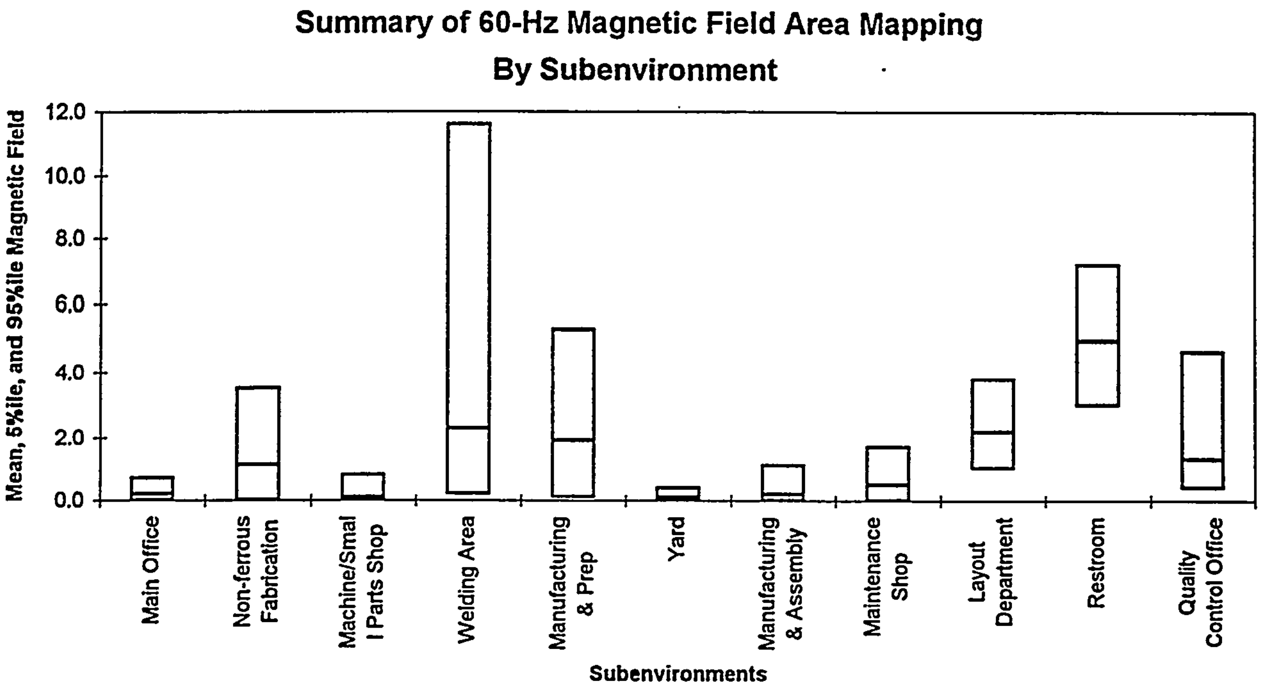
Because welding is a very frequent activity at the facility, further information regarding the characteristics of fields produced by welding equipment was of interest. A Multiwave System II® was stationed in the vicinity of a welder performing arc welding. The location of the instrument is shown on Figure 2D. The instrumentation was programmed to capture waveform data every minute for a period of 123 minutes. During the data collection no information was gathered on the location of the welder or the welding activity.

RESULTS

Area Mapping

The contour maps of magnetic fields developed based on the results of the Field Star measurements are shown in Figure 2A through 2H. (Note that though the locations of sources have also been depicted in these figures, only some of the sources were in operation at the time of the Field Star measurements. Their operating status at the time is depicted by an asterisk.)

The measurements taken in each subenvironment are summarized in Table A and depicted in chart form below. Note that the statistics are summarized from those measurements taken along the path of the Field Star® measurement wheel. The sample points were not distributed evenly over the area, nor is it assumed that peak magnitudes of fields were captured.



The highest magnitude fields found in the area mapping were located in the Welding Area, Manufacturing and Prep, and Non-ferrous Fabrication. The sources contributing the higher magnitude fields were point sources. In the Welding Area, welders and the dry-type transformer appeared to have contributed the highest fields. In Manufacturing & Prep, the subpanels appeared to have contributed the highest fields. In Non-Ferrous Fabrication, the gear motor of a turntable and the dry-type transformer of a band saw were the contributors of the highest magnitude fields.

The highest average fields, however, were found in the Restroom. This was due to a non-visible, apparent net current source in the ceiling. Because the magnetic fields produced by a net current source fall off with distance very gradually (generally at a rate of 1/d), this source contributed to elevated field levels in the Layout Department, Quality Control Office, and the east side of Manufacturing & Prep, as can be seen on the Figures 2E and 2H.

Sources of Magnetic Fields

External Utilities: The external utilities are shown on Figure 1. A 12-kV overhead distribution line runs along the southern edge of the site. Via a primary riser on a pole in the southwest corner of the site and an underground cable, power is supplied to a three-phase transformer located outside the main fabrication building. An underground secondary cable then feeds 480/277-volt, 3-phase panels on the west wall. The 12-kV distribution line supplies power for industrial/commercial uses. The current on the distribution line was not monitored because it was found to be a minor source of magnetic field within the plant.

A series of magnetic-field readings was taken in one-foot increments in a course perpendicular from the 12-kV distribution lines, to show the falloff of magnitude with distance from the lines. This lateral profile is graphically displayed in Figure 3.

Internal Sources: Sources of magnetic fields internal to the site may be included in the following general categories:

Office Equipment	computers, monitors, copiers, facsimile machine, etc.
Welding Equipment	Mig, Heliarc, and D.C. arc welding machines
Hand tools	grinders, nibblers
Industrial Motors	band saws, grinders, turning motors, forklifts
Power Sources	breaker panels, wiring, transformers
Machining Equipment	lathes, milling machines, drill presses
Shaping Equipment	oven, brakes, shears.

Many of these sources, including all welding equipment, hand tools, and some industrial motors are portable. The equipment is on wheels, or is moveable with a forklift. During any given period of time, the location of the sources may change. The locations of sources were identified during the initial walk-through, and are shown in Figures 2A-2H. Those operating at the time of the Field Star measurements have been identified with an asterisk.

Activity Patterns

Occupants: March Metalfab, Inc. employs between 60 and 70 adults on two eight-hour shifts with a half-hour lunch break. Most activity takes place during the first shift, with a partial crew on the second shift. The makeup of the occupants include the following.

16 office employees and project managers
7 machinists
17-27 fitters and welders
10-15 employees (primarily welders) working on the second shift.

This industrial environment has few "casual" users. Other than the regular employees, users might include infrequent visits by suppliers, salespersons, and others. This group was not included in the considerations of the study.

General activity patterns: As with many industrial environments, work locations are often determined by the specific equipment in use by a given employee. Such equipment will vary, based on the project at hand. Most employees did not have permanent work stations, except in office areas. The activity patterns of the occupant groups can be summarized as follows:

In the main office, employees have permanent or semi-permanent workstations. Sixteen clerical staff and project managers spend a substantial portion of the work day within the main office. Time is divided between designated workstations for each occupant, use of shared office equipment (such as the copier), and general travel in the overall subenvironment.

The machinists remained primarily within the Machine/Small Parts Shop, although no workstation was permanently maintained by any given machinist. This area, unlike other fabrication areas of the plant, included several workstations defined by permanent equipment.

Fitters and welders tended to have no permanent workstations. Their workstations were often defined by portable sources (such as welding machines, hand tools, etc.). In addition, they were exposed to more background fields throughout the plant because of their frequent relocation from workstation to workstation.

The layout engineers, quality control inspectors, and maintenance persons spent a portion of time in subenvironments with permanent sources (the quality control office, layout department and maintenance shop), and roved other subenvironments depending on the project.

A description of the uses of each subenvironment and typical occupants is presented in Table B.

Waveform Capture Measurement Results

Forty-three microenvironments were selected for waveform capture measurement. The locations of those microenvironments are shown in Figures 2A through 2H. Magnetic-field waveform data were recorded at 192 locations in the facility, by microenvironment. A summary of the magnetic-field characteristics found in each microenvironment is found in Table C, and is further summarized by subenvironment in Table D. The summary of magnetic-field characteristics for each sample point and the raw waveform data are available from Magnetic Measurements if further analysis or review of other field parameters is desired.

Resultant AC Magnetic Fields The five microenvironments with the highest magnitudes of measured fields were the five involving welding process. (Because of the difficulty and disruption of performing measurements around active welding, measurements were taken at varying distances from the sources, and should not be directly compared.)

RESULTANT AC MAGNETIC FIELDS BY MICROENVIRONMENT

Micro-environment	Sub-environment	Ave Res AC Field	Max Res AC Field	Welding Machine Type
Welder 1	Non-ferrous Area	16.7 mG	36.2 mG	Miller Syncrowave
Welder 2	Welding Area	56.2 mG	175.7 mG	Miller Deltaweld
Welder 3	Welding Area	45.3 mG	63.3 mG	Lincoln IdealArc
Welder 4	Manuf & Prep	37.9 mG	76.7 mG	Miller Dimension DC
Welder 5	Manuf & Assembly	85.1 mG	125.0 mG	Miller Mig Welder

In addition to the welding machines, grinders were a primary source of fields in microenvironments with elevated ac field levels:

RESULTANT AC MAGNETIC FIELDS BY MICROENVIRONMENT

Micro-environment	Subenvironment	Ave Res AC Field	Max Res AC Field	Primary Sources
Work Table	Non-ferrous Area	2.4 mG	3.1 mG	Mikita Grinder
Grinder	Welding Area	9.7 mG	32.9 mG	Mikita Grinder
Grinder	Maintenance Shop	5.4 mG	11.8 mG	G.E. Grinder

Microenvironments with elevated fields due to permanent sources included microenvironments near transformers and subpanels, and microenvironments affected by the non-visible net current source above the Restroom. These microenvironments included:

RESULTANT AC MAGNETIC FIELDS BY MICROENVIRONMENT

Micro-environment	Sub-environment	Ave Res AC Field	Max Res AC Field	Primary Source
Seating	Break Room	2.3 mG	7.6 mG	Dry-type transformer in weld area
Layout Desk	Layout Dept	2.7 mG	3.5 mG	Net current source in ceiling
Layout Table	Layout Dept	2.7 mG	3.0 mG	Net current source in ceiling
West Stall	Restroom	4.0 mG	4.2 mG	Net current source in ceiling
Test Table	Q. C. Office	5.1 mG	5.4 mG	Net current source in ceiling
Wecheco Lathe	Machine Shop	2.2 mG	4.6 mG	Dry-type transformer nearby

The apparent net current source in the Restroom ceiling also substantially affected the background fields in the Restroom, Layout Department, Quality Control Office, and parts of Manufacturing & Prep. Transformers and sub-panels throughout the facility, including those in the Welding Area, Manufacturing & Prep, and Manufacturing & Assembly, contributed substantially to the magnetic-field magnitude in the immediate vicinities.

DC Magnetic Fields: Most resultant static fields measured within the facility ranged from 225 mG to 700 mG. This general range of static field would be expected in an environment containing ferromagnetic materials, in buildings constructed substantially of steel. In the microenvironments involving dc welding, at least one axis of the dc field was substantially elevated. In the "Welder 2" microenvironment of the Welding Area, a resultant dc field of 4110.8 mG was measured. In the "Welder 4" of the Manufacturing & Prep Area, a maximum resultant dc field of 1047 mG was measured. Other areas in which at least one axis varied greatly from the background levels included "Welder 1," "Welder 5," the Brake, the Workbench, the Floor Mill, the Machine Shop Layout Area, and the Layout Desk.

Total Harmonic Distortion of AC Fields (THD): The THD is the root-mean-square of the individual harmonic field intensities divided by the intensity of the fundamental 60-Hz field component. It indicates the relative amount of harmonics in a field waveform without regard to frequency. In addition to the THD reported, the waveforms and the absolute values of the harmonic magnetic-field intensities were reviewed.

The THD measured at the selected sample points ranged from 3% to 1126%. The microenvironments with the lowest THD percentage were consistently seen within the Restroom, Quality Control Office, and Layout Department subenvironments. These subenvironments are dominated by the non-visible net current 60-Hz source in the ceiling, presumably part of the wiring system.

The microenvironments influenced by welders consistently had the highest magnitudes of harmonic-field intensity. In general, the fields measured in these microenvironments contained higher THD percentages. Other microenvironments with high percentage of THD, but not of high-magnitude harmonics, included points near the forklift in the Yard, and at Lisa's desk in the Main Office.

Polarization: The degree of elliptical polarization of the 60-Hz frequency component has been expressed by the ratio of the semi-minor axis to the semi-major axis. Polarization ranged widely from less than 1% near two welders to 94% near a grinder. Polarization was consistently low in the Quality Control Office. Otherwise, no patterns within the environment or subenvironments were identified.

AC-DC Relative Orientation (ac perpendicular to dc): The three-dimensional dc and ac magnetic flux density measurements were analyzed to compute the orthogonal components of the maximum axis of the 60-Hz field vector with the dc-field vector. These have been presented as ratios in Table C . The relative orientation ranged from 14.9% to 99.9%. At only six of the 192 sample points was the perpendicular component of the field less than 50% of the total 60-Hz field, as listed below:

Micro environment/ Meas Location	Sub-environment	60 Hz Field Normal to DC (mG)	60-Hz Field Normal to DC (percentage of AC)
Carl's Desk/Cntr	Main Office	0.1 mG	32.1%
Layout Area/R Rear	Machine/Sm Parts	0.2 mG	18.6%
Milling Machine/Cntr	Machine/Sm Parts	0.04 mG	33.3%
Welder 2/Cntr	Welding Area	7.81 mG	28.2%
Welder 2/R Front	Welding Area	9.55 mG	14.8%
Welder 2/R Rear	Welding Area	2.46 mG	19.7%
Welding 4/R Rear	Manuf & Prep	4.9 mG	32.1%

Further review of the waveform data could reveal information about the orientation of fields at other frequencies.

TEMPORAL-DATA COLLECTION

Net current source vicinity: A stationary EMDEX II magnetic flux density meter was deployed in the Layout Department to collect any temporal variation in the magnitude of the magnetic fields created by the non-visible source in the ceiling. Measurements of the broadband and harmonic magnetic-field intensity were collected every three seconds. It was found that the fields were very stable. The average broadband field over the period of measurement was 3.2 mG with a standard deviation of 0.1 mG. The harmonic content was 0.2 mG with a standard deviation of >0.1 mG. This data supported the assumption that the fields were produced by a wiring source, although time did not allow further investigation to identify the source.

Welding Vicinity: A stationary Multiwave System II® was deployed in the Welding Area in the vicinity of an active welder. Spot measurements were taken every minute for a period of 147 minutes. The activities over time of the welder working in the area were not recorded. The resultant ac field varied from 0.2 mG to 34.5 mG, and averaged 4.5 mG.

The total harmonic distortion varied from 20% to 836% and averaged 154%. The harmonic components of the measurements were of interest. During the first twenty minutes of data collection, the fields were characterized by a very dominant 6th harmonic, whereas the remainder of the data collection period involved a more dominant 3rd harmonic. During the second twenty minutes of the data collection, a significant increase in the resultant ac-field magnitude was experienced, the greatest contribution being from the 3rd harmonic. Large spikes in the magnitude of the 6th harmonic during this time were accompanied by spikes in the dc magnitude. For the remainder of the data-collection period, the 3rd harmonic dominated the frequency spectrum, though at a lesser magnitude. In hindsight, a log of activity in the area would have been beneficial to discern the differences between these three periods. The results of the measurements were as follows:

Parameter	Average Measurement	Measurement Range
Resultant AC Magnetic Field	4.5 mG	0.2 mG - 34.5 mG
DC Field	383.4 mG	304.8 mG - 531.9 mG
Total Harmonic Distortion	154%	20% - 836%
Polarization	29%	3% - 79%
AC Field Parallel to DC	1.4 mG	0.2 mG - 17.8 mG
AC Field Normal to DC	2.8 mG	0.2 mG - 27.5 mG

DISCUSSION

This magnetic-field assessment indicated that the exposures in this industrial facility were not influenced by external sources. The two unique features influencing exposure were: the mobile nature of the workspaces, people, and equipment; and the prevalence of welding activities. The waveform capture data collected indicated that the welding equipment contributed to the peak exposures with respect to dc magnitude, ac magnitude, harmonics, and other magnetic field parameters. All fabricating equipment in general could be classified as point sources; no equipment contributed broadly to background exposure. Although this study did not focus on discerning between exposures from the various types of welding equipment, further study at this location, or further study of welding equipment in a controlled environment, would provide additional information about magnetic-field exposures with respect to welding activities.

TABLE A
SUMMARY OF 60-HZ MAGNETIC-FIELD AREA MAPPING
BY SUBENVIRONMENT

	Peak	Mean	Median	Std Dev	L95	L5
Main Office	1.7 mG	0.2 mG	0.1 mG	0.2 mG	<0.1 mG	0.7 mG
Non-ferrous Fabrication	32.3 mG	1.1 mG	0.2 mG	3.8 mG	<0.1 mG	3.5 mG
Machine/Small Parts Shop	3.3 mG	0.1 mG	0.0 mG	0.4 mG	<0.1 mG	0.8 mG
Welding Area	60.0 mG	2.3 mG	0.8 mG	5.2 mG	0.2 mG	11.6 mG
Manufacturing & Prep	93.2 mG	1.9 mG	0.4 mG	8.0 mG	0.1 mG	5.3 mG
Yard	3.2 mG	0.1 mG	0.0 mG	0.3 mG	<0.1 mG	0.4 mG
Manufacturing & Assembly	3.9 mG	0.2 mG	0.1 mG	0.5 mG	<0.1 mG	1.1 mG
Maintenance Shop	2.7 mG	0.5 mG	0.2 mG	0.6 mG	<0.1 mG	1.7 mG
Layout Department	3.8 mG	2.2 mG	2.3 mG	1.0 mG	1.0 mG	3.8 mG
Restroom	7.3 mG	5.0 mG	5.3 mG	1.3 mG	3.0 mG	7.2 mG
Quality Control Office	5.4 mG	1.3 mG	1.4 mG	1.3 mG	0.4 mG	4.7 mG

TABLE B
OCCUPANTS, ACTIVITIES, AND SOURCES BY SUBENVIRONMENT

SUB-ENVIRONMENT	Est # people / People present	Description of use	General Sources
Main Office	13 / 12	Clerical staff are regularly only in office, in regular workstations. Project managers have regular workstations, but spend some time each day in production areas.	**Portable:** None **Permanent:** computers, monitors, copier, facsimile machine, typewriters, blueprint machines, and printers, vending machines on contiguous wall
Non-ferrous Fabricating	2 to 3 / 4	Specialized welders and fabricators use this area. All equipment is moveable, and is moved on a regular basis.	**Portable:** Welders, grinders, turntables, band saw, air cleaner **Permanent:** breaker panel
Machine/Small Parts Shop	6 to 7 / 5	Machinists occupy the space full time, utilizing the permanent equipment.	**Portable:** Grinders, task lighting **Permanent:** Drill presses, lathes, mills, transformer
Manufacturing & Assembly	~3 / 5	Reserved for special projects. At time of study used for welding and drilling.	**Portable:** welders, drilling machine, band saw **Permanent:** subpanel
CMM	<1	Occasional use by measurement inspectors.	Unknown. No access on days of study.
Manufacturing & Prep	~10 / 11	Fitters and welders regularly in space. About 15 people observed in area over first day.	**Portable:** welders, grinders, nibblers, air cleaner **Permanent:** brakes, shear, main electric panels, oven, drill, press, seam welders
Welding	5 to 7 / 5	Primarily welders performing welding activities.	**Portable:** welders, air cleaners, grinders, turning motors **Permanent:** Transformer, seam welders
Quality Control Office	~3 in and out / 2	Three full-time inspectors use the desk area and test table area on an in-and-out basis. Occasionally occupied by project managers and others.	**Portable:** Hardness tester **Permanent:** Unidentified net current source in restroom ceiling, subpanel, air conditioner, copier
Restroom	occa-sional / 0	All plant employees except office staff use for a few minutes several times per day.	**Portable:** None **Permanent:** Ceiling fan, refrigerator, unidentified net current source in ceiling
Layout Department	-1 / 1	Regularly occupied by layout personnel. Occasionally by project managers and others.	**Portable:** None **Permanent:** Air conditioner, microwave, fan unidentified net current source in restroom ceiling
Maintenance Shop	~1-3 / 0	Regularly occupied by two full-time maintenance personnel. One occupant in desk area most of time.	**Portable:** Grinder **Permanent:** Drill press, parts cleaner, ceiling fan, grinder
Breakroom	occa-sional	Regularly occupied by certain production employees at lunch and breaks. (Others break at various locations in plant.) Occasionally visited by all employees.	**Portable:** none **Permanent:** drink machines, refrig-erator, transformer on contiguous wall
Yard	occa-sional / 0	Occasional use by most production employees. Moving, storage prep activities.	**Portable:** Forklifts **Permanent:** Utility distribution line contiguous

TABLE C
MAGNETIC-FIELD DATA BY MICROENVIRONMENT
Sheet 1 of 5

SUBENVI-RONMENT	MICRO-ENVIRONMENT (N)	Primary Sources at time of measure-ments	Resultant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60-Hz-%	60-Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
MAIN OFFICE	LISA'S DESK (5)	Monitor, CPU, HP Printer						
	Average		0.6	523.3	47.5	0.3	0.5	0.4
	Max		1.1	556.7	108.5	0.5	1.0	0.5
	Std Dev		0.3	31.2	34.2	0.2	0.3	0.1
	COPIER(5)	Cannon Copier						
	Average		0.9	367.5	38.8	0.3	0.8	0.4
	Max		2.5	416.2	60.4	0.7	2.3	0.9
	Std Dev		0.9	30.6	17.6	0.2	0.8	0.3
	CARL'S DESK (5)	Monitor, CPU, Adding Machine						
	Average		0.3	510.2	42.9	0.4	0.3	0.1
	Max		0.7	517.0	51.9	0.7	0.7	0.1
	Std Dev		0.2	6.1	9.7	0.2	0.2	0.0
	BACKGROUND (2)							
	Average		0.3	496.1	31.2	0.6	0.3	0.2
	Max		0.4	497.2	41.6	0.8	0.4	0.2
	Std Dev		0.2	1.5	14.7	0.3	0.1	0.1
NON-FERROUS FABRICA-TION	WELDER 1 (5)	Miller Synchro-wave Welder						
	Average		16.7	487.6	36.8	0.2	15.0	6.8
	Max		36.2	679.2	44.8	0.3	31.4	18.1
	Std Dev		13.4	147.2	12.8	0.1	11.4	7.9
	WORK TABLE (5)	Mikita Grinder, Turntable Gear-rmotor						
	Average		2.4	410.5	55.4	0.5	2.0	1.2
	Max		3.1	472.6	80.3	0.9	2.8	2.1
	Std Dev		0.9	99.2	20.7	0.3	0.7	0.6
	STG CABINET (1)	Turntable Gear-motor						
	Average		1.1	444.8	11.6	0.3	0.5	0.9
	Max		1.1	444.8	11.6	0.3	0.5	0.9
	Std Dev							
	BACKGROUND (2)							
	Average		0.4	500.1	52.5	0.3	0.4	0.2
	Max		0.7	521.1	57.1	0.5	0.6	0.3
	Std Dev		0.3	29.7	6.4	0.3	0.3	0.2

TABLE C
MAGNETIC-FIELD DATA BY MICROENVIRONMENT
Sheet 2 of 5

SUBENVI-RONMENT	MICRO-ENVIRONMENT (N)	Primary Sources at time of measure-ments	Resultant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60-Hz-%	60-Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
MACHINE/ SMALL PARTS SHOP	FLOOR MILL (4)							
	Average	Ohio Floor Mill	0.9	300.9	30.5	0.3	0.9	0.1
	Max		1.3	607.1	43.6	0.3	1.3	0.2
	Std Dev		0.5	207.8	10.4	0.1	0.5	0.1
	WECHECO LATHE(5)	Wecheco Lathe, 45 kVA Dry-Type Transfor-mer						
	Average		2.2	463.4	39.0	0.5	1.8	1.1
	Max		4.6	531.9	52.1	0.8	4.2	2.2
	Std Dev		1.5	58.8	12.7	0.2	1.3	0.9
	LATHE (5)							
	Average	Colchester Lathe	0.9	312.2	29.0	0.1	0.8	0.3
	Max		1.5	344.8	38.6	0.3	1.4	0.4
	Std Dev		0.5	31.5	8.2	0.1	0.5	0.1
	LAYOUT AREA (5)							
	Average	Fluore-scent Lighting	0.8	325.2	23.8	0.2	0.6	0.5
	Max		1.2	563.5	24.6	0.2	1.0	0.9
	Std Dev		0.3	143.6	0.9	0.1	0.3	0.3
	MILLING MACHINE(5)							
	Average	Gridding Lewis Mill	0.2	439.2	44.9	0.4	0.2	0.1
	Max		0.3	726.4	79.1	0.5	0.3	0.1
	Std Dev		0.1	233.3	24.8	0.1	0.1	0.0
	BACKGROUND (4)							
	Average		0.1	449.3	71.9	0.5	0.1	0.0
	Max		0.1	464.0	148.7	0.8	0.1	0.1
	Std Dev		0.0	21.8	51.5	0.3	0.0	0.0
BREAK ROOM	SEATING (5)	Dry type transfor-mer, vending machines						
	Average		2.3	404.2	21.1	0.4	2.1	0.8
	Max		7.6	431.0	23.8	0.7	7.5	1.5
	Std Dev		3.0	23.7	1.6	0.2	3.0	0.6

TABLE C
MAGNETIC-FIELD DATA BY MICROENVIRONMENT
Sheet 3 of 5

SUBENVI-RONMENT	MICRO-ENVIRONMENT (N)	Primary Sources at time of measure-ments	Resultant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60-Hz-%	60-Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
WELDING AREA	WELDER 2 (5)	Miller Deltaweld DCWelder Air Cleaner						
	Average		56.2	1580.0	87.2	0.1	51.9	21.7
	Max		175.7	4110.8	107.5	0.5	163.8	63.6
	Std Dev		70.3	1513.8	13.6	0.2	65.6	25.4
	WELDER 3 (3)	Lincoln IdealArc Welder						
	Average		45.3	395.4	692.3	0.0	45.2	1.6
	Max		63.3	435.4	1126.1	0.1	63.2	4.2
	Std Dev		16.3	34.7	444.4	0.0	16.3	2.3
	GRINDER (4)	Mikita Grinder						
	Average		9.7	358.1	47.7	0.6	5.7	7.6
	Max		32.9	377.4	60.5	1.0	17.7	27.7
	Std Dev		15.5	20.6	10.2	0.3	8.0	13.4
	OFFICE (5)							
	Average		0.5	400.9	33.1	0.3	0.5	0.1
	Max		0.7	421.7	39.1	0.4	0.6	0.2
	Std Dev		0.1	22.2	7.2	0.1	0.1	0.1
	ROLLERS (1)	Turning motors, nearby welders						
	Average		0.4	473.2	31.1	0.5	0.4	0.2
	Max		0.4	473.2	31.1	0.5	0.4	0.2
	Std Dev							
	BACKGRND (14)							
	Average		0.6	453.1	29.2	0.3	0.4	0.4
	Max		1.1	555.9	64.6	0.7	0.9	0.6
	Std Dev		0.2	78.6	19.4	0.2	0.2	0.2
MANUFAC-TURING & PREP	BRAKE (4)	Pacific Hydraulic Press Brake						
	Average		0.3	212.3	22.8	0.4	0.2	0.1
	Max		0.3	269.1	33.0	0.8	0.3	0.2
	Std Dev		0.0	64.5	7.7	0.3	0.1	0.0
	PACIFIC SHEAR (1)	Pacific Hydraulic Shear						
	Average		0.1	529.5	29.0	0.1	0.1	0.1
	Max		0.1	529.5	29.0	0.1	0.1	0.1
	Std Dev							
	WELDER 4 (4)	Miller Dimension DC Welder, Subpanels						
	Average		37.9	766.3	103.6	0.1	35.3	12.6
	Max		76.7	1047.5	130.3	0.2	74.6	17.8
	Std Dev		28.8	237.7	28.2	0.1	28.6	7.3
	BACKGROUND (14)							
	Average		0.7	480.1	15.2	0.3	0.6	0.3
	Max		2.8	891.4	33.0	0.6	2.4	1.4
	Std Dev		0.7	135.7	8.0	0.2	0.7	0.3

TABLE C
MAGNETIC-FIELD DATA BY MICROENVIRONMENT
Sheet 4 of 5

SUBENVI-RONMENT	MICRO-ENVIRONMENT (N)	Primary Sources at time of measure-ments	Resultant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60-Hz-%	60-Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
YARD	FORKLIFT (3)							
	Average		0.5	492.0	134.4	0.6	0.5	0.1
	Max		0.8	515.4	156.0	0.9	0.8	0.2
	Std Dev		0.3	25.4	27.2	0.3	0.3	0.1
	BACKGROUND (2)							
	Average		0.1	452.1	82.5	0.3	0.1	0.0
	Max		0.1	452.6	132.7	0.3	0.1	0.0
	Std Dev		0.0	0.7	70.9	0.1	0.0	0.0
MANUFAC-TURING & ASSEMBLY	WELDER 5 (4)							
	Average	Miller MIG Welder	85.1	412.7	65.8	0.1	84.1	11.5
	Max		125.0	546.3	81.1	0.3	122.4	25.3
	Std Dev		29.5	163.2	13.5	0.1	28.4	10.2
	STEEL PREP A (5)							
	Average		0.2	458.0	44.2	0.2	0.2	0.2
	Max		0.3	510.4	49.2	0.3	0.3	0.2
	Std Dev		0.1	43.7	3.6	0.1	0.1	0.0
	WELD PREP AREA(5)							
	Average		1.3	551.8	30.5	0.2	1.1	0.6
	Max		2.2	642.5	31.9	0.3	1.7	1.6
	Std Dev		0.6	90.3	2.6	0.1	0.4	0.5
	STEEL PREP B (5)							
	Average		0.2	403.2	48.4	0.7	0.2	0.1
	Max		0.3	493.8	55.6	0.9	0.2	0.2
	Std Dev		0.0	68.8	5.7	0.1	0.0	0.0
	BACKGROUND (3)							
	Average		1.3	399.4	30.8	0.2	0.7	1.1
	Max		3.5	499.5	48.1	0.4	1.6	3.1
	Std Dev		1.9	86.7	15.3	0.2	0.8	1.7
MAINTE-NANCE SHOP	SHOP (5)							
	Average		0.2	304.2	33.7	0.1	0.2	0.0
	Max		0.3	332.1	37.1	0.3	0.3	0.1
	Std Dev		0.0	25.4	4.0	0.1	0.0	0.0
	WORKBENCH (5)							
	Average		0.8	555.7	29.9	0.3	0.7	0.4
	Max		1.1	725.6	34.5	0.5	0.9	0.7
	Std Dev		0.2	131.6	2.7	0.1	0.1	0.2
	GRINDER (5)							
	Average	G.E. Grinder	5.4	414.2	8.9	0.8	4.4	2.9
	Max		11.8	440.7	11.8	0.8	11.0	5.5
	Std Dev		4.6	26.2	1.9	0.0	4.2	2.1
	BACKGROUND (2)							
	Average		0.5	352.5	19.4	0.4	0.4	0.1

TABLE C
MAGNETIC-FIELD DATA BY MICROENVIRONMENT
Sheet 5 of 5

SUBENVI-RONMENT	MICRO-ENVIRONMENT (N)	Primary Sources at time of measure-ments	Resultant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60-Hz-%	60-Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
	Max		0.6	361.4	22.5	0.6	0.6	0.2
	Std Dev		0.2	12.6	4.4	0.3	0.2	0.0
LAYOUT AREA	LAYOUT DESK (5)							
	Average	Net current source in ceiling	2.7	480.3	6.2	0.4	2.4	1.1
	Max		3.5	944.3	7.2	0.6	3.0	1.7
	Std Dev		0.6	284.6	1.0	0.1	0.5	0.4
	LAYOUT TABLE (5)							
	Average	Net current source in ceiling	2.7	416.4	6.9	0.1	2.2	1.4
	Max		3.0	471.8	7.2	0.2	2.3	2.0
	Std Dev		0.3	35.0	0.2	0.0	0.1	0.6
	BACKGROUND (1)							
	Average		1.3	433.6	7.2	0.4	1.2	0.7
	Max		1.3	433.6	7.2	0.4	1.2	0.7
	Std Dev							
RESTROOM	WEST STALL (5)							
	Average	Net current source in ceiling	4.0	219.7	3.7	0.2	3.4	1.9
	Max		4.2	268.7	4.8	0.6	4.0	3.4
	Std Dev		0.2	34.3	0.7	0.2	0.5	0.9
	BACKGROUND (2)							
	Average		6.4	416.2	5.8	0.2	4.5	4.5
	Max		6.5	453.0	5.8	0.2	4.8	4.7
	Std Dev		0.2	52.0	0.1	0.0	0.5	0.2
QUALITY CONTROL	DESK 2 (5)							
	Average		1.2	391.0	11.9	0.2	0.9	0.8
	Max		1.3	460.1	13.3	0.2	1.1	0.9
	Std Dev		0.1	64.0	1.2	0.1	0.2	0.1
	TEST TABLE (5)							
	Average	Net current source in ceiling	5.1	434.0	4.7	0.1	5.0	1.0
	Max		5.4	739.6	5.3	0.2	5.3	2.0
	Std Dev		0.3	174.3	0.4	0.0	0.3	0.6
	BACKGROUND (2)							
	Average		1.6	469.3	7.6	0.2	1.0	1.2
	Max		2.1	491.8	10.7	0.2	1.3	1.6
	Std Dev		0.7	31.8	4.5	0.0	0.4	0.5

TABLE D
MAGNETIC-FIELD DATA BY SUBENVIRONMENT
Sheet 1 of 2

Sub-environment	Resultant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60Hz-%	60Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
MAIN OFFICE (17)						
Min	0.2	335.8	11.7	0.1	0.1	0.1
Average	0.6	470.4	41.7	0.3	0.5	0.3
Max	2.5	556.7	108.5	0.8	2.3	0.9
StdDev	0.5	72.4	20.9	0.2	0.5	0.2
NON-FERROUS (13)						
Min	0.2	234.4	11.6	0.1	0.2	0.1
Aveerage	7.5	456.6	44.4	0.3	6.6	3.1
Max	36.2	679.2	80.3	0.9	31.4	18.1
StdDev	10.9	110.4	19.4	0.3	9.5	5.4
MACHINE/SMALL PARTS SHOP (28)						
Min	0.1	146.4	17.6	0.1	0.1	0
Average	0.9	382.2	39	0.3	0.7	0.4
Max	4.6	726.4	148.7	0.8	4.2	2.2
StdDev	1	147	25.9	0.2	0.8	0.5
BREAK ROOM (5)						
Min	0.7	375.3	19.7	0.2	0.6	0.3
Average	2.3	404.2	21.1	0.4	2.1	0.8
Max	7.6	431	23.8	0.7	7.5	1.5
StdDev	3	23.7	1.6	0.2	3	0.6
WELDING (32)						
Min	0.3	288.1	8.9	0	0.2	0
Average	14.6	604.4	103.4	0.3	13.3	4.7
Max	175.7	4110.8	1126.1	1	163.8	63.6
StdDev	34.4	694	224.5	0.2	32.1	12.7
MFG & PREP (23)						
Min	0.1	128.5	4.5	0	0.1	0.1
Average	7.1	485.5	32.5	0.2	6.6	2.4
Max	76.7	1047.5	130.3	0.8	74.6	17.8
StdDev	18	217.2	35.8	0.2	17.1	5.5
YARD (5)						
Min	0.1	451.6	32.4	0.2	0.1	0
Average	0.3	476	113.6	0.4	0.3	0.1
Max	0.8	515.4	156	0.9	0.8	0.2
StdDev	0.3	28.3	49.3	0.3	0.3	0.1

TABLE D
MAGNETIC-FIELD DATA BY SUBENVIRONMENT
Sheet 2 of 2

Sub-environment	Result-ant AC MF - mG	Resultant DC MF - mG	Res Total Harmonic Distortion of 60Hz-%	60Hz Elliptical Polarization	AC Magnetic Field Normal to DC-mG	AC Magnetic Field Parallel to DC-mG
MFG & ASSEMBLY22)						
Min	0.1	177.3	19.1	0	0.1	0.1
Average	16.1	450.6	44.2	0.3	15.7	2.5
Max	125	642.5	81.1	0.9	122.4	25.3
StdDev	35.1	104.7	14.9	0.3	34.7	5.9
MAINENANCE (17)						
Min	0.2	269.3	6.5	0.1	0.2	0
Average	1.9	416.2	23.6	0.4	1.6	1
Max	11.8	725.6	37.1	0.8	11	5.5
StdDev	3.2	123.2	11	0.3	2.8	1.7
LAYOUT ROOM (11)						
Min	1.3	222.9	4.7	0.1	1.2	0.7
Average	2.6	447	6.6	0.3	2.2	1.2
Max	3.5	944.3	7.2	0.6	3	2
StdDev	0.6	184.2	0.8	0.2	0.5	0.5
RESTROOM (7)						
Min	3.6	191.2	3	0.1	2.5	1.2
Average	4.7	275.8	4.3	0.2	3.7	2.6
Max	6.5	453	5.8	0.6	4.8	4.7
StdDev	1.2	102.2	1.2	0.2	0.7	1.5
QUALITY CONTROL (12)						
Min	1.1	314	4.3	0	0.7	0.5
Average	2.9	422	8.2	0.1	2.6	1
Max	5.4	739.6	13.3	0.2	5.3	2
StdDev	2	116.4	3.8	0.1	2.1	0.4

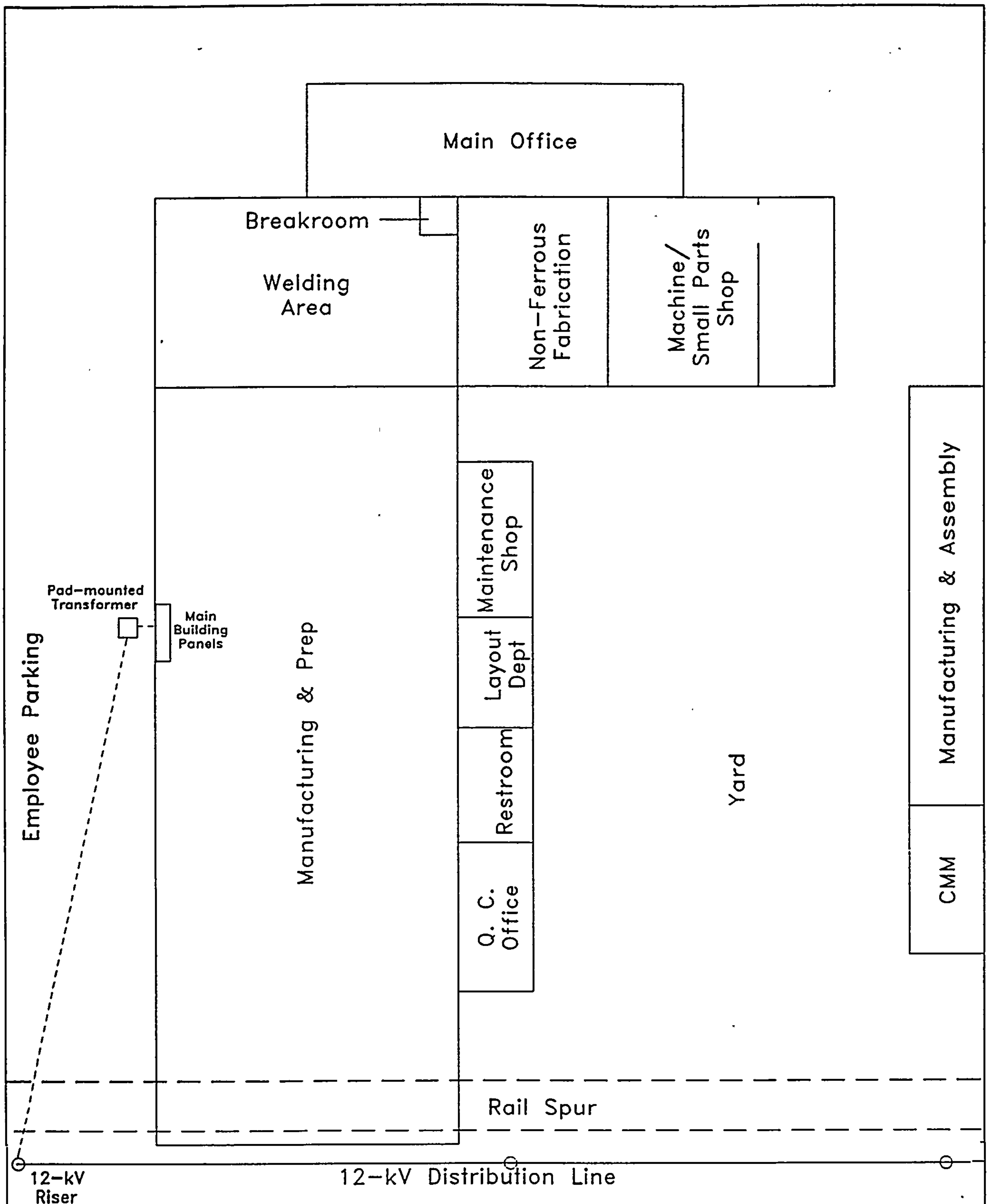


Figure 1: Facility Layout

Magnetic Measurements
San Francisco, CA

Magnetic Field Assessment
March Metalfab, Inc., Hayward, CA

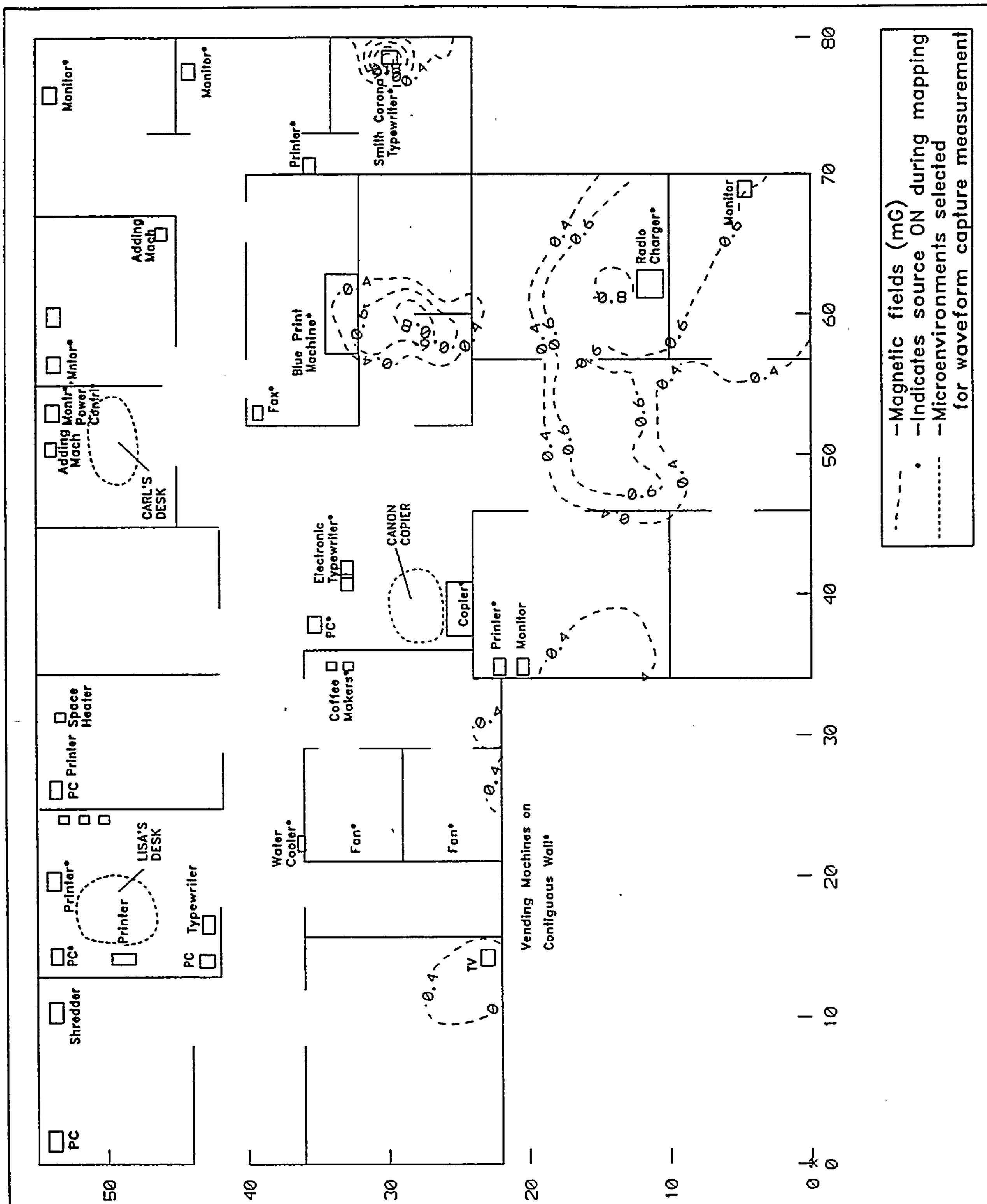


Figure 2A: Main Offices
Resultant Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc., Hayward, CA

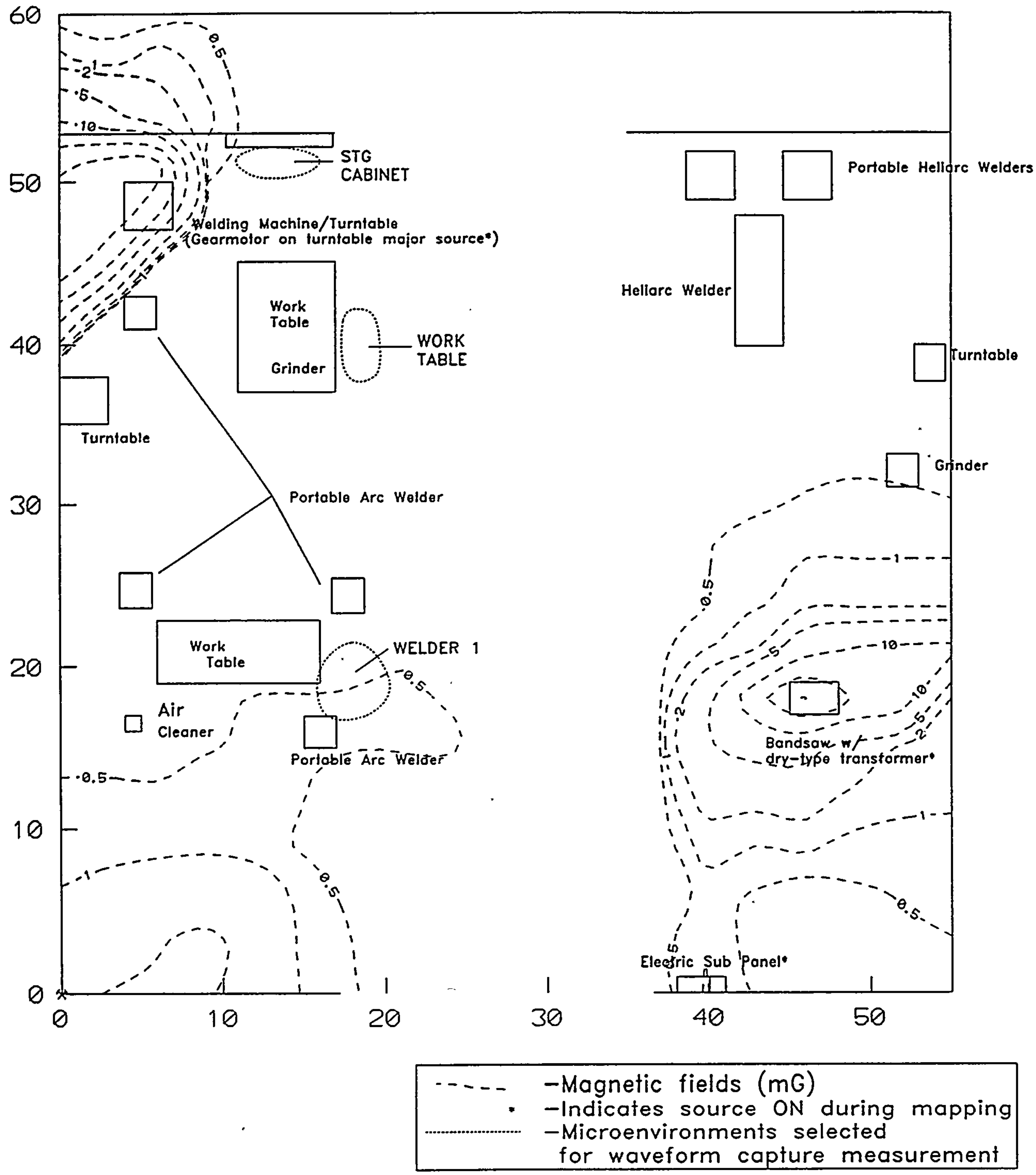


Figure 2B: Non-ferrous Fabrication
Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc. Hayward, CA

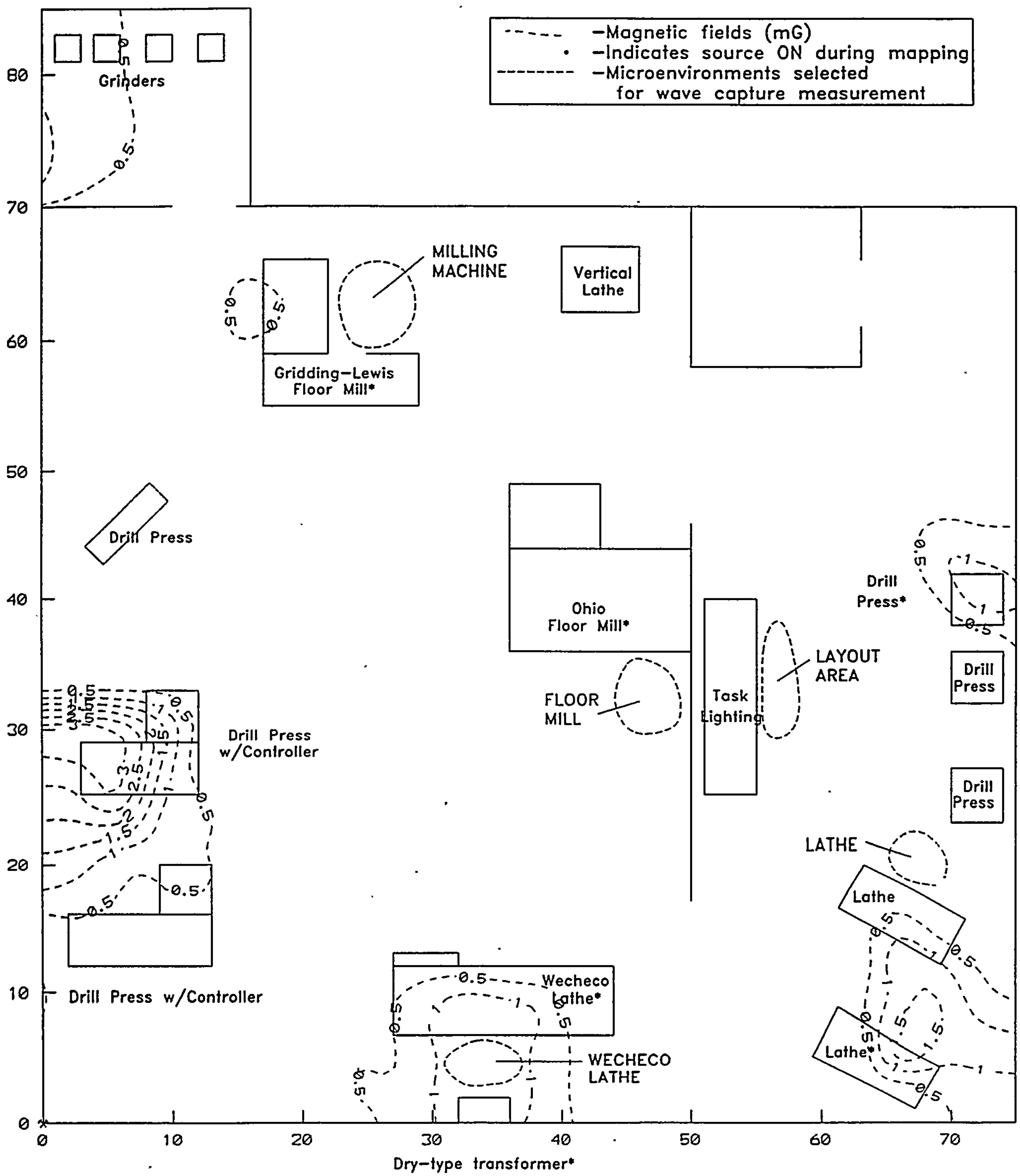


Figure 2C: Machine/Small Parts Shop
Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc. Hayward, CA

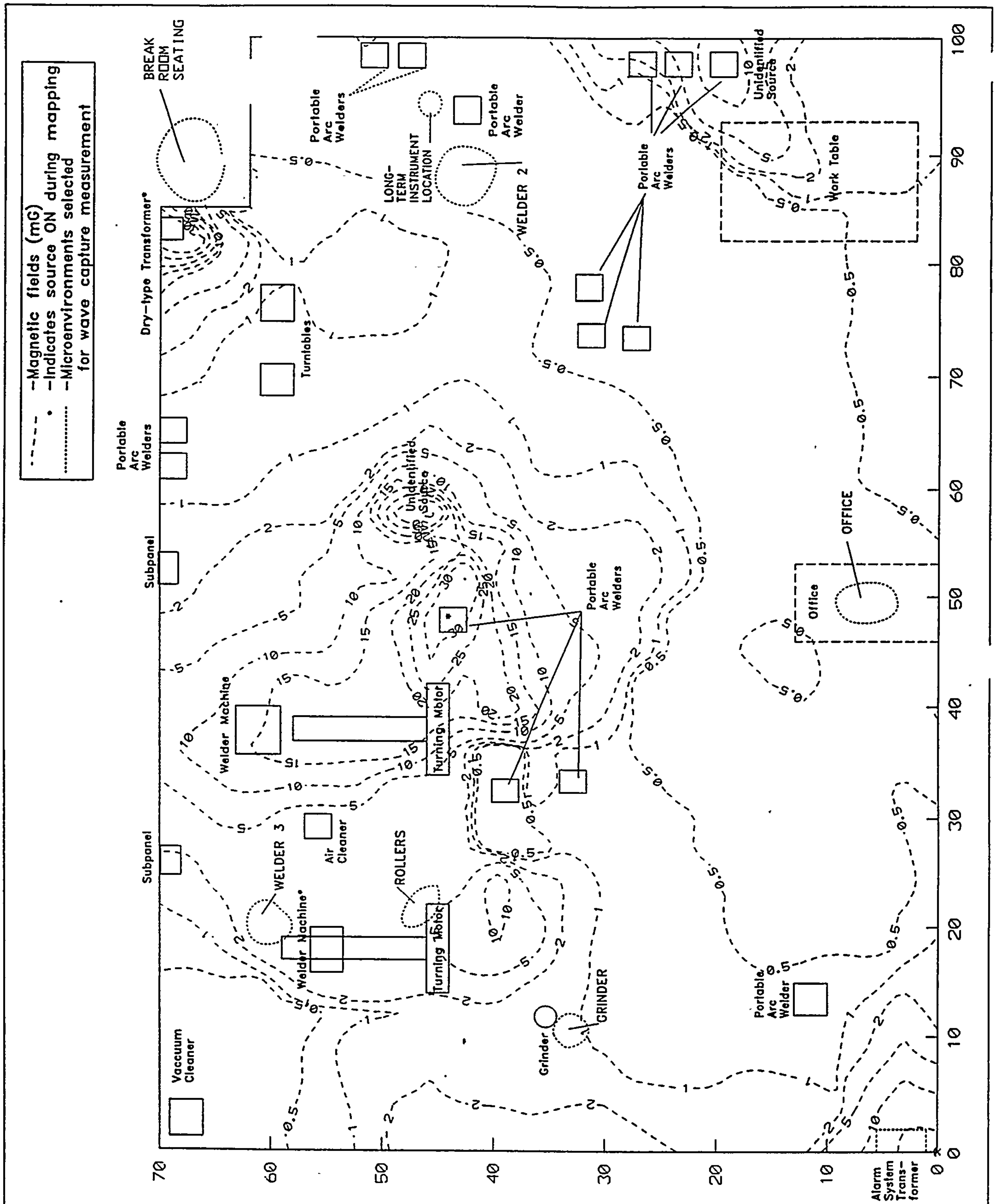


Figure 2D: Welding Area

Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc. Hayward, CA

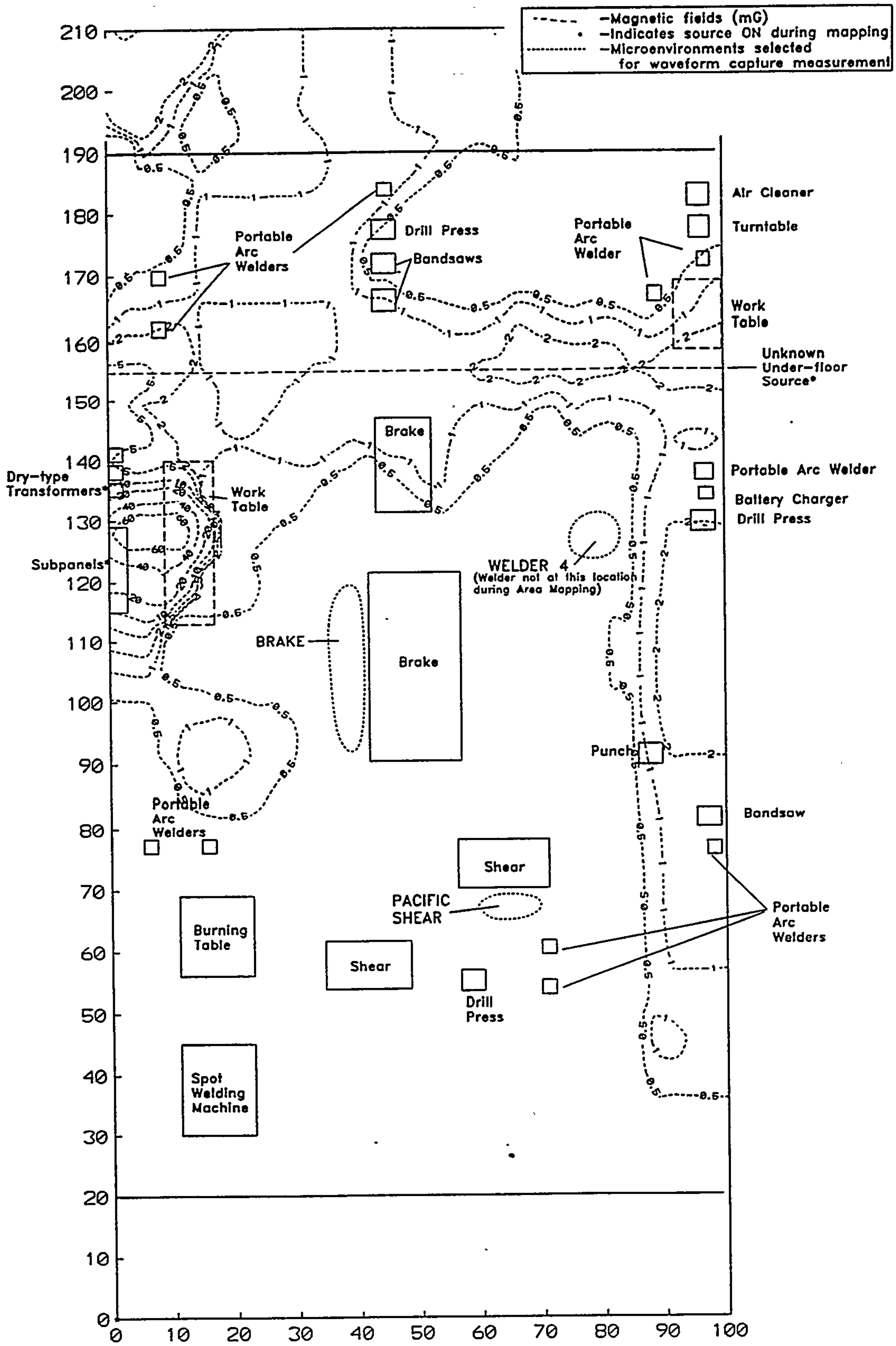


Figure 2E: Manufacturing, Parts Prep and Fabrication
Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc. Hayward, CA

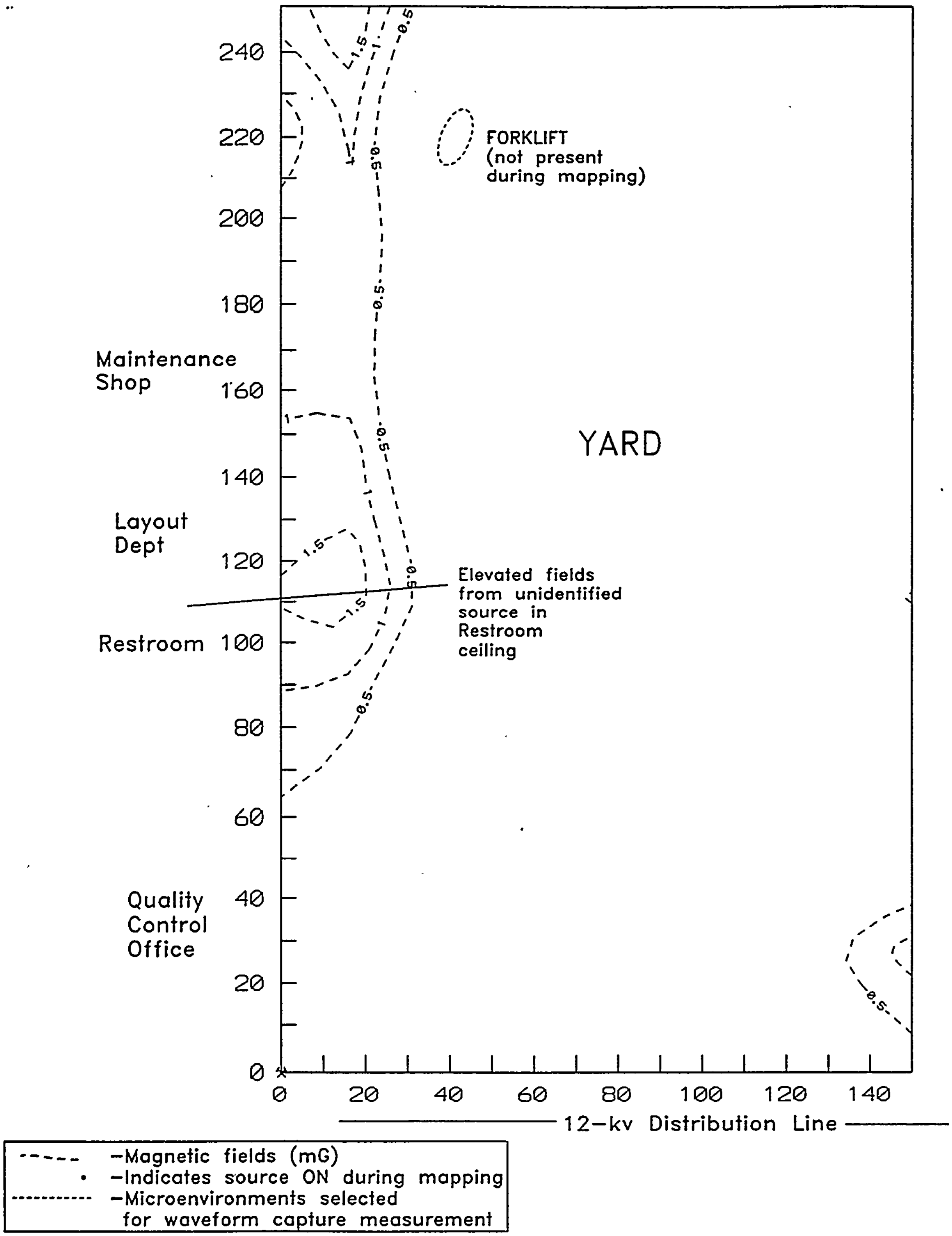


Figure 2F: Yard

Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc. Hayward, CA

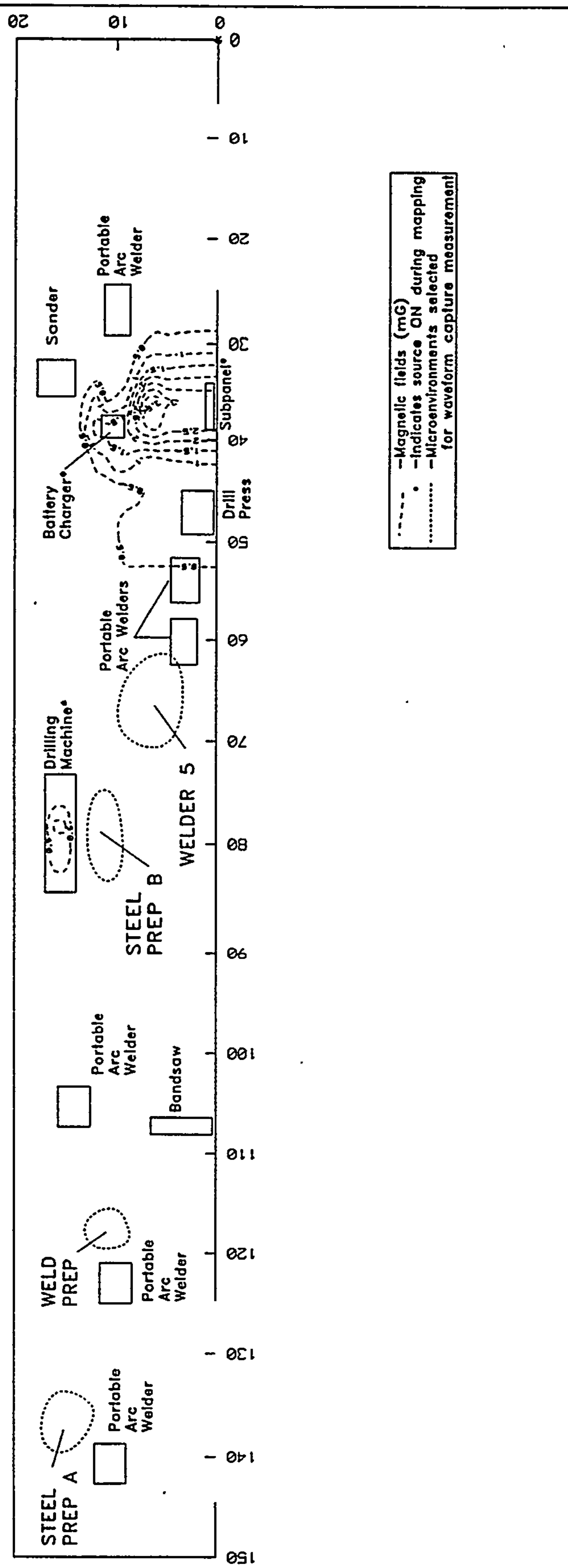


Figure 2G: Manufacturing & Assembly Area
Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements
San Francisco, CA

Magnetic Field Assessment
March Metal Fab, Inc. Hayward, CA

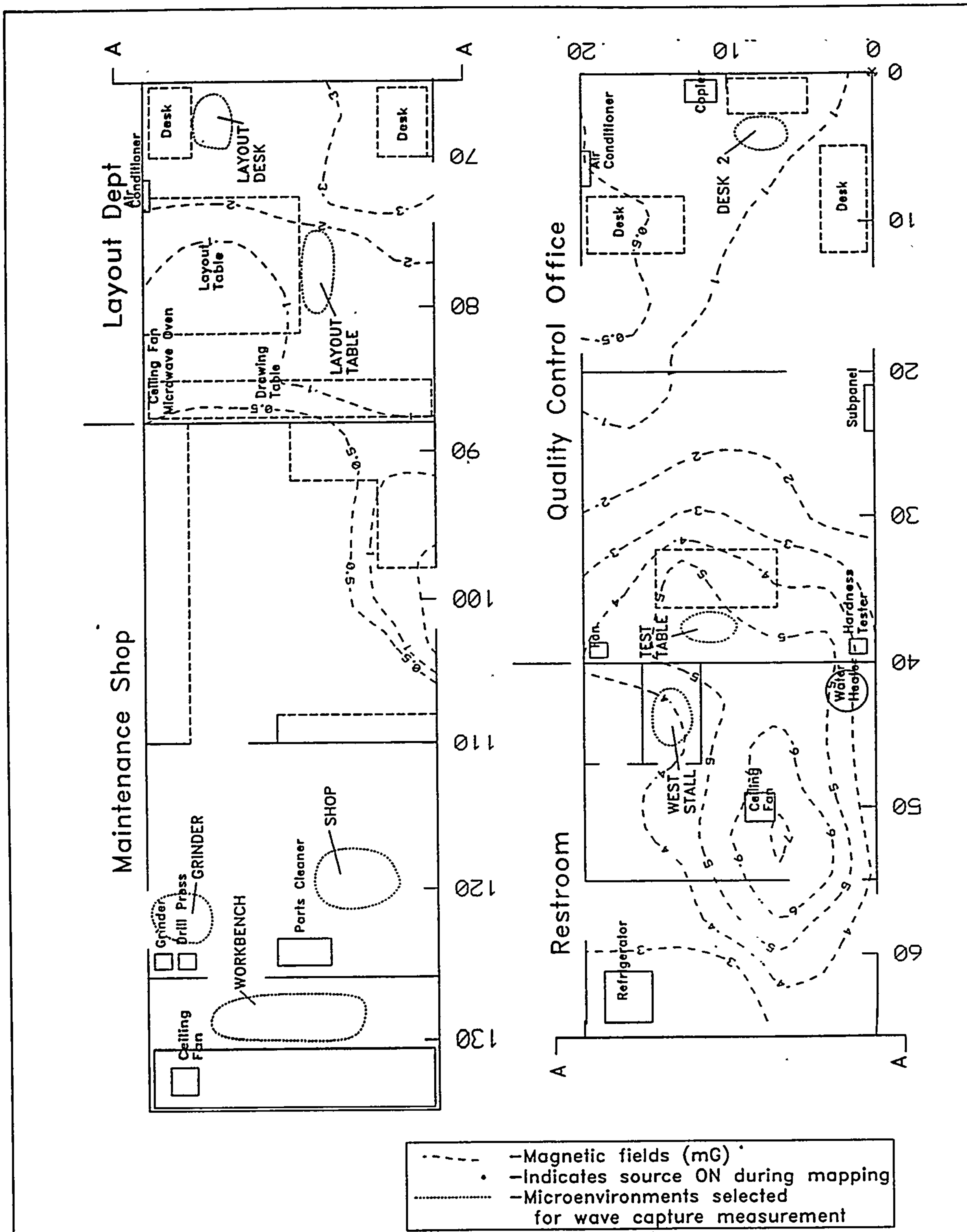
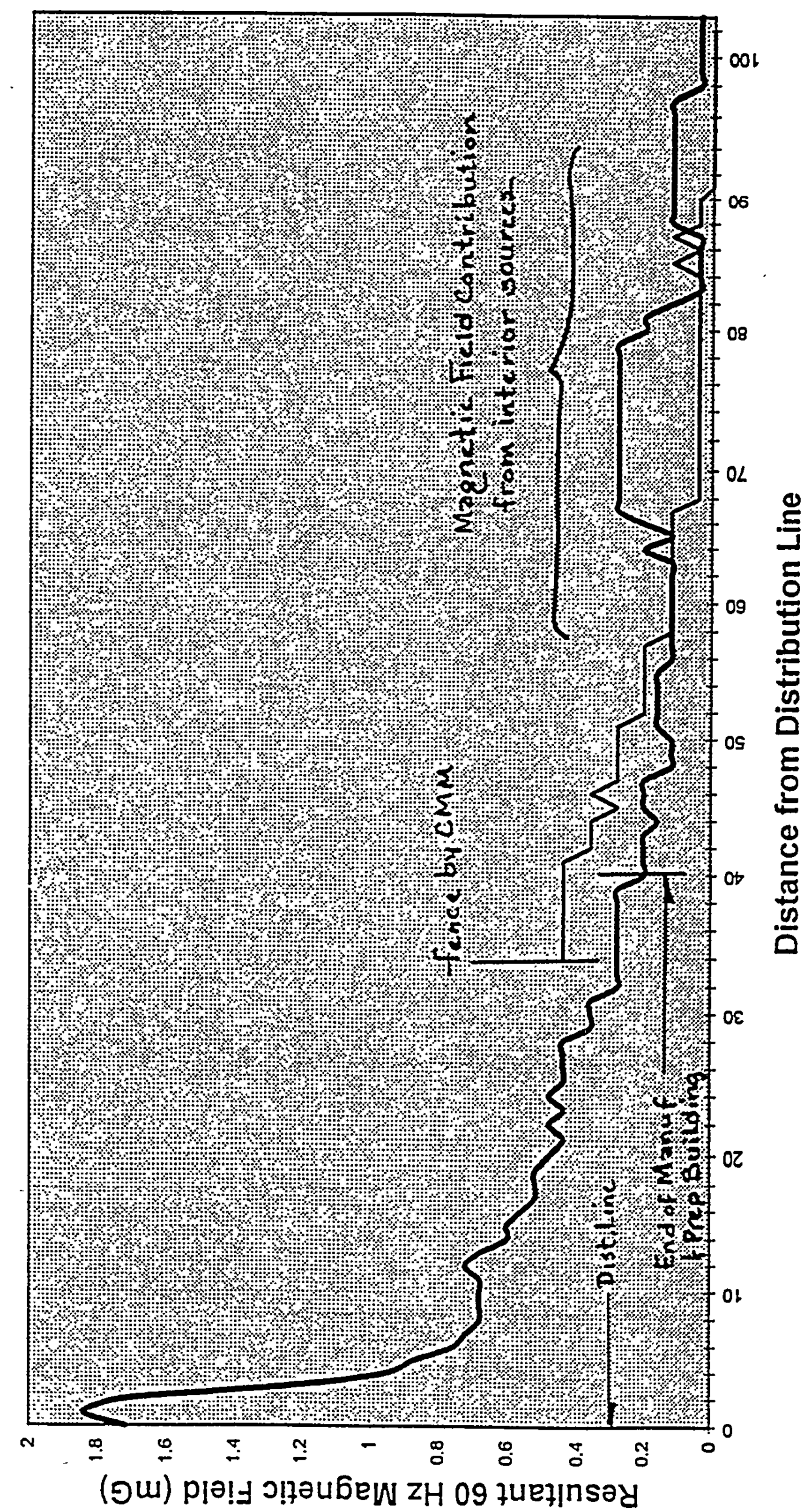


Figure 2H: Maintenance, Layout Dept, Restroom, and Q. C. Office Resultant AC Magnetic Fields and Locations of Sources

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment March Metal Fab, Inc. Hayward, CA

Figure 3
Magnetic Field Profile from
12-kv Distribution Line



APPENDIX B.3: GROCERY STORE PILOT STUDY REPORT

FELTON GROCERY OUTLET
MAGNETIC FIELD ASSESSMENT

Magnetic Measurements
San Francisco, CA 94914

Study Date: October 25, 1995

ABSTRACT

A magnetic field assessment was performed at the Felton Grocery Outlet, a grocery retail facility in Felton, California. The assessment was performed to determine typical sources and characteristics of magnetic-field exposure, and as a pilot study for developing recommendations for environment-specific magnetic field measurements. The facility is a typical food store, with the sales floor and checkout occupied by both employees and patrons, and storage and ancillary operations in the rear, occupied almost wholly by employees. Magnetic field sources include refrigeration equipment, the cash register systems, office equipment, and building electrical and mechanical equipment. A mapping of the magnetic flux density was performed throughout the facility to identify the sources, and waveform capture measurements were performed at a set of selection points. Temporal measurements were performed in two locations. The sources with the highest measured magnetic field magnitudes involved the subpanels, the freezer door heating element, and the operating microwave. However, areas near these sources are not occupied for substantial periods of time. The refrigeration, office equipment, and transformer provided the higher levels of time-weighted average exposure. The cash register systems were found to have very highly variable magnetic fields over time. The magnitudes of the ac fields, the dc fields, the harmonics, and the ac-dc orientation were all within those levels which might be expected in the course of a day by any individual.

INTRODUCTION AND PURPOSE

A magnetic field assessment was performed at the Felton Grocery Outlet in Felton, California. The purpose of the project was to determine sources and characteristics of magnetic-field exposure to the employees and patrons of the store. The project also pilot-tested the recommended guidelines for environment-specific field measurements in a retail setting. Measurements were performed on October 25, 1995.

DESCRIPTION OF THE SITE

The Felton Grocery Outlet is a typical grocery retail facility. The date of construction of the facility is unknown, but a renovation occurred in the early 1960's. The facility includes 13,300 square feet of floor space on one level. As with most food stores, the space is compromised substantially of the sales floor and checkout, with storage, receiving, and other ancillary operations to the rear of the store. A layout of the store is shown in Figure 1.

RAPID Environmental Classification: The Felton Grocery Outlet may be classified as:

Environmental Group:	*Trade and Services*
Environment:	*5400: Food Store*

The environment may be divided into the following classifications of subenvironments:

Subenvironment	Classification
Check-out / Lobby	b-cash register area
Sales Floor	a-merchandise area
Freezer Section/Deli Case	c-refrigerated area
Stock Area	d-stock room
Office	x-office
Loading Dock	i-shipping

INSTRUMENTATION

The instrumentation available for the subject study included one Field Star® 1000 magnetic flux density meter, one Multiwave System II® waveform capture system, and one EMDEX II® magnetic flux density meter.

Field Star® 1000: The Field Star® 1000 was used to perform the area mapping of ac magnetic fields during source identification. It was also used to perform a measurements over time in an area of elevated fields. The Field Star® 1000 is manufactured by Dexsil Corporation of Hamden, Connecticut. It has a range of 0.04 mG to 1000 mG, and is filtered to capture the 60-Hz component of the ac fields only. It contains three orthogonal magnetic-field sensor coils for measuring the x-, y-, and z- axis components of the magnetic fields. The resultant is calculated by computing the square root of the sum of the squares of the simultaneous measurements by the three orthogonal coils. The meter was calibrated within six months of the study, and was verified immediately after the study.

MULTIWAVE SYSTEM II®: The Multiwave System II® was used for the collecting magnetic-field waveform data at selected locations. The Multiwave System II® is manufactured by Electric Research and Management, Inc. of State College, PA. The instrument digitizes and stores analog waveforms from a triaxial Faraday induction coil ac-magnetic-field sensor and a triaxial fluxgate magnetometer dc-magnetic-field sensor. The Multiwave System II® was operated with a base frequency of 15-Hz at a rate of 7680 samples/second per active channel. This resulted in 512 digitized samples for each 16.67 ms period of the 60-Hz based frequency.

EMDEX II: A hand-held EMDEX II® was used as a scoping tool in the source identification. It was also used to perform measurements over time in an area of suspected highly varying fields. The EMDEX II® magnetic flux density meter is manufactured by Enertech Consultants, Inc. of Campbell, CA. It has a range of 0.1 to 3000 mG, a frequency bandwidth of 40 Hz to 800 Hz, and filters for a harmonic component bandwidth of 100 Hz to 800 Hz. Like the Field Star® 1000, it contains three orthogonal magnetic-field sensor coils for measuring the x-, y-, and z- axis components of the magnetic-field magnitude. The resultant is calculated by computing the square root of the sum of the squares of the simultaneous measurements by the three orthogonal coils. The meter calibration was verified within thirty days of the study, and the operation of the three sensor coils was verified immediately prior to the study.

ASSESSMENT METHODS

The magnetic-field assessment was planned and performed using the following study schedule: source identification and activity-pattern data collection were performed on the morning of the visit; temporal measurements were initiated, and the project team met to define the site's microenvironments and plan the focussed measurements. Finally, the waveform capture measurements were performed and the temporal measurements were concluded.

Source Identification: The technicians used four sources of information to locate and identify the magnetic-field sources within the facility:

1) Upon arrival at the site, the informant (the General Manager) provided a quick tour of the store.

2) A visual inspection was performed of the site. Visible possible sources were identified and documented on site sketches.

3) Area mapping was performed as follows: The Field Star® 1000 was attached to a recording wheel at a height of one meter above the floor. The wheel was "driven" by a technician in a pattern through each subenvironment, with particular attention to those areas where employees and/or patrons would spend time. At 1-foot increments, the meter was triggered to record a magnetic flux density measurement and the relative location of that measurement. This data was interpolated into a three-dimensional plot, providing an overall picture of the magnetic flux density at the facility. The results of the area mapping task were reviewed to identify areas of elevated ac fields.

4) If any area of elevated field identified in the mapping task did not correspond with a visually identified source, the technicians returned to the site and located the source using an EMDEX II® hand-held magnetic flux density meter.

Activity-pattern Data Collection: Data on the locations of the employees and patrons was collected to determine where and near what sources they spent their time, so that the magnetic-field measurement plan could be formulated relevant to the occupants' exposure.

1) The site informant completed a general written questionnaire about the site and its occupants.

2) During the tour of the site, the informant explained the uses of each subenvironment within the site.

3) Simultaneously with the source investigation, the technicians performed a visual inspection to select primary areas of activity as they related to sources.

4) The site informant took part in a 30-minute interview, wherein he was questioned about the occupants and activities in each subenvironment.

5) Photographs were taken of the employees and patrons in the process of working and shopping.

Identification of Microenvironments and Selection of Microenvironments for Waveform Capture Measurement: A microenvironment may be described as an area characterized by the homogeneity of activity patterns and the homogeneity of field variability. The source data and activity pattern information were analyzed collectively to determine the exposure-relevant areas of the site, and thus to define microenvironment boundaries. Because the project purpose was to identify and characterize sources of exposure, many of the microenvironments defined to be of interest were source-based (such as "compactor", or "cash register #4"). The number of points selected for measurement in each microenvironment depended on the expected variability of the field within the microenvironment and the physical size of the microenvironment.

Waveform Capture Measurements: Waveform capture measurements were performed in the afternoon of October 25, 1995 while the store was in operation. For each microenvironment, a series of measurement points were selected to best include and characterize the range of exposure for the worker. It is acknowledged that the series of measurements may not have captured the peak location of exposure in each microenvironment. At all selected locations, spot measurements were made with the instrument's sensor staff oriented vertically and in line with the facility grid, with the sensors at a height of 1 m (3.3 feet) above the floor.

Temporal Data Collection: From the preliminary information gathered during the initial site tour and area-mapping task, the checkout area was identified as an area of high occupancy and elevated magnetic fields. Substantial temporal variability was also suspected. Therefore, the EMDEX II® meter was positioned under a checkout counter (within one foot of an employee) to determine the temporal characteristics of magnetic field from the cash register system. The location of the instrument is shown in Figure 1. Every 1.5 seconds for a period of 237 minutes, the instrument recorded the broadband ac magnetic flux density. Events involving area sources or activities were not documented.

The temporal variability of the magnetic fields from the box compactor was also of interest. The Field Star® 1000 was stationed near the traffic area and near the compactor in the stock area. The location of the instrument is shown in Figure 1. The instrumentation was programmed to record the magnetic flux density every minute for a period of 228 minutes.

RESULTS

Sources of Magnetic Fields

External Utilities: The external utilities are shown on Figure 1. Utility service is provided via an underground cable leading from a utility primary splice box at the corner of the property to the three-phase transformer located outside the Break Room. A secondary trench leads from the transformer to the building's main switch. The transformer and main switch were found to significantly contribute to the magnetic fields within the Break Room.

Internal Sources: Sources of magnetic fields internal to the site included lighting, building mechanical equipment, refrigeration equipment, and appliances. These sources are considered "point" sources and the magnetic fields fall off rapidly with distance. They included the following:

SOURCE TYPE	TYPICAL OPERATION
Automatic Doors	Power always on, intermittent use
Cash Registers System	Power usually on, intermittent use
Fluorescent Lighting	Always on
Frozen Foods Cases	Power always on, recurring cycle
Deli/Dairy Case, including fans and anti-sweat heater	Power always on, recurring cycle?
Fans	Always on?
Box Compactor	On only with use
Electrical Subpanels	Always on, current varies with power usage
Walk-In Coolers	Power always on, recurring cycle
Walk-In Freezer	Power always on, recurring cycle
Microwave	On only with use
Refrigerator	Power always on, recurring cycle
Time Clock	Power always on, infrequent use
Monitors	Power always on
Printer	Power always on, infrequent use
Adding Machines	Power always on, infrequent use
Forklift	On only with use

The sources in each subenvironment are shown in Table 1.

Activity Patterns

Occupants: Felton Grocery Outlet operates between 8 am and 8 pm Monday through Saturday, and between 10 am and 5 pm on Sunday. Some stocking activities take place while the store is closed. Felton Grocery Outlet employs 8 part-time and 3 salaried employees. The store handles 12,000 customers per month, for an average period of 20 minutes per customer. Because the "casual" users —the customers—make up a substantial portion of the building occupancy, their activities were considered in this study together with the employees.

The number of occupants and their activities in each subenvironment are described in Table 1.

Waveform Capture Measurement Results

Twenty-three (23) microenvironments were selected for waveform capture measurement. Magnetic-field waveform data were recorded at 76 locations in the facility, by microenvironment. The locations of those microenvironments and the ac magnetic flux density recorded during each measurement are shown in Figures 2A and 2B. In addition, a series of spot measurements were performed near the external utilities to confirm any contributions to magnetic-field exposure.

A summary of the magnetic-field characteristics found in each microenvironment is listed in Table 2, including a summary for the site. Note that the sample points were not distributed linearly over the area, nor were they distributed linearly based on the time of occupant exposure. The "mean" and "maximum" measurements have been reported only to provide a relative indication of the field parameters, and not to represent time-weighted-average, spatial average, or true peak.

The summary of magnetic field characteristics for each sample point and the raw waveform data are available from Magnetic Measurements if further analysis or review of other field parameters is desired.

Temporal Measurement Results Meters were stationed in the compactor area and cash register area to capture information regarding the temporal variability of the magnetic fields from each of these sources. The results of these studies are shown graphically in Figure 3A and Figure 3B, respectively. The box compactor was operated at 12:41, indicating that the first of the four peaks in magnetic field apparent in Figure 3A was related to that operation. Most likely, all four peaks of 2.2 to 2.5 mG occurring during the temporal measurement may be attributed to compactor use.

Figure 3B confirms substantial variability in the magnetic field exposure at the cash register. (It may be assumed that the exposure from all four cash registers is similar.) Although the background magnetic fields with the cash register system on were 0.8 mG, numerous spikes occurred with magnitudes as high as 8.8 mG The graph shows a cessation in these spikes from 2:30 p.m. to 3:05 p.m. This perhaps was due to the clerk taking a break.

Data Results Summary

Resultant AC Magnetic Fields The highest levels of magnetic field magnitude were found in the following microenvironments:

Microenvironment	Peak Measurement	Source
Freezer	30.9 mG	Heater element for freezer door
Stock Area	30.9 mG	Subpanel
Kitchen	25.4 mG	Microwave oven while operating

These may be considered the peak levels which an employee may experience during the course of a day. However, the freezer and area in immediate vicinity of the subpanels are not areas of consistent use, and the microwave oven only operates occasionally, so they would not contribute substantially to the employees' time-weight-average exposure. Only a few customers would occasionally be exposed in these areas.

Those microenvironments which are frequently occupied, and in which the magnetic field magnitudes are elevated include the following:

Microenvironment	Average Measure	Peak Measure	Regular Occupants	Continuous or RecurringSources
Frozen Foods #1	1.2 mG	1.7 mG	Employees/ Customers	Refrigeration
Frozen Foods #2	1.1 mG	2.0 mG	Employees/ Customers	Refrigeration
Deli/Dairy Case	1.1 mG	1.5 mG	Employees/ Customers	Refrigeration, Fans, Defrosters
Break Area	3.0 mG	3.0 mG	Employees	Exterior Transformer
Stock Common Area	1.4 mG (not incl subpanel)	30.9 mG (subpanel)	Employees	Compactor, mechanical and electrical systems
Office Desk #1	1.1 mG	2.4 mG	Employees	Monitor, CPU, Printer
Cash Register (assume all similar)	0.8 mG	8.8 mG	Employees	Cash Register System
Check Out	0.9	see Note 1	Customers	Cash Register System

Note 1: The waveform capture spot measurements did not capture substantially elevated magnetic field measurements in the Cash Register #4 or Check Out #4 microenvironments. However, it was learned from the temporal measurements at Cash Register #1 that frequent magnetic field spikes occur in this vicinity, as shown in Figure 3B. It may be assumed that these spikes affect all cash register and check out microenvironments to some extent.

DC Magnetic Fields: The earth's dc-magnetic field approximates 500 mG in this region. The resultant static fields measured within the facility ranged from 273 mG to 636 mG. The highest variation from the earth's dc-magnetic field was found near the freezer cases. Still, this general range of static field would be expected in an environment containing ferromagnetic materials.

Total Harmonic Distortion of AC Fields (THD): The THD is the root-mean-square of the individual harmonic field intensities, divided by the intensity of the fundamental 60-Hz field component. It indicates the relative amount of harmonics in a field waveform without regard to frequency. In addition to the THD reported, the magnitude of the third harmonic, 180-Hz, was been reported.

The THD measured at the selected sample points ranged from 4% to 80.8%. Except in the Deli/Dairy Case Area (max of 80.8%) and at Desk #1 (max of 76.7%), the measured THD was below 36%, indicating only minor contributions of harmonics. Further investigation is required to identify the magnetic field sources contributing these higher levels of harmonics at the Deli/Dairy Case and Desk #1. The highest level of third harmonics was found at the microwave oven in operation in the kitchen area, although the overall THD at this location was 25.7%.

AC-DC Relative Orientation (AC perpendicular to DC): The three-dimensional dc and ac magnetic flux density measurements were analyzed to compute the relative orientation of the maximum axis of the 60-Hz field vector with the dc field vector. These have been presented as the angle between the two vectors in degrees. The angle ranged from 29° to 90° with an average of 50°.

DISCUSSION

This magnetic field assessment indicates that the exposures in this retail facility were mostly influenced by its internal sources and the building transformer. Both customers and employees were exposed to some areas of increased magnetic field exposure. The customers were exposed to fields from refrigeration units (freezer cases, deli/dairy case) and to magnetic fields from the cash register system. In addition to these sources, employees were exposed to magnetic fields from office equipment, refrigeration units for storage, the compactor, and the buildings mechanical and electrical systems. The magnitude of the ac fields, the dc fields, the harmonics, and the ac-dc orientation were all within those levels which might be expected in the course of a day by any individual. The temporal variation in exposure due to the magnetic fields from the cash register systems, and the time-weighted-average exposures of given individuals were not studied sufficiently to reach a comparison with typical exposure, and might warrant further investigation.

TABLE 1
OCCUPANTS, ACTIVITIES, AND SOURCES BY SUBENVIRONMENT

SUB-ENVIRONMENT	Customer Use	Employee use	Description of use	General Sources
Check Out and Lobby	400 cust 5 min ea	2-4 clerks 7 hrs/day 1-2 baggers 2 hrs/day	Clerks and baggers utilize area for checkout. Customers consistently travel though area.	Automatic doors, Cash register system
Sales Floor	400 cust 10 min ea	2 empl 5 hrs/day	Employees stocking, cleaning, assisting. Customers shopping.	Soffit lighting, overhead lighting
Freezer Area/Deli Case	400 cust 5 min ea	2 empl 6 hrs/day	Employees stocking, cleaning, assisting, leaning into cases. Customers shopping, leaning into cases.	Freezers, deli case fluorescent lighting, deli case anti-sweat heaters, defrosting heaters, fan.
Stock Area General	6 cust/day 5 min	3 empl 2-4 hrs/day	Employees use area for stocking, storing, compacting boxes, etc. Travel through regularly to use restroom, break room, loading dock, etc. Occasional customer will use restroom.	Walk-in freezer, walk-in cooler, lighting, restroom fans and lighting, box compactor, electrical subpanels.
Stock Area-Freezer	None	1 empl 2 hrs/day	Employees use for stocking, storing,	Walk-in freezer.
Stock Area - Break Room	None	12 empl 15-45 min/day	Employee breaks. Time clock used by 10 employees, microwave used sporadically.	Microwave, time clock, refrigerator, lighting, exterior transformer.
Office	None	1-2 empl 8 hrs/day	Use for admin duties. Computer used consistently. Printer used 3 hrs/day, adding machine used 1 hr/day.	Monitor, CPU, printer, adding machines, lighting
Loading Dock	None	2 empl 2.5 hrs/wk	Unloading stock using forklift upon arrival by suppliers.	Forklift

TABLE 2
SUMMARY OF MEASUREMENTS OF MAGNETIC-FIELD CHARACTERISTICS BY MICROENVIRONMENT

MICRO-ENVIRONMENT	# OF DATA PTS	MEAN (MAXIMUM) MEASUREMENT				
		AC FIELDS RMS (mG)	DC FIELDS (mG)	AC FIELDS 180-Hz (mG)	THD AC Field (percent)	AC-DC Angle 60 Hz (degrees)
Automatic Door	2	1.1 (1.2)	392.2 (395.6)	0.1 (0.1)	11.3% (11.4)%	41.1 (56.9)
Cash Register #4	5	0.8 (0.8)	425.5 (444.1)	0.1 (0.2)	11.4% (23.6)%	43.0 (69.0)
Check Out #4	5	0.9 (1.3)	461.0 (480.5)	0.1 (0.2)	12.3% (24.0)%	29.8 (59.5)
Aisle #1	3	0.8 (0.9)	518.4 (636.3)	0.1 (0.1)	9.3% (11.2)%	54.7 (66.4)
Aisle #2	1	0.7	489.1	0.0	6.7%	36.2
Aisle #3	1	0.7	453.0	0.0	7.6%	42.4
Aisle #4	1	0.7	456.1	0.0	6.9%	44.1
Aisle #5	1	0.7	428.6	0.0	7.4%	38.3
Frozen Foods #1	7	1.2 (1.7)	540.0 (863.2)	0.1 (0.1)	7.4% (17.9)%	45.1 (88.6)
Frozen Foods #2	7	1.1 (2.0)	545.9 (752.4)	0.1 (0.1)	7.4% (12.7)%	45.8 (90.0)
Deli/Dairy Case	4	1.1 (1.5)	446.6 (489.2)	0.3 (0.5)	44.8% (80.8)%	57.8 (67.2)
Freezer	4	13.8 (30.9)	273.8 (337.1)	0.1 (0.2)	4.0% (10.7)%	77.0 (82.2)
Break Area	3	3.0 (3.0)	444.6 (467.4)	0.9 (0.9)	35.2% (35.8)%	64.6 (85.4)
Kitchen Area	2	2.0* (25.4)	386.0 (391.9)	0.4* (6.2)	26.0% (26.3)%	63.7 (76.9)
Compactor	2	2.3 (3.2)	388.1 (400.0)	0.5 (0.7)	23.6% (24.1)%	78.7 (84.2)
Men's Room	1	0.9	419.6	0.2	22.6%	30.7
Ladies' Room	1	1.1	416.1	0.2	20.9%	28.7
Deli Cooler	1	1.1	315.8	0.2	17.2%	34.7
Stock: Common	8	1.4 (3.5)	430.2 (484.1)	0.2 (0.5)	14.7% (33.2)%	49.2 (83.8)
Subpanels in Stock	2	20.4 (30.9)	373.0 (507.3)	1.0 (1.5)	6.1% (6.5)%	44.6 (46.0)
Desk #1	5	1.1 (2.4)	317.2 (377.0)	0.2 (0.6)	32.3% (76.7)%	50.3 (63.6)
Desk #2	5	0.9 (1.0)	384.2 (426.4)	0.1 (0.1)	9.6% (15.9)%	36.9 (45.1)
Fork Lift	6	1.1 (1.3)	436.7 (633.4)	0.2 (0.3)	25.2% (32.9)%	68.4 (89.4)
ALL MEASUREMENTS	76	2.7 (30.9)	434.2 (863.2)	0.3 (6.2)	16.3% 80.8%	50.0 (90.0)

* Peak kitchen measurement performed with microwave oven in operation. Mean RMS and 180-Hz ac fields listed do not include this measurement

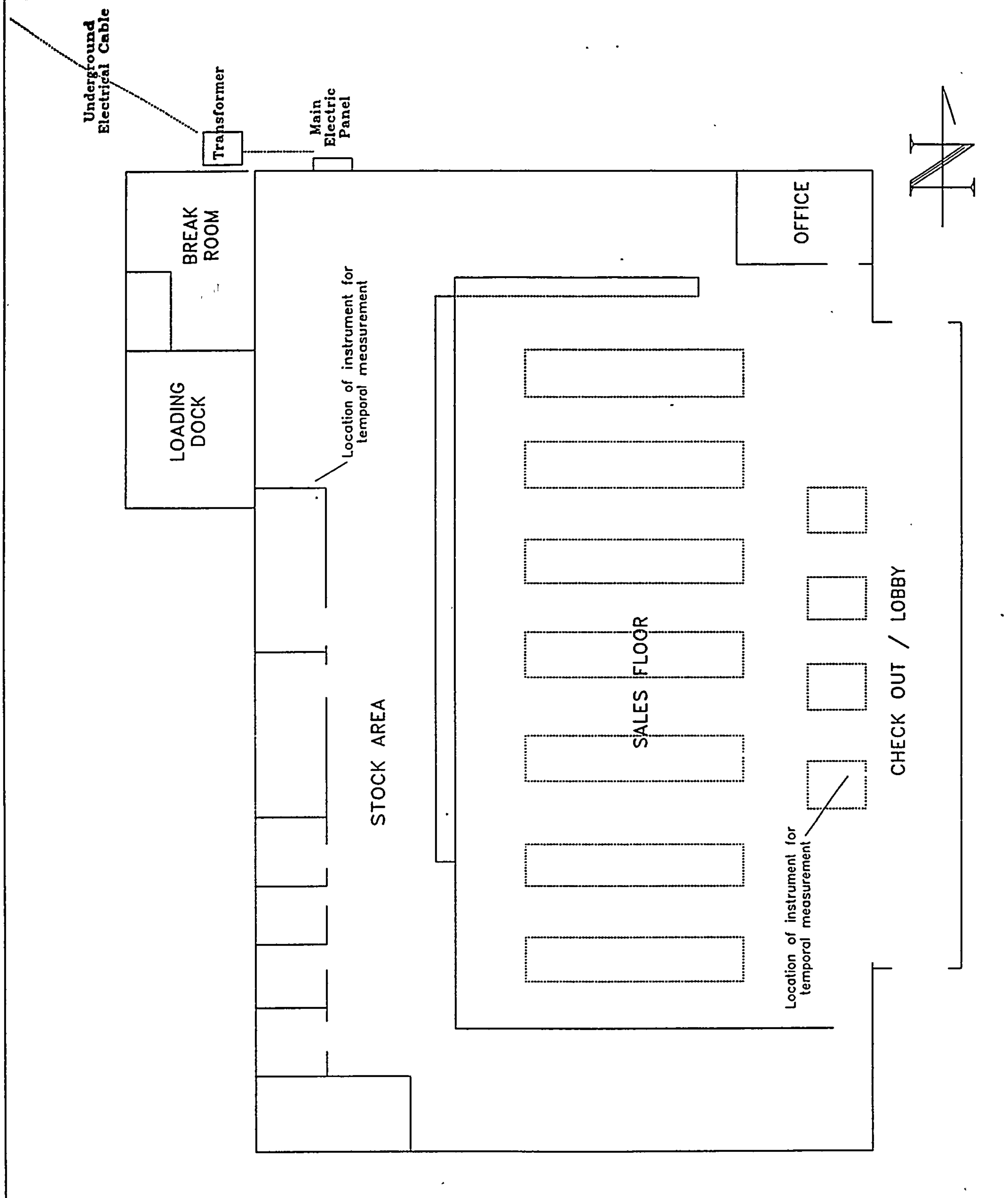


Figure 1: Site Map

Magnetic Measurements, Kentfield, CA	Magnetic Field Assessment, Felton Grocery Outlet

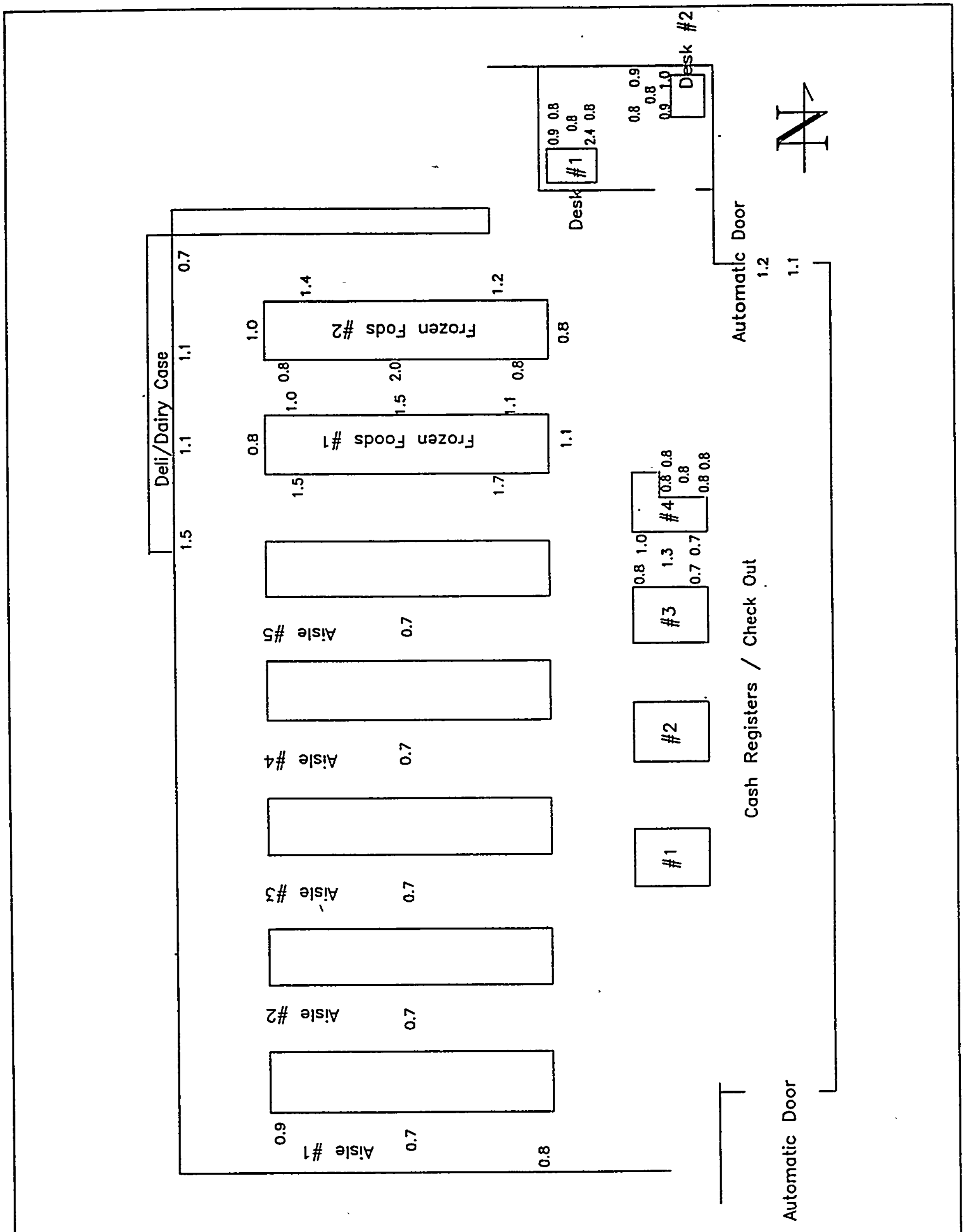


Figure 2A: Resultant AC Magnetic Fields in Check Out/ Lobby, Sales Floor, Freezer Section/Deli Case, & Office

Magnetic Field Assessment Felton Grocery Outlet	Magnetic Measurements Kentfield, CA

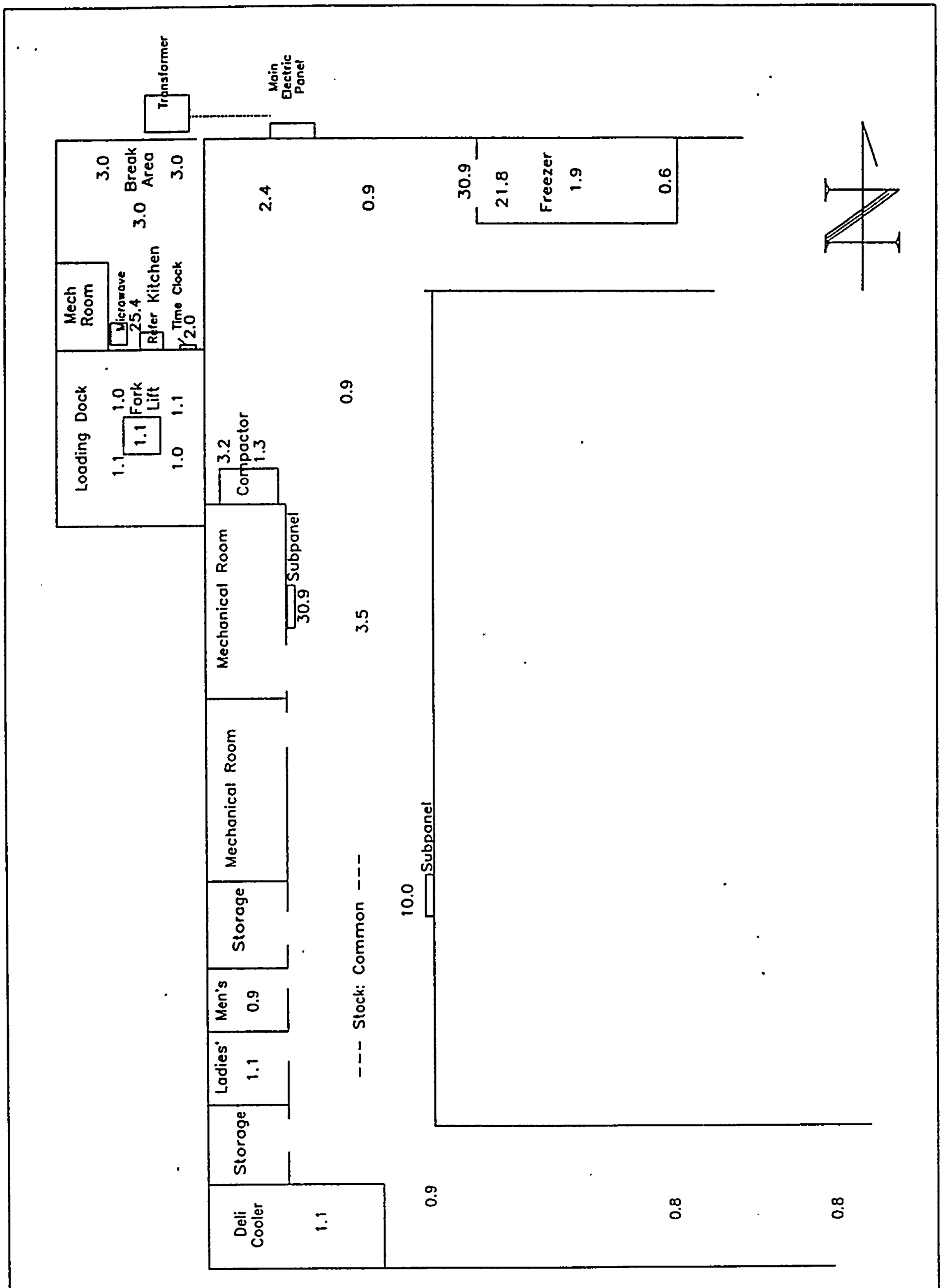


Figure 2B:Resultant AC Magnetic Fields in Stock Area

Magnetic Measurements San Francisco, CA	Magnetic Field Assessment Felton Grocery Outlet

Figure 3A: Temporal Measurement at Compactor

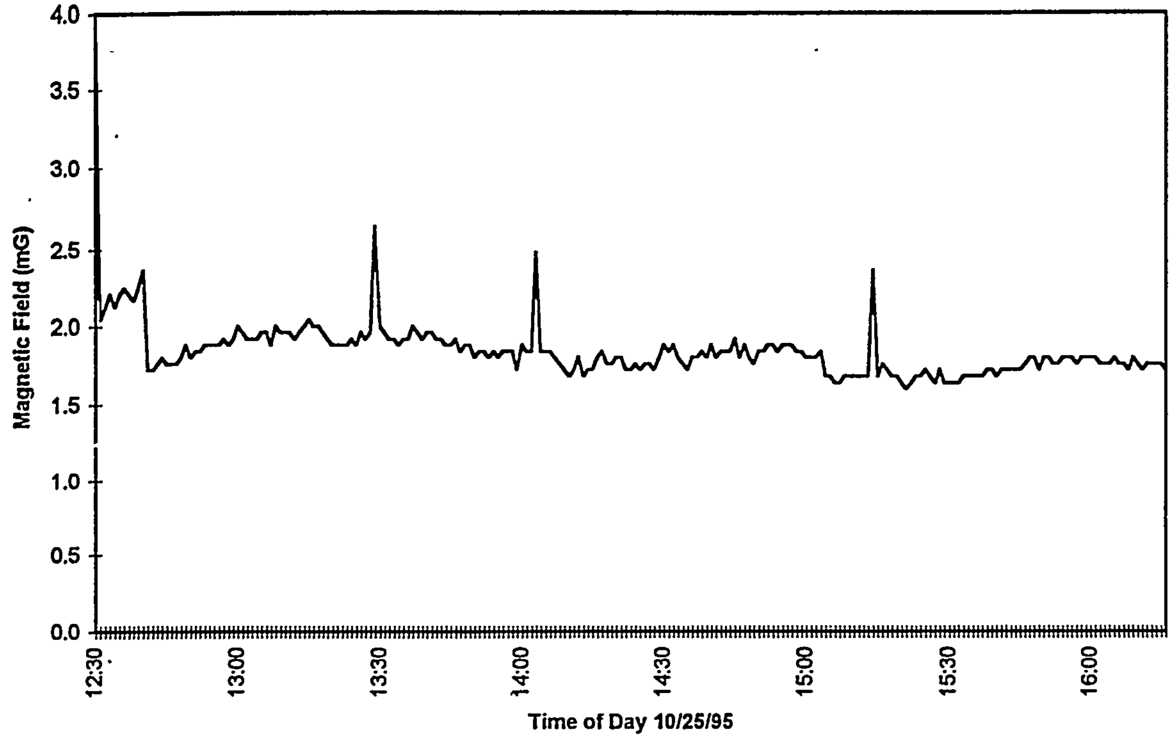
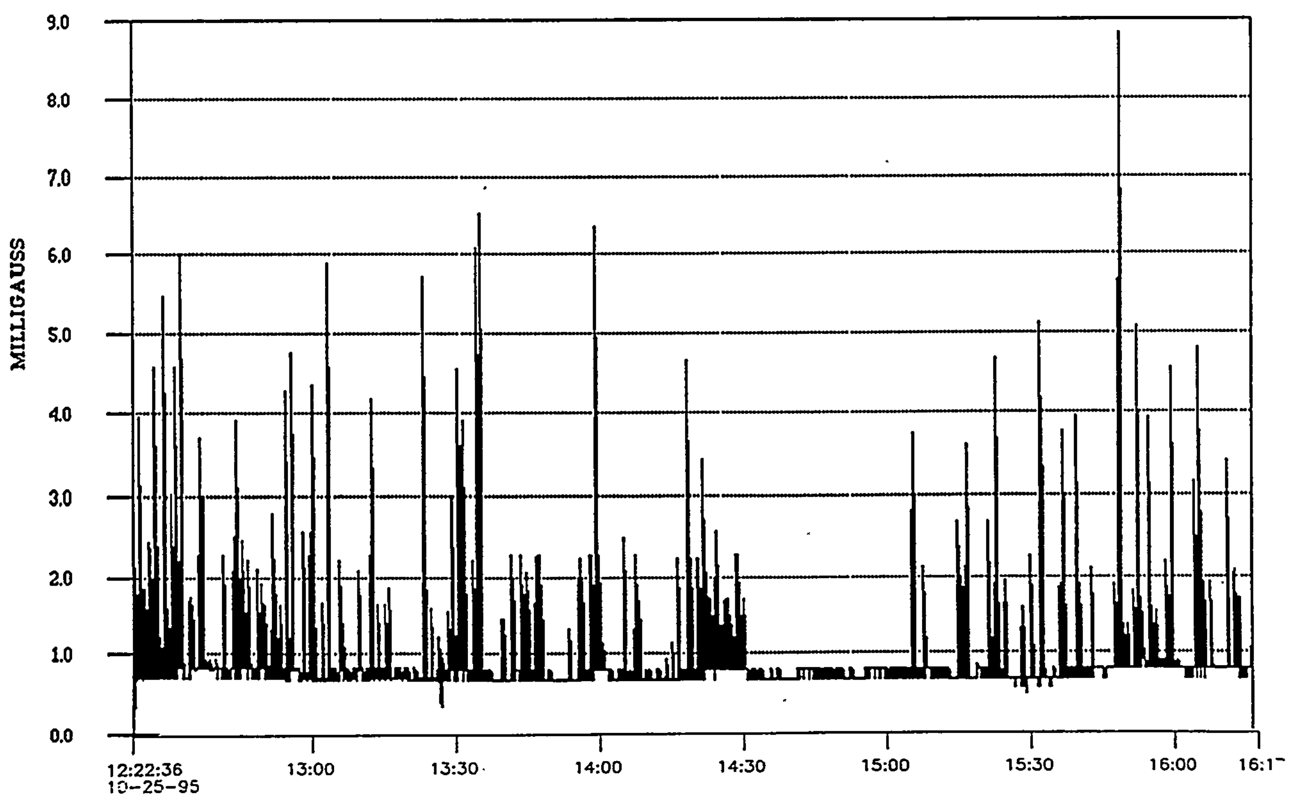


Figure 3B: Temporal Measurement at Cash Register/Check Out



APPENDIX C.1: SAMPLE DATA-COLLECTION PROTOCOL CHECKLIST

PRIOR TO MEETING:

______1. Make informational phone call.

______2. Send information letter.

______3. Confirm date and time of meeting. Identify site contact for measurement period. Estimate expected quality of information and their time availability for activity-pattern data collection.

______4. Obtain maps of the site

______5. Send *Facility Questionnaire.*
Provide list of sources typical to environment group.
Form: ***Example of Source List***
Request that sources be identified on the site map.

______6. Document site information.

______ Document purpose of study.

______ Determine use of environment and environment code.
(This step will determine whether the activity-pattern info is necessary for only full-time occupants or guests as well.)

______7. Prepare for measurements.

- ______ Verify equipment calibration and functionality.
- ______ Recharge equipment/change batteries.
- ______ Synchronize time of any equipment, computers, and watches.
- ______ Refill form notebooks and field kits.
- ______ Configure instrumentation.
- ______ Produce area sketches.
Form: Subenvironment Data Sheet

DAY ONE:

______8. Meet with contact person:
introductions and appreciation
review day's schedule
review any questions from site
retrieve questionnaire
safety and security
proprietary issues: photographs, responses to employee questions.

______9. Take quick tour of the facility for orientation.

- ______ Document areas on copy of sketch submitted earlier.
- ______ Find out # of people in each area.
- ______ Begin documentation of site information on ***Initial Walk-through: Project Data Sheet.***

______10. Sketch site, including exterior sources, building's electrical facilities, location of long-term recorders.
Form: ***Site sketch***

______11. Draw/confirm/complete sketches of each area on ***Initial Walk-through: Subenvironment Data Sheet.***

______12. Plan field mapping route.
Divide the environment into groups of subenvironments that will be mapped. Name the subenvironments.
Design the route assuming grid pattern in each area, including the edges, in an effort to capture the sources.

______13. Perform mapping of subenvironments.

- ______ Pilot mapping wheel along desired route.
- ______ Document the route on the site sketch.
- ______ Note the visible sources on the ***Subenvironment*** sketch.
- ______ Note locations of people through visual determination.

______14. Perform mapping of periphery and lateral profiles.

- ______ Pilot mapping wheel along desired route.
- ______ Document the route on the site sketch.
- ______ Note the visible sources on the ***Site*** sketch.

______15. Identify magnetic-field sources.

______ Download the mapping information for subenvironments, and periphery so that possible sources can be graphically located.

______ Compare the map information with the sketch of visually identified sources.

______ Return to unidentified sources (i.e., they showed on map, but not in visual sketch) to "sniff" them out.

______ Document the operations of each source O/I/R/X.

______ Document each source on the ***Subenvironment Data Sheet***, with identifying information, and indication of field levels.

______16. Determine rough definitions of microenvironments with "bubbles," based on sources and on activity patterns obvious from walk-through (how do we document this?).

______17. Meet with site contact person to perform activity-pattern survey : ***Form : Activity-Pattern Questionnaire***
1. identify persons and/or groups
2. determine total time per person or group in environment
3. identify use of each location
4. Collect source operation information (O/I/R/X).

______ 18. Determine appropriate locations for long-term recording meters, based on the day's data. Set up meters for data collection.

______19 Debrief with site contact person. Explain plans for next day.

NIGHT ONE:

______20. Determine locations for waveform measurements EXPOSURE RELEVANCE!

______ Determine the sample of subenvironments that will be characterized, if time doesn't allow sampling in all.

______ Determine approximate number of measurements in each subenvironment .

______ Identify microenvironments by overlaying the magnetic-field findings with activity-pattern areas.

______ Select number of measurements in each microenvironment.

Form: ***Spot Measurement Location Decision Matrix*** (one page for each subenvironment)

______ Select locations of measurements in each microenvironment.

______21. Determine any special measurements required (transients, short temporal, operating on/off, etc.).

______22. Download all data and perform data management (file-naming, backup etc.).

______23. Prepare forms and instrumentation for following day.

DAY TWO:

______24. Document site information on data collection forms.

______25. Take Multiwave measurements at the selected locations.
Form: ***Spot Measurement Data Collection***

______ 26. Take any special measurements (transients, short temporal, operating on/off, etc.).

______27. Take appropriate photographs of environment.

______28. Collect long-term recorders.

______29. Debrief with site contact person. Explain how results will be distributed.

LATER:

______30 Download data and perform data management using file naming conventions.

______31. Compile report.

______32. Thank you letter.

APPENDIX C.2: PRE-SITE-VISIT QUESTIONNAIRE

MAGNETIC-FIELD SURVEY
FACILITY QUESTIONNAIRE

Name of Facility: ____________________ DATE: ____________________

Who will be our contact during the measurement period? (Name): ____________________

CONSTRUCTION

What was the year of the original construction? ____________________

Have there been any major additions since the original construction? ____________________

If yes, What areas? ____________ Dates of additions ____________________

What is the approximate size of the facility? ________________s.f.

What is the approximate size of the entire site? ____________ s.f.

EMPLOYEES

What are the typical operating hours of the company? ____________________

How many employees work full shifts at the site? ____________________

First shift: ______ Second Shift: ________ Third Shift ___________

How many employees are at the facility for less than full shifts (i.e., field technicians who spend a few hours per day at the facility)

First shift: ______ Second Shift: ________ Third Shift ___________

If the employees are grouped such that their job descriptions and their locations within the facility are similar, please list those groups (i.e., clerical, welders, fabricators, etc.) and the number in each group.

____________________ ____________________ ____________________

____________________ ____________________ ____________________

____________________ ____________________ ____________________

Does the facility involve any retail trade or services for which many outside persons would regularly visit the facility? ______ If yes, please describe ____________________

SAFETY

Are there any work safety issues or rules that we should be aware of prior to visiting the site? (i.e., hardhat requirements) ____________________

APPENDIX C.3: SAMPLE COMMON SOURCE LIST (FOR USE BY INFORMANT)

Commercial Office Sources

BUILDING EQUIPMENT
Area lighting ______
Circuit panel ______
Electric door locks ______
Elevator ______
Interior wiring ______
Transformer ______

OFFICE EQUIPMENT
Blueprint machine ______
Coffee maker ______
Computer monitor ______
Computer ______
Copy machine ______
Dictaphone ______
Electric pencil sharpener ______
Electric clock ______
Electric typewriter ______
Electric stapler ______
Electric fan ______
Fax machine ______
Hot plate ______
Message recorder ______
Micro-fische viewer ______
Microwave ______
Network server ______
Optical scanner ______
Paper shredder ______
Phone switch ______
Plotter ______
Printer ______
Radio ______
Refrigerator ______
Slide projector ______
Space heater ______
Task lighting ______
Television ______
Typewriter ______
VCR ______
Water cooler ______

APPENDIX C.4: SOURCE IDENTIFICATION SKETCH AND DATA SHEET

PROJECT: ____________________ SUBENVIRONMENT: ____________________

DATE: ____________________ TIME: from __________ to __________

X,Y,Z Area Base Location in Relation to Project X,Y,Z Base ____________________

Note: show north arrow, the x,y,z base point, and the x and y directional arrows on this sketch

	TIME	SOURCE CODE	DESCRIPTION	OPER O/I/R/X	MF @ ____	MF @ ____
_1						
_2						
_3						
_4						
_5						
_6						
_7						
_8						
_9						
0						

APPENDIX C.5: ACTIVITY-PATTERN INTERVIEW PROTOCOL

Magnetic Field Assessment
Activity Pattern Measurement Interview

LOCATION: ______________________ LOCATION CODE: __________

SITE SPACE CODE: ______________ NUMBER OF FIELDS: __________

MAGNETIC FIELD IDENTIFICATION: ______________

INTERVIEWER ID: ____________ DATE: ________, ________, 19 ____
Month Day Year

START TIME: ___ ___ : ___ ___ AM
PM

RESPONDENT FIRST NAME: ______________

I am interested in asking you some questions about the activities of people, including you, in the space(s) within this room. I want to understand who works in this room, near certain machines and sources of magnetic fields. In trying to answer these questions keep in mind that often this type of information can vary. What we are looking for is your best estimate about the people and activities that occur in an average day. *(IF RESPONDENT IS CONCERNED ABOUT ACCURACY REASSURE HIM/HER THAT WE WILL ACCEPT THE INFORMATION THEY CAN GIVE UNLESS THERE IS ANOTHER PERSON WHO WOULD BE A BETTER SOURCE INFORMATION ABOUT THE FLOW OF EMPLOYEES AND THEIR ACTIVITIES IN THIS SPECIFIC SPACE.)*

First I would like you to look at this map of the space we are talking about. Notice where the (NAME MACHINES, EQUIPMENT, ETC. LISTED ON MAP) are on the map. *(POINT OUT DOORS, WINDOWS OR LOCATION OF OTHER IDENTIFIERS THAT WOULD HELP ORIENT THE RESPONDENT.)*

1. A. Do you understand the space we want to talk about when you look at this map?

Yes...............*(SKIP TO Q2)*.................1

No..2

B. Let's look at this together. Where is the confusion? *RECORD VERBATIM.*

ONCE R UNDERSTANDS THE SPACE PROCEED.

2. We'd like you to think about all of the people who work in this space or come into it during an average day, week or month.

   A. How many people are occupants of the space, that is they have a desk or work area within this space and spend several hours a day, or more there?

   ____

   B. Now think of the people who aren't occupants but come into this space and use it on a regular or daily basis. (1 hour or more per day on average.) How many people are there like that?

   ____

   C. Our third category of users is casual users. These would be people who come in and use this space regularly but not daily, perhaps they use it once or twice a week or every two weeks for a day or two, something like that. How many people are there like that?

   ____

   D. Last of all, let's think of occasional users, people who come in infrequently, but may stay for several hours when they are here. How many people are there like that?

   ____

Sheet 3 of 7

COMPLETE THE CHART BELOW FOR EACH USER IN GROUP 2A.

3. Next I'd like further information about the occupants of this space, that is, those people who have a work space here.

A. Give me the first name of each occupant. (FOR EACH, ASK B - G.)

B. What is (NAME)'s approximate age. Would you say under 18, between 18 and 30, 31 - 40, 41 - 60, or over 60 years? (Your best guess will be fine.)

C. _IF UNSURE, ASK_: Is (NAME) male or female?

D. What is (NAME)'s primary occupation, that is what are his/her main tasks or duties?

E. In an average day, how many minutes or hours does (NAME) spend in this space? *(IF EQUIPMENT IN SPACE, ASK F)*

F. _IF EQUIPMENT, ASK_: Does (NAME) operate (EQUIPMENT) in this space?

G. _IF YES, ASK_: About how many minutes or hours in an average day does he/she operate (EQUIPMENT)? *(IF MORE THAN 1 PIECE OF EQUIPMENT, REPEAT F AND G FOR OCCUPANT ON A NEW LINE.)*

A. FIRST NAME	B. AGE					C. SEX		D. OCCUPATION	E. TIME SPENT	--------IF EQUIPMENT------		
										F. OPERATE		G. HOW LONG
	<18	18-30	31-40	41-60	60+	M	F			Yes	No	
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS

COMPLETE THE CHART BELOW FOR EACH USER IN GROUP 2B.

4. Now think about people who aren't occupants but use this space on a regular or daily basis. *(1 HOUR OR MORE DAILY.)*

   A. Give me the first name of each regular user of this space. (FOR EACH, ASK B - G.)

   B. What is (NAME)'s approximate age. Would you say under 18, between 18 and 30, 31 - 40, 41 - 60, or over 60 years? (Your best guess will be fine.)

   C. *IF UNSURE, ASK*: Is (NAME) male or female?

   D. What is (NAME)'s primary occupation, that is what are his/her main tasks or duties?

   E. In an average day, how many minutes or hours does (NAME) spend in this space? *(IF EQUIPMENT IN SPACE, ASK F.)*

   F. Does (NAME) operate (EQUIPMENT) in this space?

   G. *IF YES, ASK*: About how many minutes or hours in an average day does he/she operate (EQUIPMENT)? *(IF MORE THAN 1 PIECE OF EQUIPMENT, REPEAT F AND G FOR OCCUPANT ON A NEW LINE.)*

A. FIRST NAME	B. AGE					C. SEX		D. OCCUPATION	E. TIME SPENT	--------IF EQUIPMENT------ F. OPERATE		G. HOW LONG
	<18	18-30	31-40	41-60	60+	M	F			Yes	No	
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS
	1	2	3	4	5	1	2		____ 1=MIN 2=HRS	1	2	____ 1=MIN 2=HRS

Sheet 5 of 7

COMPLETE THE CHART BELOW FOR EACH USER IN GROUP 2C.

5. Now think of the casual users. These would be people who come in and use this space regularly but not daily, perhaps once or twice a week, or every two weeks for a day or two.

   A. Give me the first name of each casual user. *(FOR EACH, ASK B - G.)*

   B. What is (NAME)'s approximate age. Would you say under 18, between 18 and 30, 31 - 40, 41 - 60, or over 60 years? (Your best guess will be fine.)

   C. *IF UNSURE, ASK*: Is (NAME) male or female?

   D. What is (NAME)'s primary occupation, that is what are his/her main tasks or duties?

   E. In an average day, how many minutes or hours does (NAME) spend in this space? *(IF EQUIPMENT IN SPACE, ASK F.)*

   F. Does (NAME) operate (EQUIPMENT) when he/she is in this space?

   G. When (NAME) is here, about how many minutes or hours in an average day does he/she operate (EQUIPMENT)? *(IF MORE THAN 1 PIECE OF EQUIPMENT, REPEAT F AND G FOR OCCUPANT ON A NEW LINE.)*

A. FIRST NAME	B. AGE					C. SEX		D. OCCUPATION	E. TIME SPENT	--------IF EQUIPMENT------		
										F. OPERATE		G. HOW LONG
	<18	18-30	31-40	41-60	60+	M	F			Yes	No	
	1	2	3	4	5	1	2		___ 1=MIN 2=HRS	1	2	___ 1=MIN 2=HRS
	1	2	3	4	5	1	2		___ 1=MIN 2=HRS	1	2	___ 1=MIN 2=HRS
	1	2	3	4	5	1	2		___ 1=MIN 2=HRS	1	2	___ 1=MIN 2=HRS
	1	2	3	4	5	1	2		___ 1=MIN 2=HRS	1	2	___ 1=MIN 2=HRS
	1	2	3	4	5	1	2		___ 1=MIN 2=HRS	1	2	___ 1=MIN 2=HRS
	1	2	3	4	5	1	2		___ 1=MIN 2=HRS	1	2	___ 1=MIN 2=HRS

Sheet 6 of 7

IF EQUIPMENT IN THE SPACE, ASK 6.

6. A. Last of all think about those occasional or infrequent users. When they use this space do any of them operate equipment while they are here?

Yes.................................... 1

No............... *(SKIP TO Q7)*................. 2

B. What equipment do they operate? *(LIST EACH AND ASK C - E.)*

C. How many of these occasional or infrequent users use (EQUIPMENT)?

D. On the average, about how often in a week or year do they use (EQUIPMENT)?

E. When they use it, about how many minutes or hours do they use it?

B. EQUIPMENT?	C. NUMBER OF OCCASIONAL USERS?	D. HOW OFTEN?	E. How long?
________	____	____ times per 1 = week 2 = month 3 = year	____ ____ 1 = minute 2 = hours
________	____	____ times per 1 = week 2 = month 3 = year	____ ____ 1 = minute 2 = hours
________	____	____ times per 1 = week 2 = month 3 = year	____ ____ 1 = minute 2 = hours
________	____	____ times per 1 = week 2 = month 3 = year	____ ____ 1 = minute 2 = hours
________	____	____ times per 1 = week 2 = month 3 = year	____ ____ 1 = minute 2 = hours
________	____	____ times per 1 = week 2 = month 3 = year	____ ____ 1 = minute 2 = hours

Sheet 7 of 7

7. A. Last of all, are there any other users of this space or the equipment in this space that we haven't talked about?

Yes...1

No............. *(SKIP TO CLOSE)* 2

B. Please explain how they use this space? *(RECORD VERBATIM.)*

CONSIDER THIS RESPONSE -- IF THE USERS CAN BE CATEGORIZED INTO ONE OF THE FOUR USER TYPES GO BACK TO THE APPROPRIATE CHART AND LIST, ASKING ALL APPROPRIATE QUESTIONS.

CLOSE

This is all of the information I need about the use of this space. Thanks for your help

IF ANOTHER MICROENVIRONMENT, COMPLETE AN INTERVIEW ABOUT IT.

APPENDIX C.6: LOCALIZED ACTIVITY-PATTERN SHORT-INTERVIEW PROTOCOL

INTERVIEWER ID: ____________ DATE: ________, ________, 19 ____
Month Day Year

LOCATION: ______________________________

SUBENVIRONMENT: ______________________________

SUBENVIRONMENT CODE: ____________/MICROENVIRONMENT CODE: __________

START TIME: ___ ___ : ___ ___ AM
PM

RESPONDENT FIRST NAME: ________________

I am interested in asking you some questions about the activities of people in this location. I want to understand who works in this location, near certain machines and sources of magnetic fields. In trying to answer these questions, keep in mind that what we are looking for is your best estimate about people and activities in this location in an average day.

First I would like you to look at this map of the space we are talking about. Notice where the (NAME MACHINES, EQUIPMENT, ETC. LISTED ON MAP) are on the map. (POINT OUT DOORS, WINDOWS, OR LOCATION OF OTHER IDENTIFIERS THAT WOULD HELP TO ORIENT THE RESPONDENT.)

1. A. Do you understand the space we want to talk about when you look at this map?

Yes ....(SKIP TO Q2) 1

No 2

B. Let's look at this together. Where is the confusion? RECORD VERBATIM (ONCE R UNDERSTANDS THE SPACE PROCEED.)

2. We'd like you to think about this space and the people who work in this space or come into it during an average workday.

A. On an average workday, about how many minutes or hours is this space occupied by at least one person?

__________ 1=min
2=hrs

B. When it's occupied, how many people usually work in or occupy this space at the same time?

____

IF EQUIPMENT SOURCES NOTED ON MICROENVIRONMENT MAP, ASK FOR EACH:

C. When the space is occupied, about how many minutes or hours in an average day is the (EQUIPMENT) being operated (OR: in operation, turned on)?

Equipment:____________________________ ________ 1=min
2=hrs

Equipment:____________________________ ________ 1=min
2=hrs

Equipment:____________________________ ________ 1=min
2=hrs

Equipment:____________________________ ________ 1=min
2=hrs

APPENDIX C.7: NON-MAGNETIC-FIELD DATA SHEET

PROJECT: ____________________ DATE: ____________________

Environment Classification # _ _ _ _ Description____________________

Age of Environment ____________ Approx Size of Environment ____________

Description of Typical Occupants ____________________

Description of Uses ____________________

Time Factors Affecting Loads or Use ____________________

Contact Person ____________________Field Technician(s)____________________

Instrumentation ____________________ Calibration Check Dates

Weather ____________________

Information about external utilities____________________

____

Magnitude of Supply Voltage ____________________

Peak Power ____________________

Current Levels ____________________

Work Safety Issues____________________

____

APPENDIX C.8: PHOTOGRAPH LOG

Sketch the locations and directions of the photographs taken.

Note: show north arrow, the x,y,z base point, and the x and y directional arrows on this sketch

Number	Time	Description
______	____	____________________
______	____	____________________
______	____	____________________
______	____	____________________
______	____	____________________
______	____	____________________
______	____	____________________
______	____	____________________
______	____	____________________

APPENDIX C.9: SPOT-MEASUREMENT LOCATION DECISION MATRIX

Page No. _____

MAGNETIC-FIELD SURVEY
SPOT-MEASUREMENT LOCATION
DECISION MATRIX

PROJECT ____________ SUBENVIRONMENT ____________ DATE ____________

Microenvironment		Source number(s) from Initial Walkthru Data Sheet	Time Spent in Microenvironment (Note name of Persons and/or Groups)					Total person-hours spent in micro - environ ment	% of total person hours at site	Size of Micro-environ ment (S/M/L)	Variabilit y of MF magnitu de (L/M/H)	Focus (S/N/W)	No. of Samples
#	Description												
			Estimate hrs/wk for each occupant. If micro- environment is just passed thru, indicate "P"										
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													

APPENDIX D: DEFINITIONS OF COMMON MAGNETIC-FIELD PARAMETERS AND METRICS

AC-DC Angle - The angle between the peak ac field at the frequency of interest and the dc-field vector.

AC - DC Parallel Magnitude (AC||DC) - The portion of the ac vector that is parallel to the dc vector: can be expressed as an absolute number (magnitude), or a percentage of the total ac vector, at the frequency of interest (or the magnitude of the projection of the ac vector onto the dc vector).

AC-DC Perpendicular Magnitude (AC ⊥ DC) - The portion of the ac vector that is perpendicular to the dc vector: can be expressed as absolute number (magnitude), or a percentage of the total ac vector, at the frequency of interest (or the magnitude of the projection of the ac vector onto a vector perpendicular to the dc vector and in the same plane as the ac and dc vectors).

Axial Ratio - See polarization.

DC Magnitude - The static or non-time varying component, or zero-frequency end, of the electromagnetic-field spectrum.

Extremely Low Frequency (ELF) -Defined by the Institute of Electric and Electronics Engineers (IEEE) as the frequency range of 3 Hz to 3 kHz.

Harmonic - A frequency that is numerically the multiple of the fundamental frequency. For example, the 2nd, 3rd and 4th harmonics of a 60-Hz wave are 120 Hz, 180 Hz, and 240 Hz, respectively.

Harmonic Magnitude -The magnitude of magnetic field in a certain harmonic or band of harmonics.

Harmonic Phase - The phase angle of a specific harmonic frequency relative to the fundamental frequency of the magnetic field.

Low Frequency (LF) - Defined by IEEE as the frequency range of 30 kHz to 300 kHz.

Orientation - For a dc magnetic field, orientation is a simple line in three-dimensional space, with the direction defined by north magnetic-pole physics. For ac magnetic fields—power-frequency, or harmonics—orientation of a single-frequency field is normally in a spatial plane, with the field vector tracing an ellipse in the plane.

Peak Magnitude - For any sampling period, peak magnitude is the maximum positive or maximum negative magnitude (relative to zero).

Polarization (or Axial Ratio) - The measure of the ellipsisity of the ac magnetic field defined by the ratio of Bmin/Bmax. An axial ratio of zero defines a linearly polarized magnetic field; and, at the other extreme, an axial ratio of one defines a circularly polarized magnetic field.

Resultant magnitude - The square root of the sum of the squares $((Bx^2 + By^2+Bz^2)^{1/2})$ in the broadband or frequency of interest, where Bx,By, and Bz are the spatial components of the dc or ac field.

Total Harmonic Distortion - The root-mean-square sum of the magnetic-field harmonic magnitudes divided by the power-frequency (60-Hz in North America) rms magnetic-field magnitude.

$$(\Sigma\ (\text{harmonics})^2)^{1/2}/\text{60-Hz magnitude.}$$

Transient Field - A non-periodic, non-continuous, usually very short duration magnetic field that usually relates to an abrupt change in current in the source of the field.

Very Low Frequency (VLF) - Defined by the IEEE as the frequency range of 3 kHz to 30 kHz.