RESEARCH RECOMMENDATIONS FROM WORKSHOP PANELS

RESEARCH RECOMMENDATIONS FOR *IN VITRO*/CELLULAR MECHANISM STUDIES

INTRODUCTION

The research recommendations for *In Vitro*/Cellular Mechanism Studies are the result of deliberations and discussions of a panel of scientists with expertise in electric and magnetic fields (EMF) research and cellular processes. A focus for panel deliberations was provided by a plenary paper authored by Dr. Stephen Cleary. This paper summarized research results obtained using *in vitro* systems to investigate effects of extremely low frequency EMF on cellular processes. The plenary paper also described the advantages of *in vitro* studies for exploring, evaluating and more thoroughly understanding the underlying cellular interactions with EMF and the possible relationship of these effects to specific diseases in humans. Designing and conducting occupationally relevant *in vitro* studies requires information from other types of studies and disciplines. Addressed at the Workshop were *in vivo* studies, epidemiology, exposure assessment and control technologies. *In vitro* studies are thus one component of a larger effort involving at least four other equally important components. The agenda for *In Vitro*/Cellular Mechanism Studies must therefore involve information generated by other disciplines. This illustrates the need for a coordinated, integrated, interdisciplinary approach to achieve the desired result, namely protection of workers from adverse effects of extremely low frequency EMF exposure.

These research recommendations are included in the following categories:

- Relate *In Vitro* and Workplace Exposures
- EMF Dosimetry for the Cellular Level
- Theoretical Studies and Models
- Reference Criteria
- Research Priorities for Health End Points

RELATE *IN VITRO* AND WORKPLACE EXPOSURES

- **Correlate Exposure Parameters for In Vitro Studies with Potentially Harmful Exposures Found in the Workplace**

A detailed occupational exposure assessment must be conducted by qualified individuals in order to provide EMF parameters for *In Vitro*/Cellular Mechanism Studies. This assessment must provide appropriate ranges of the following exposure parameters:

(a) peak and average electric and magnetic field strengths;
(b) fundamental and harmonic frequencies of oscillating fields; frequency spectrum and timed dependence of pulsed or transients;
(c) amplitude and frequency of ambient (background) EMF;
(d) local geomagnetic fields (amplitude, declination); and
(e) concentration or amplitude of physical or chemical factors encountered in the workplace that may serve as confounders or co-stressors.

Occupational exposure assessments should be conducted on the basis of pertinent epidemiological studies linking EMF occupational exposures to specific health effects as well as pertinent existing information (e.g., intensity windows and resonance conditions) presently available from EMF *in vitro* and *in vivo* studies already in the literature.

EMF DOSIMETRY FOR THE CELLULAR LEVEL

- **Develop Methods of Occupational Dosimetry which Reflect Exposures at the Cellular Level**

Once appropriate exposure assessments have been conducted, the information must be utilized to construct laboratory exposure systems which duplicate established workplace exposures at the cellular level. For *In Vitro*/Cellular Mechanism Studies this is more complicated than simply exposing cells to the ambient fields described in the exposure assessments. While this might be appropriate for whole animal studies or for potential effects caused directly by the magnetic field, a number of endogenous factors are known to alter the electric field by the time they reach the target organ or cell in question. It is thus imperative that appropriate methods of theoretical and experimental dosimetry be developed and applied to permit accurate extrapolation of occupational EMF exposure levels to exposure at the cellular level.

THEORETICAL STUDIES AND MODELS

- **Develop Theoretical Models to Clarify Mechanisms**

Development of theoretical studies and models with particular emphasis on mechanisms that seem to hold promise (e.g., non-linear and resonance concepts) must be an important part of this research agenda. These studies and models are necessary because of the multitude of possible experimental exposure parameters, and other conditions which need to be elucidated prior to conducting definitive *In Vitro*/Cellular Mechanism Studies. Theoretical studies are further warranted because of the unique nature of reported EMF biological effects including nonlinear, non-equilibrium phenomena. Theoretical models must provide information for "hypothesis" testing and concurrently reduce the number of experiments necessary to achieve scientifically credible results. Models may be many or singular. A form of theoretical research coupled with actual laboratory studies might be the utilization of a single robust model to examine the importance of specific EMF parameters on selected molecular and cellular processes. The parameters investigated would be occupationally relevant as well as consistent with one or more theoretical mechanisms. Whereas predictions derived from this model might not be directly applicable to an occupational setting, the utility would lie in providing direction and valuable insight regarding the interpretation and assessment of occupationally relevant *in vivo* or *in vitro* studies.

REFERENCE CRITERIA

- **Develop Reference Criteria for Experimental Design and EMF Field Characterization**

To reduce ambiguity and uncertainty in progressing toward a unified understanding of biological actions of EMF, standardized criteria for conducting and reporting the results of *in vitro* studies must be encouraged. This must include means of linking experimental results obtained in one laboratory with those from other laboratories. This can be accomplished by replicate experiments in several laboratories. Specific aspects of a study might be repeated before an investigator moves ahead in testing new hypotheses. Replication of experiments will provide a means of identifying confounders that are responsible for divergent results from different laboratories. Intrinsic to the concept of research reference criteria is the selection of appropriate tissues and cells, complete with rationale. Lastly, the nature of *in vitro* studies indicate the need to control a number of experimental variables. These variables must be considered in developing standardized experimental criteria. Above all, the research criteria should place equal consideration on the selection, control and replication of the EMF parameters as on the importance attached to maintaining and replicating studies of effects on tissues and cells.

RESEARCH PRIORITIES FOR HEALTH END POINTS

- **Define the Significant Health End Points**

From an occupational perspective, the disease of greatest concern with respect to EMF exposure is cancer. In view of this, the highest priority should be assigned to *in vitro* studies which help to define the nature of this problem. This may be accomplished by *in vitro* studies of the effects of occupationally relevant EMF on the proliferation of normal human cells (including immune system cells), and transformed cells. These studies should provide insight regarding EMF-induced cancer promotion and possible immunosuppressive effects; the latter as they relate to the cancer process. Several molecular events/processes intrinsic to cell proliferation and carcinogenesis are amenable to investigations employing *in vitro* techniques. Among these are biomolecular synthesis, intercellular communication, regulation and induction of ornithine decarboxylase, binding and transport of cations (principally Ca^{++}) and other cell membrane-dependent events. Other targets for EMF occupationally induced adverse effects that should be investigated using *in vitro* methods include: the male and female reproductive systems, endocrine and neuroendocrine systems, alterations in fetal development, and non-cancer aspects of immune system function. Regardless of the disease or system being investigated, the focus of *in vitro* research should be on:

(a) mechanisms of interaction of EMF with biological systems;
(b) the delineation of those EMF parameters that may be particularly critical in these interactions;
(c) the physiological consequences of those interactions; and
(d) the relationship to EMF related diseases.

Elucidation of the mechanisms of EMF effects on biological systems and potential health impairment provide a starting point for worker protection and a means of intervening to affect disease outcomes.

RESEARCH RECOMMENDATIONS FOR *IN VIVO* STUDIES

INTRODUCTION

Panel deliberations on *in vivo* research needs evolved from the review of past research in the plenary paper authored by Dr. Larry E. Anderson. Much previous *in vivo* research into effects of extremely low frequency electric and magnetic fields (EMF) has been exploratory in nature. Experiments have been conducted to demonstrate the presence or absence of biological effects, and there have been essentially no theoretical bases concerning likely mechanisms for, or consequences of EMF exposure. Many of the efforts have been pilot studies. Replication has not been attempted frequently, and when it has been attempted, ability to replicate observations has seemed poor. Apparent explanations for this include inadequate characterization and reporting of exposure conditions and insufficient quality control. Many of the research recommendations presented below are directed at resolving these issues.

As determined by this NIOSH assembled panel, some phenomena have emerged which are of sufficient credibility or potential importance to form a basis from which hypotheses can be generated and a logical research agenda can be developed.

One of the most interesting of the biologic phenomena resulting from *in vivo* experiments using EMF exposure is the inhibition of nocturnal melatonin syntheses in the rodent pineal gland, a key finding of considerable importance in its own right. In addition, the pineal gland is closely tied to the central nervous system (CNS). Inhibition of melatonin synthesis forms a basis on which hypotheses can be developed; specifically those regarding plausible mechanisms for epidemiologically observed associations between presumed power frequency EMF exposure and the incidence of cancer. This is especially true for hormone-dependent cancers such as breast cancer, in both males and females, and prostate cancer. Pineal effects also provide a basis for formulating hypotheses relative to the effects of EMF exposure on the development, maturation, and degeneration of critical systems and processes such as those involved in CNS function and mammalian reproduction.

Melatonin inhibition produced by EMF exposure provides a basis for studying the interactions of EMF exposure with factors such as occupation, shift work, trans-meridian travel, sleep disturbance, medication, and age. Changes in calcium ion binding to cell surfaces and changes in the movement of calcium ions across cell membranes are other EMF biological effects that have been repeatedly observed *in vitro* and which might relate to altered melatonin and neurotransmitter synthesis, disturbance of CNS electrical activity, and alteration in cardiac function.

Based on these considerations, the *In Vivo* Panel identified seven major research recommendations. Within each of these areas, specific recommendations were identified.

- Conduct studies with scientific rigor
- Meticulously characterize EMF exposures
- Characterize the critical effects of EMF
- Study neuroendocrine dysfunction produced by EMF
- Conduct definitive studies of the role of EMF in carcinogenesis
- Study reproductive and developmental effects of EMF
- Study cardiovascular effects of EMF

CONDUCT STUDIES WITH SCIENTIFIC RIGOR

As indicated in the Introduction, results from *in vivo* research on EMF usually have not been replicated. Replication has usually not been attempted, and when it has been, the ability to replicate has been poor. The *In Vivo* Panel considered as its first priority the following recommendations to improve reproducibility and credibility of extremely low frequency EMF research and reporting.

- **Design Experiments to Test Specific Hypotheses,Based upon the Best Evidence from Prior Research and Theory.**

- **Define Exposure Regimens Carefully and Thoroughly.**

- **Improve Reproducibility and Validity Through Use of such Methods as Improved Documentation, Quality Assurance, Experienced Personnel, Interlaboratory Studies, and Double-Blind Control Procedures.**

- **Conduct Studies in a Logical Progression Once an Effect has been Established.**

  The critical exposure parameters (electric or magnetic field, field strengths, intermittency, and dose response) should be determined as well as the critical biological parameters (species, age, diurnal variations).

- **Validate *in Vitro* and Epidemiology Findings with *in Vivo* Studies.**

  Effects on calcium ions, alterations in cell to cell communication, malformations in pulsed EMF-exposed chicken eggs, and reports of occupational cancers are examples of phenomena which should be pursued with mammalian *in vivo* experiments.

- **Repeat Studies in Several Species such as Rodent, Primate and Human to Aid in Extrapolation of Findings and to Establish Predictiveness of Animal Data.**

- **Increase Communication between Laboratories, Government Agencies, Workers, and the Concerned Public.**

CHARACTERIZE EMF EXPOSURES

There are many variables of EMF that can be manipulated or controlled in *in vivo* experiments and the *In Vivo* Panel considered the following items of high priority for the conduct, reporting, and interpretation of studies.

- **Use the Latest Available Technology for Exposure Systems.**

- **Require Substantial, and to the Extent Possible, Completely Documented Characterization of EMF Measurements, Including Ambient Fields.**

  The characterization should include:
  (a) electric and magnetic fields and their combinations;
  (b) continuous versus intermittent application;
  (c) field strength and intensity;
  (d) frequency;
  (e) type of field—sinusoidal vs. pulsed; and
  (f) rate of change for pulsed fields (dB/dt)

- **Define EMF Exposure in Relation to Possible Interactions with Biological Rhythms (e.g., Light/Dark Cycle; Shift Work; Extended Workdays; Diurnal CNS Functions such as Mood, Alertness and Task Performance; Variation in Stage of Maturation; and Seasonal Variations in Functions of the Reproductive System).**

CHARACTERIZE CRITICAL EFFECTS OF EMF

Ascertaining of critical effects on which to focus research is essential. While some effects have emerged as the most repeatable and most plausible, none have been well established and fully characterized. The following recommendations are necessary to firmly delineate the critical effects of EMF.

- **Use Scientifically Accepted Methods;**
- **Stress Quality Assurance Procedures, Experimental Design, and Quality Control of Exposures;**
- **Formulate and Test Hypotheses Based on Previous Studies and Theory;**
- **Conduct Studies to Replicate Key Findings;**
- **Determine which Factors of the Exposure Variables are Associated with Biological Effects and Determine Dose-Response Relationships for Those Effects; and**
- **Develop an Understanding of Mechanisms by which Biological Effects Occur.**

NEUROENDOCRINE DYSFUNCTION PRODUCED BY EMF

Reports of neuroendocrine dysfunction have appeared in the literature, but few have been confirmed. The key exposure parameters have not been defined and dose-effect relationships have not been established. Inhibition of melatonin synthesis appears to be an established effect from which linkage to other effects may evolve. In addition, behavioral effects need further attention, as do other effects on the central nervous system, including sleep disturbances. The *In Vivo* Panel recommends the following research on neuroendocrine dysfunction.

- **Characterize Neural, Endocrine, and Neuroendocrine Responses to Power.**

  Endocrine functions need to be confirmed, and extended as appropriate. For example, for melatonin:

  (a) characterize effects in relation to exposure parameters;

(b) determine mechanisms of interaction with species variables, exposure variables, and with other organ systems; and
(c) determine the endocrine linkage to the possible role of EMF in carcinogenesis, immunology, mammalian reproduction, and behavior.

The following additional recommendations are made for research on the nervous system.

- **Conduct Definitive Dose-Response Studies on Behavioral Effects.**

- **Study Central Nervous System Processes such as Short-Term Memory, Arousal, Attention, and Learning, Using Electrophysiologic, Pharmacologic and Other Methods.**

- **Determine the Potential for EMF Exposure to Produce Sleep Disturbances or Alter Mood.**

DEFINITIVE STUDIES OF THE ROLE OF EMF IN CARCINOGENESIS

Several epidemiology studies raise concern for electrical workers, as well as the general population. It is incumbent upon the *in vivo* research community to diligently pursue this issue as per the following recommendations.

- **Conduct *in Vivo* Tests of Tumor Initiation, Promotion and Progression by EMF.**

(a) concentrate on leukemia, brain, and hormone-dependent tumors;
(b) use animal models with predictable background tumor incidence;
(c) design experiments to detect tumors with statistical power that is acceptable by current design standards;

(d) use appropriate, including positive and negative, controls; and
(e) conduct careful dosimetry of tumor initiators, promoters, and EMF.

REPRODUCTIVE AND DEVELOPMENTAL EFFECTS OF EMF

Some human studies, as well as animal studies, have shown effects on reproduction and development. However, many of the studies have been pilot in nature, have used inappropriate models, or might not be relevant to workers. Most studies reporting effects on animal development have utilized chick embryos, a test model which has limited use in predicting human risk but is useful in evaluating mechanisms. Therefore there is a need for further research as follows.

- **Study Potential Reproductive and Developmental Effects of EMF Exposures, Including Mechanisms of Interaction, Using Appropriate Models and Protocols.**

- **Study Shifts in Patterns of Development, Maturation, and Degeneration of Animal Systems such as the Nervous, Reproductive, and Immune Systems.**

CARDIOVASCULAR EFFECTS OF EMF

Effects of EMF on the heart beat of dogs and human subjects have been reported, leading to the following recommendations.

- **Conduct Confirmatory Studies in Humans and Other Animal Species, Especially Primates.**

- **Characterize the Critical Exposure Parameters.**

- **Conduct Mechanistic Studies related to the Effects of EMF on such Phenomena as Calcium Ions and Neurotransmitters and Their Role in Cardiovascular Function.**

RESEARCH RECOMMENDATIONS FOR EPIDEMIOLOGIC STUDIES

INTRODUCTION

Based on the plenary paper by Dr. Gilles Thériault, there are several "generations" of epidemiology studies of workers exposed to electric and magnetic fields (EMF). These studies can be categorized in the following way:

First Generation

Hypothesis generating studies, including proportionate mortality ratio (PMR) analyses of State mortality data and standardized mortality ratio (SMR) analyses of large occupational groups of workers not specifically designed to study EMF.

Second Generation

Hypothesis testing studies with little or no information on exposure. Exposure was mostly defined by job/occupation with expert judgement alone defining exposed groups.

Third Generation

Hypothesis testing with improved data on exposure. Most of these studies are ongoing and involve male utility workers where the exposures are to 60 and 50 Hz fields. The primary hypothesis being tested in these studies is that exposure to such fields is associated with an increase in cancer, especially leukemia and brain cancer.

In light of these previous and ongoing studies, the Epidemiology Panel considered the gaps in occupational epidemiologic studies of EMF, and the types of information that are needed before new studies can be conducted which will contribute new knowledge to the field.

Research Recomendations

The Panel believed there was a need to conduct additional epidemiologic studies especially in occupational groups other than utility workers; and other potential health effects need to be considered besides leukemia and brain cancer. The following recommendations related to the epidemiology of EMF in the workplace were discussed.

- Characterization of exposure
- Health effects/responses of interest
- Methodological issues
- Potential worker populations to study

CHARACTERIZATION OF EXPOSURE

- **Develop Better Exposure Information**

  The panel's primary recommendation was the need for better information on exposure. Researchers should consider conducting exposure assessments or surveys of selected occupational groups/jobs in order to characterize their potential for exposure to EMF. This will provide needed information to select highly exposed populations for study. The epidemiologists need to work with those planning the exposure assessments to determine which jobs/occupations need to be characterized. It is important to consider EMF exposures other than 60 and 50 Hz and groups other than male utility workers.

- **Characterization of Exposure in New Epidemiologic Studies**

  All new epidemiologic studies should include a characterization of exposure. Lack of good exposure information has been a major gap in most of the epidemiologic studies done to date. Other parameters such a harmonics, resonance, and high frequency transients should also be characterized.

HEALTH EFFECTS/RESPONSES OF INTEREST

The panel prioritized the responses of interest as follows.

- **Cancer — (based on previous study results)**

  (a) Leukemia
  (b) Brain cancer
  (c) Breast cancer (in women and men)
  (d) Malignant melanoma
  (e) Non-Hodgkins lymphoma (NHL)

- **Reproductive Effects**

  (a) Cancer in children of exposed workers
  (b) Adverse pregnancy outcomes (including low birth weight, miscarriage and birth defects)
  (c) Disordered ovulation
  (d) Diminished fertility in men and women
  (e) Sperm abnormalities

- **Other Health Effects - (based on hormonal changes observed experimentally)**

  (a) Sleep disorders
  (b) Behavioral changes (including depression and suicide)
  (c) Motor neuron diseases
  (d) Immunologic changes

- **Non-disease end points and biomarkers**

  The epidemiologist and experimental biologist need to work together to identify relevant biomarkers based on *in vitro* and *in vivo* studies. The issue of melatonin is an example.

METHOLODOLOGICAL ISSUES

- **Develop Common Protocols**

  Common protocols should be developed for both exposure assessments/characterization as well as the epidemiologic analyses, so that studies can be combined for future meta-analysis. This may be important for obtaining the necessary sample size to address various hypotheses.

- **Conduct Multi-center Studies**

  Multi-center studies should be considered, so that large enough populations of sufficient size are available for study. This approach is currently being used for some of the ongoing studies of utility workers.

- **Use Existing Data Bases to the Extent Possible**

  The use of existing databases should be explored. If there are appropriate populations that have been previously studied, they should be further evaluated if exposure to EMF can be documented. For example, a large cohort mortality study of aluminum reduction workers has been conducted, where the effects from magnetic fields have not been evaluated. This population is exposed to strong magnetic fields created by the use of direct current. There are also existing studies of welders that could be reanalyzed. The use of registries that might be used to identify cases for case/control studies should be evaluated. An example of this type of registry is the birth defects registry that has been developed by researchers at the Centers for Disease Control.

- **Formulate Appropriate Hypotheses**

  Hypotheses need to be well formulated based on previous epidemiologic studies or on laboratory findings, and appropriate study designs need to be planned. For example, incident cancer studies rather than mortality studies should be considered for cancers with a potentially prolonged clinical course, such as breast cancer. This may involve the use of cancer registries.

- **Identify Potential Confounders**

  Potential confounders need to be identified. For the cancer studies, smoking and other occupational exposures may be important, including benzene (for leukemia) and sun rays (for melanoma). Other potential confounders (depending on the population under study) include soldering fumes, solvents, polychlorinated biphenyls, etc. Other factors related to the demographics of the population may be important as well, such as, socio-economic status.

- **Improve Analytical Techniques**

  Analytical techniques need to be improved to control for confounding; and interaction should be examined, e.g. interaction between chemical exposures and EMF exposure, especially if EMF acts as a cancer promoter.

- **Continue Hypothesis Generating Studies**

  Hypothesis generating studies, such as PMR studies based on union or company death benefit records should continue to be pursued. The International Brotherhood of Electrical Workers (IBEW) or Utility company/union records are examples of such study groups. These studies should include as much information as possible on potential exposures, and should only be done to focus or refine hypotheses.

POTENTIAL WORKER POPULATIONS TO STUDY

The goal in any new epidemiologic study is to identify a population with known "high" exposure to EMF. The importance of electric versus magnetic fields is not completely clear at this time. Ideally, it would be preferable to identify a population where a subset is highly exposed, but where there is also significant variation of exposure to EMF with no other confounding exposures.

Research Recomendations

- **Identify Exposed Women Workers**

  There is a need to identify an exposed population of women workers so that the hypotheses relating to reproductive effects and breast cancer can be addressed.

- **Identify Populations Exposed to Non-Power Line Frequencies**

  Populations exposed to EMF at frequencies other than power line frequencies of 50 and 60 Hz should be studied.

- **Study Rare Diseases**

  Rare diseases of interest require large populations that can be identified through existing data bases such as company personnel or union records.

- **Worker Populations to be Studied:**

  (a) Health care workers especially intensive care unit (ICU) nurses, users of nuclear magnetic resonance instrumentation, and workers involved in shifts that could alter their melatonin levels;
  (b) Welders;
  (c) Aluminum reduction potroom workers;
  (d) Electric railroad workers; and
  (e) Other workers who work around electric machinery/motors.

Research Recommendations for Exposure Assessment Studies

Recent epidemiologic research has generated substantial scientific interest in the possible association between exposure to electric and magnetic fields (EMF), principally from AC electricity, and adverse health outcomes, such as leukemia and brain cancer. The need for conducting exposure assessments has been emphasized throughout this workshop for three reasons. First, the validity of these epidemiologic studies and the applicability of the results to other worker populations depends, in part, on careful quantification of exposure to electric and magnetic fields. Second, the results of such assessments in worker populations may influence the selection of exposure conditions for *in vitro* and *in vivo* experimental studies. Third, the design and implementation of control measures to reduce worker exposures will rely heavily on the information obtained in conducting such assessments.

There has been considerable progress during the past decade in documenting EMF exposures, primarily in the utility industry. However, much research remains to be done. The Exposure Assessment Panel identified specific research needs in the six general areas suggested by Dr. T. Dan Bracken in his plenary paper.

- Measurement guidelines
- Exposure metrics in epidemiologic studies
- Measurement instrumentation
- EMF dosimetry
- Non-utility sources of exposure
- Worker communication

The specific research needs identified by the Panel are discussed below.

MEASUREMENT GUIDELINES

- **Develop Procedures for Evaluating Worker Exposures**

The industrial hygienist or health physicist is the health professional most often charged with assessing occupational exposures to electric and magnetic fields. Since their formal training usually has not covered EMF, guidance is needed to assure adequate exposure evaluations. Further, if standardized measurement protocols are used, researchers can compare exposure data from various sources measured by different investigators. Such protocols should specify measurement parameters, such as distances, frequencies, duration and number of measurements, and other physical parameters, similar to the guidance of the Institute of Electrical and Electronics Engineers (IEEE) for measuring electric and magnetic fields near power lines.

- **Develop Procedures for Comprehensive Exposure Assessment**

Comprehensive EMF measurements should be conducted in research studies to characterize the emissions and exposures from both industrial equipment and consumer products. The data generated should be used in analyzing potential hazards, specifying exposure and dose parameters for biological studies, selecting worker groups for inclusion in epidemiologic investigations, and determining the need for, and types of, control technology required to ameliorate worker exposures. Detailed protocols should be developed to assure comparability of the measurement data. They should include types of measurements to be made, instrumentation requirements, and measurement procedures, including the location and duration of the measurement and the frequency range.

- **Design and Evaluate Training Programs**

Most health and safety professionals have minimal training, education or experience in assessing EMF exposures. These professionals will require specialized training programs on the basic EMF principles, the possible health effects from EMF exposure, the applicable occupational exposure guidelines, and the standardized measurement protocols. The programs should include instrument demonstrations and laboratory sessions involving measurements of EMF sources, using both survey meters and personal dosimeters, and data analysis should be discussed. Methods for evaluating the effectiveness of these training programs should be developed and implemented.

EXPOSURE METRICS IN EPIDEMIOLOGIC STUDIES

- **Develop Better Methods for Measuring Exposure in Epidemiologic Studies**

Epidemiologic studies often employ only simple exposure hierarchies, such as exposed vs. unexposed occupations. More accurate measurements of worker exposures are needed. Uniformity in conducting exposure assessments will allow researchers to define exposed occupations and job titles more accurately, to identify potential surrogate measures for exposure, and to reconstruct exposures in retrospective studies. This research should also determine whether it is feasible to integrate the results of comprehensive worker exposure assessments into simpler techniques or exposure indices for use in large epidemiologic studies of occupational groups. These simpler methodologies might include questionnaires, expert panel evaluations, job/task classification matrices, or exposure prediction models.

Research is needed to determine the field variables that are thought to have biological significance, and to design instrumentation to measure these variables adequately. For example, some researchers have suggested that the orientation and frequency of the field, in addition to the exposure duration and variability, are significant variables in producing effects in experimental studies. Further, since non-work exposures may be important contributors to total EMF exposure, personal dosimeters should be used to record and store both occupational and non-occupational exposure measurement data over extended time periods. Research is needed on how to analyze measurement data, including summary statistics and exposure prediction models.

MEASUREMENT INSTRUMENTATION

- **Evaluate Instrument Performance and Develop Quality Assurance Programs**

Many companies manufacture both survey instruments and personal dosimeters for measuring electric and magnetic fields. The manufacturers provide specifications on the technical characteristics of their instrumentation, including frequency response, accuracy, dynamic range, isotropic response, and susceptibility to electromagnetic interference. However, an independent assessment of these instruments is needed to assure the user that the instrument will perform according to the manufacturer's specifications and that the measurement data obtained with the instrument are precise and accurate. Such evaluations should be conducted by an independent body (e.g., a government agency) or a university or private laboratory under supervision of an independent organization. The results of this independent testing should be disseminated.

Instrumentation used to assess occupational EMF exposures must be evaluated on a long-term basis. Important operating characteristics (e.g., frequency response, accuracy, and reproducibility) should be tested extensively to determine that the long-term instrument response is stable. Measurement and calibration standards must be developed for manufacturers and testing laboratories to use in quality assurance programs. For data logging instruments, quality assurance measures are needed because of the vast quantity of data that can be accumulated.

- **Develop and Evaluate Contact Current Meters**

Extremely low frequency electric and magnetic fields induce currents in exposed humans. These currents result from the interaction of the field with the body through inductive and capacitive coupling, and the induced current is a measure of the field energy absorbed by the body. Meters will be required for measuring currents induced by both electric and magnetic fields. In addition, the electric field can cause contact currents upon touching any conducting object in the field. These currents may cause shocks and/or burns when a worker touches the object. Thus, an instrument is needed to measure the potential contact currents in the workplace. All current meters must be evaluated to assure that they provide accurate and meaningful measurements of these currents without enhancing the worker's exposure.

- **Develop Instruments for Measuring Transient Fields**

Workers are often exposed to large transient magnetic fields generated by switching currents produced, for example, when equipment is cycled on and off. These transient fields are of short duration, on the order of milliseconds or less, and can not be quantitated adequately by currently-available survey meters. In addition to the peak value of magnetic flux density, the change in this quantity per unit time, dB/dt, also has possible significance for hazard assessment. Personal dosimeters are needed that will measure these transient magnetic fields and their time rate of change. This will allow adequate assessment of occupational exposure to these fields.

EMF DOSIMETRY

- **Develop Modeling Techniques for Dose Assessment**

Present exposure assessment techniques allow the measurement of only electric and magnetic field strength in the environment. These field strength measurements do not determine adequately a worker's EMF exposure. These fields are capacitively and inductively coupled to the worker's body, resulting in the production of both surface and internal induced currents and electric fields. Dosimetric modeling techniques are needed that will estimate the distribution of these currents and electric fields throughout the body, based on measurement of the unperturbed electric and magnetic field strengths and their spatial and temporal variations.

The determination of these induced fields and currents and their distribution in anatomical models of humans is an important phase in the study of mechanisms of interactions between these fields and human tissues and organs. The identification and investigation of these interaction mechanisms is a critical first step in specifying a dose measure for use in both epidemiologic and laboratory studies.

NON-UTILITY SOURCES OF EXPOSURE

- **Identify and Rank Non-Utility Sources of Exposure**

Data are lacking on EMF exposures in non-utility occupations. This research and hazard surveillance would identify sources of exposure in non-utility industries. Criteria should be developed for use in establishing priorities for selection of sources and work places where exposure assessments will be conducted. For example, occupational sources of exposure can be classified according to power consumption, source-worker distance and duration of worker exposure to the source. High priority should be given to industries having high electrical power consumption, equipment operating at high current, and sources near workers. Of particular interest are work places with welding equipment, electrical transportation, large motors and electric furnaces.

After the non-utility sources and work places have been cataloged, exposure assessments should be conducted for these occupations, based on the ranking and the magnitude of the exposed population. More extensive exposure assessments must be carried out according to the measurement guidance discussed above. Particular attention should be given to measuring a worker's exposure over extended durations with personal dosimeters. This will allow tracking of the time history of the exposure intensity, including peak values, fluctuations in the intensity over time, and time-weighted-average values. The results of these assessments can be compared with those from utility occupations and relative exposure rankings among and between the occupational groups can be derived.

- **Determine the Size of the Exposed Population**

  Limited exposure measurement data and other factors indicate that workers in different work sites or using different sources may have vastly different exposures. The number of workers exposed to electric and magnetic fields of various magnitudes should be determined for different job titles, occupations, and industries. In conjunction with exposure data, this population information can be used to identify groups for epidemiologic studies and to provide input into determining priorities for designing and implementing control measures.

- **Collect Existing Occupational Exposure Data**

  The Electric Power Research Institute (EPRI) and other groups have collected considerable data on worker EMF exposure for a number of occupations in the utility industry. Limited exposure data are also available for occupations and work places in non-utility industries. Recent epidemiologic investigations that have included exposure assessment have been conducted on workers in a number of non-utility occupations. The feasibility and utility of collecting worker exposure data from these studies and other data sources in a central repository for analysis should be evaluated.

WORKER COMMUNICATION

- **Develop and Validate Ways of Effectively Communicating Exposure Information to Workers**

The concepts of electromagnetic fields, their generation, and the resulting worker exposure are complex and difficult to explain in non-technical language. The problem is further complicated by our lack of understanding of the mechanisms by which these fields are absorbed in biological systems and the impact of such exposure on worker health. Thus, providing workers with a perspective on EMF exposure and its attendant risk is a difficult task and requires an understanding of their viewpoints and concerns about EMF exposure. Ways of effectively communicating with workers regarding these concepts and issues must be developed and validated.

RESEARCH RECOMMENDATIONS ON METHODS FOR REDUCING EXPOSURES

INTRODUCTION

The reduction of exposure to electric and magnetic fields (EMF) can be accomplished through the evaluation of existing EMF sources and the causes of these fields, taking steps to reduce their magnitudes and through research and development into control technologies not yet available. Some mechanisms of exposure reduction can be accomplished with available technologies while other approaches will require long term research and development. Accomplishing a reduction in human exposure to low frequency EMF is dependent on a knowledge of what effect the various field parameters have on the relative biological effectiveness of the field. This may include the fields frequency, magnitude or strength, wave form (harmonic content), duration, electric and magnetic components and their phase relationships, etc. It is possible, for example, that a reduction in one field parameter may result in an increase in the magnitude of another parameter with unknown consequences. Without an understanding of the relative importance of the parameters, a comprehensive strategy for exposure reduction is difficult to achieve.

The research recommendations for methods for reducing exposures are the result of discussions of a panel of scientists with experience in EMF controls. The panel began it's discussion following William Feero's paper and plenary presentation on "Magnetic Field Management." The scientists, upon concluding their discussions, identified the following needs.

- Identify and characterize EMF sources
- Review and recommend electrical code changes
- Continue research on field cancellation techniques
- Materials research
- Work practices
- Substitution
- Transient suppression
- Personal protective equipment
- Training and education

A summary of the needs suggested by the panel members is outlined below.

IDENTIFY EMF SOURCES

- **Identify and Characterize EMF Sources**

  The identification and characterization of EMF sources are important to any control strategy. Attention should be paid to the magnitude of the EMF as a function of frequency and phase. This information will be useful when determining the effectiveness of the various controls and help to ensure that controlling one portion of the frequency spectrum does not increase fields in other portions of the spectrum.

REVIEW AND RECOMMEND ELECTRICAL CODE CHANGES

- **Recommend Code Changes to Reduce EMF Exposure**

  One source of magnetic fields in buildings is multiple ground return paths in building wiring. Multiple grounds are the result of electrical code or maintenance and repair practices that do not consider generation of magnetic fields. The objective of reviewing the electrical code would be to identify:

  (a) those sections of the National Electrical Code that are concerned with commercial building grounding systems;
  (b) why existing practice has developed to the point it is now; and
  (c) how existing practice/code requirements might be altered to reduce occupational exposures to EMF resulting from dispersed neutral return currents in the building's ground system.

Source reduction is a primary approach to reducing exposure to any hazardous physical or chemical agent. Research into computer modeling of magnetic fields from building wiring can offer designs for placement of wires in new construction that would reduce exposures to EMF and would potentially identify mechanisms for reducing existing fields.

- **Develop Safe Installation Practices**

Electrical wiring installation practices should be developed that will lead to lower EMF levels in the workplace. Also, installation practices must be carefully reviewed to ensure installers and users are not placed at increased risk of electrocution, fire or other hazards as a result of changes in wiring practices.

- **Develop Computer EMF Models**

EMF intensities can be estimated with computer models. When computer models are available, recommendations to modify the electrical code to apply these models should be made.

CONTINUE RESEARCH ON FIELD CANCELLATION TECHNIQUES

- **Use Computer Models of Fields to Develop Control Strategies**

EMF intensities can be estimated through the use of mathematical models using principles of electricity and magnetism. Computers could be used to calculate field strengths and test designs of measures to reduce fields. Development and validation of methods is required. Validation, to adequately model building features, may require the construction of laboratory facilities so that experiments can be conducted to determine the number of necessary parameters. The key electrical parameters incorporated into the model(s) and computer simulations can then be adjusted to determine the resulting magnetic field sensitivity to the various parameters.

- **Review Industrial Equipment and Appliance Design to Reduce Exposure**

  The wiring and circuit design of industrial equipment, power tools and office appliances should be examined for methods to reduce EMF. Controls are best implemented during the design and fabrication process. Still, retrofit also may be required.

- **Develop Cancellation Techniques**

  The routing and location of wiring in buildings, tools, appliances and other equipment can result in cancellation of EMF through the interaction of opposing fields. Active or passive methods can be devised that will reduce EMF through phase cancellation. Research and modelling in these techniques is needed.

MATERIALS RESEARCH

- **Develop More Effective Shielding Materials**

  Shielding offers another effective approach to reduce or eliminate exposures from EMF. Electric fields can be reduced or eliminated with the use of conducting materials. Magnetic fields are more difficult to shield, generally requiring more expensive materials, which often must be formed into special shapes and then annealed. The effectiveness of commonly used shielding materials is uncertain at low magnetic field strengths (under 0.5 gauss). Research is needed to develop better materials for shielding from magnetic fields. For example, superconducting materials do not allow magnetic fields to penetrate. Continued research into the development of high temperature superconductors may result in improved magnetic field shielding materials.

WORK PRACTICES

- **Develop Generic Administrative Controls to Reduce Exposure**

  Where cancellation, shielding and personal protective equipment controls are ineffective or impractical, administrative controls of work practices, such as increasing the distance between the worker and the source and minimizing exposure times, should be used. Task redesign and workstation design methods should be developed. Modelling of EMF (once developed, described earlier) should consider the location of workers, work stations, etc., relative to the routing of building wiring and the location of the building's structural steel. There are special situations where it may be impossible to reduce EMF intensities (e.g., substations, cable tunnels, and electrical vaults). When this occurs, robots could be used to do the work. Development of robots for these situations is needed.

SUBSTITUTION

- **Design More Efficient Appliances (Tools, etc.)**

Once EMF sources have been identified, appliances that generate lower EMF should be designed. Also, higher efficiency appliances may have lower field intensities. When this occurs substitution could be recommended (care should be taken to understand the EMF from the substitute).

TRANSIENT SUPPRESSION

- **Reduce Transient EMF**

Large transient EMF intensities can occur when equipment is switched. Modification to a circuit design can often reduce the generation of transient fields. A study of generic approaches to such modifications would be useful.

PERSONAL PROTECTIVE EQUIPMENT

- **Develop Appropriate Personal Protective Equipment**

Personal protective equipment is recommended for use when other control measures are not completely effective or in emergency situations. Personal protective equipment for use in shielding against exposure to EMF is not currently available. Material research results may yield light weight, practical materials that can be fashioned into functional garments.

TRAINING AND EDUCATION

- **Include EMF Source Reduction in Training Curricula**

Training and education are usually not considered control techniques. Still, education of professionals and workers in the concerns associated with exposure to EMF will help to reduce future EMF exposures. Electrical engineering curricula can be used to discuss the sources of EMF and teach concepts that reduce or eliminate them. Therefore, future engineers will design equipment that have low field characteristics. Workers can be taught about the sources of EMF and concepts to reduce their exposure to EMF. Knowledge at all levels can provide the most permanent approach to eliminate the risk associated with EMF exposures.