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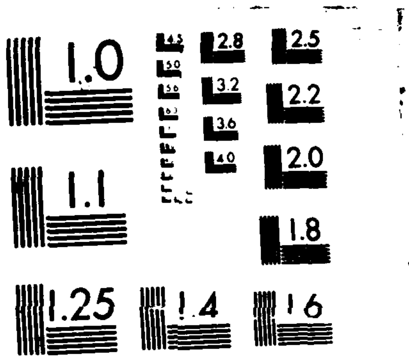

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RDL Report No. 26

EXTREMELY LOW FREQUENCY (ELF) COMMUNICATIONS PROGRAM
NON-IONIZING ELECTROMAGNETIC RADIATION
LITERATURE EVALUATION AND ASSESSMENT

1977-1986 Literature Review
Final Report

November 1986

Prepared for:

Department of the Navy
Space and Naval Warfare Systems Command
Washington, D.C. 20363-5100

Prepared by:

Research & Development Laboratories
5721 West Slauson Avenue
Culver City, California 90230-6509
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Deliverable 0001, Contract No. N00039-86-C-0136

RDL

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The objective of this program is to conduct a thorough and comprehensive review, evaluation, and assessment o the published professional literature containing scientific information pertaining to biological effects, including but not limited to human health effects of nonionizing electromagnetic radiation, germane to the Extremely Low Frequency (ELF) Communications Program.

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- Reproductive Effects
- Metabolism, Growth, and Development
- In Vivo Physiological Studies Including Neural and Neuraoendocrinological Effects
- In Vitro Cellular Studies Including Membrane and Extracellular Interactions
- Theraputical Effects
- Physical Hazards Inclduing Electric Shocks and Effects on Electronic Medical Devices

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Chapter I

OVERVIEW, SUMMARY, AND CONCLUSIONS

1.1. Overview

The objective of this program is to conduct a thorough and comprehensive review, evaluation, and assessment of the published professional literature containing scientific information pertaining to biological effects, including but not limited to human health effects of nonionizing electromagnetic radiation, germane to the Extremely Low Frequency (ELF) Communications Program.

The published professional literature reviewed, evaluated and assessed includes books, research reports, project reports, and articles and papers in peer-reviewed journals that discuss and/or describe biological and health effects of nonionizing electromagnetic radiation in the frequency range of 1-300 Hz. In some instances documents discussing effects of frequencies above 300 Hz were also reviewed if, in the reviewer's opinion, the scientific information was important to understanding the issues under consideration. The review and evaluation included both domestic and international literature published in English and foreign languages.

This task provides a continuation of the previous efforts by the National Academy of Sciences (NAS) and the

American Institute of Biological Sciences (AIBS). NAS report entitled "Biological Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer", which was published in 1977, covers the literature up to 1977. The evaluation by the AIBS was published in the report entitled "Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields", which covers the literature up to March 1984.

In addition to the above mentioned reports, as an adjunct to the literature evaluation and assessment of biological and health effects, the following documents were considered:

- Evaluation of Data on Monkeys Exposed to ELF Radiation; National Academy of Sciences, 1978.
- Representative Electromagnetic Field Intensities Near the Clam Lake (WI) and Republic (MI) ELF Facilities; Department of the Navy, 1983.
- Library Listing of January 7, 1985, for Biological Effects of ELF Electromagnetic Fields for the Period of 1977 to March 1984; developed by IIT Research Institute, 1985.
- Literature published throughout the period of April 1985 to March 1986.

It should be stated that the committee convened by the NAS has reviewed the literature associated with ELF electric and magnetic fields, and the results published in the 1977 report indicate that electric and magnetic fields associated with the Navy's ELF Communications System "... will not cause a significant and adverse biological disturbance, except in the event of electric shock ...". Later on, reviewing a possible ELF biological effects associated with 60-Hz electromagnetic fields, Sheppard (1983) reported that "... no health hazards due to 60-Hz high voltage transmission line electric fields are established ..., a strongly expressed biological effect in humans is not very likely ..., and a pathological effect is even less likely." More recently, the Florida State Science Advisory Commission conducted a review of biological effects of ELF electric and magnetic fields. The Commission (FEMFSAC 1985) concluded that "... it is unlikely that 60-Hz electric and magnetic fields associated with high voltage transmission lines has led, or can lead, to public health problems." The Commission went on to state that some ambiguities in the literature precluded their categorical conviction that absolutely no public health problem existed.

Finally, after a careful and comprehensive review of the literature on bioeffects of ELF electric and magnetic fields, the 1985 AIBS committee concluded that "it is unlikely that exposure of living systems to ELF electric and magnetic fields in the range of those associated with the Navy's ELF Communications System can lead to adverse public health effects or to adverse effects on plants and animals".

Chapter I of this report presents brief summaries for nine different and, in our opinion, the most important issue areas associated with the ELF electric and magnetic field bioeffects. These general issue areas are:

- Physical Hazards Including Electric Shocks and Effects on Electronic Medical Devices
- Therapeutical Effects
- In Vitro Cellular Studies Including Membrane and Extra-cellular Interactions
- In Vivo Physiological Studies Including Neural and Neuroendocrinological Effects
- Metabolism, Growth, and Development
- Reproductive Effects
- Cancer Risk
- Behavioral Effects
- Ecological Effects.

The summaries are based solely on the results of evaluations of nearly five hundred IIT-retrieved citations dating from 1977-March 1985 and on over two hundred Research & Development Laboratories (RDL)-retrieved citations that appeared in professional literature from March 1985 to March 1986. The overall conclusion at the end of Chapter I integrates all of the summaries into one compact statement on the status of current scientific knowledge of possible effects on living systems exposed to ELF electric and magnetic fields.

One of the main tasks of the ELF Communication Program is the development of an ELF bioeffects library, an integral part of which is the development of a data base computer file. RDL has developed two separate data base computer files capable of delivering bibliographic records of all relevant literature retrieved by IIT Research Institute and RDL, respectively. These data bases allow one to search for the particular citation(s) based on such information as title, author's name, source, author's institutional affiliation, and index number. A detailed description of the developed ELF bioeffects libraries, including data base computer file features and operation, is presented in Chapter II.

Chapter III presents details on the review, evaluation, and assessment procedures.

Chapter IV presents a more thorough discussion of the evaluated and assessed literature used in preparation of the summary in Chapter I. The review is confined to the same categories and order as those outlined in Chapter I.

1.2. Summaries and Conclusions

Physical Hazards, Including Electric Shocks and Effects on Electronic Medical Devices

The two principal physical effects of ELF electric and magnetic fields that are potentially harmful to humans are the influence of these fields on implanted medical devices, such as cardiac pacemakers, and electric shocks and spark discharges delivered from charged metal objects in the vicinity of a high-voltage source. Pacemaker sensitivity results from electromagnetic interference (EMI) that can produce malfunctions characterized by either an aberrant pacing rate or a reversion to a fixed-rate pacing mode. The latter type of malfunction can lead to pacemaker stimuli that are competitive with the heart's endogenous firing rate. Problems with EMI are limited to pacemakers of the "unipolar" design, which form a large antenna loop between the cathode lead that is implanted in the heart and the case of the pacemaker, which serves as the anode. Approximately 250,000 people in the United States have implanted pacemakers of the unipolar design. Research reports reviewed by RDL staff and consultants indicate that the threshold 50/60-Hz field levels that produce pacemaker malfunctions have r.m.s. intensities greater than 1.5 kV/m in the case of the electric field component, and 21 μT in the case of the magnetic field component. These field levels are well above those associated with an ELF Communications System, and no pacemaker-related problems should result from human exposure to the fields in air near an ELF antenna. A similar conclusion pertains to the risk of electric shocks and spark discharges resulting from the contact of humans with ungrounded (or poorly grounded) metal objects in the vicinity of an ELF antenna.

Therapeutic Effects

During the last 15 years a large number of clinical trials and laboratory animal studies have demonstrated the efficacy of pulsed magnetic fields in the facilitation of bone fracture reunion. These fields are applied by external Helmholtz coil applicators placed about the limb containing a bone fracture, and the electric currents thereby induced in the region of the fracture are believed to be responsible for the accelerated healing that is observed. All thirty articles reviewed during the past year reported success in bone fracture treatment by pulsed fields, with the majority of the reports giving estimates of an 80-90 percent success rate. A similar success of pulsed field therapy for bone fractures was indicated in studies on laboratory animals. The laboratory studies have also provided an indication that ELF pulsed fields may be beneficial for the treatment of ligament, tendon, and nerve injuries. Several in vitro studies on bone cells and other types of tissue cells have indicated that exposure to ELF pulsed fields leads to an enhanced growth rate and DNA synthesis rate. Overall, the results of the in vivo and in vitro laboratory studies are consistent in predicting that pulsed fields should facilitate bone growth in the region of a fracture. The magnetic field intensities that produce these effects, however, are approximately 15-150 times greater than the maximum 72-80 Hz magnetic fields present in air in the vicinity of an ELF antenna.

In Vitro Cellular Studies, Including Membrane and Extracellular Interactions

The literature reviewed on effects observed in vitro revealed many reports of changes in cellular functions that often involved either cell proliferation, DNA synthesis, or other protein synthesis. The pattern of results supported the concept of a cell membrane mediated effect involving calcium, cyclic AMP, and other factors of intracellular second messenger systems. None of the research reviewed during 1986 investigated thresholds for these phenomena, and generally experiments were done at only one or a few field conditions. Likewise, the results from one or more aspects of the studies with sinusoidal fields were positive and indicated electric or magnetic field influences on cellular processes. Frequently, the authors attributed effects to events at the cell membrane. Research with nervous system tissues sometimes gave positive responses at field levels relevant to some environmental exposures, but rarely at the level of Extremely Low Frequency Communications System (ELFCS) electric fields.

A number of the cited research articles include new (at the time of publication) and important information on cellular responses to various electromagnetic fields (EMFs); however, none of the reports has been flagged as containing significant new information which would require reevaluation of the health and safety issues of ELFCS environmental fields considered in the 1985 AIBS report.

In Vivo Physiological Studies, Including Neural and Neuroendocrinological Effects

Physiologic and neuroendocrine effects were evaluated in experiments ments on small animals exposed in vivo to ELF electromagnetic fields. Some studies involved lengthy exposure periods. There have been significant findings for various ELF electromagnetic fields that show influences on the neuroendocrine system. Because the neuroendocrine system is an important element of the body's response to environmental conditions and physiological status, such effects may have important implications for environmental exposures. At present, the physiological significance of the reported effects is uncertain, and many tests show no overall disruption of the neuroendocrine system. Effects of chronic exposure to strong electric fields may be related to sensory effects or direct field influences on tissues, but the mechanisms are undetermined. The field strengths tested were in the range greater than 1000 V/m, as compared to the maximum ELFCS electric field strength of 160 V/m. Magnetic fields of relevant frequency and field strength have been studied less extensively, and it is not possible to draw conclusions from the few reports. Reports of magnetic field-related neuroendocrine effects involve field levels above 0.1 mT and ranging to 20 mT, far in excess of ELFCS magnetic fields.

A number of the cited research articles include new (at the time of publication) and important information on physiological responses to various EMFs following exposures in vivo; however, none of the reports has been flagged as containing significant new information that would require reevaluation of the health and safety issues of ELFCS environmental fields considered in the 1985 AIBS report.

Metabolism, Growth, and Development

As indicated in the 1985 AIBS report, adequate evaluation of studies investigating developmental toxicology requires that experiments meet the criteria for scientific merit (see Ch. III, Sec. 3.4), and that a dose-response relationship be determined. In addition, replicability of the results is essential in drawing definite conclusions for a given study. The available literature is full of conflicting results. Many results were obtained with questionable experimental methods, and failures to replicate findings are common. Most of the studies lack dose-response relationships. Moreover, most of the research reporting positive effects employs high intensity electric and/or magnetic fields, which exceed by several orders of magnitude those produced by the ELFCS.

Although some studies report on retardation of embryogenesis [Cameron et al. (1985); Seto et al. (1983)], the others observed no embryological effects [Pafkova (1985); Maffeo et al. (1984)]. Some studies (i.e., where mammals such as rats and mice were exposed to an intense electromagnetic field) suggest an increase in weight and growth rate [Saha et al. (1981); Saha et al. (1982); Rooze et al. (1982); Dodge (1985)], whereas other studies indicate an absence of effects on weight and growth rate [Mathewson et al. (1977a); Mathewson et al. (1977b); Portet (1984); Reed (1985)]. Similarly, there are contradictory reports on the effects on metabolic processes due to exposure to high intensity electric fields [Shandala et al. (1981); Shandala et al. (1983); Archer et al. (1981)].

Upon review of experimental methods and results for literature reviewed in 1986, it is impossible to draw definite conclusions concerning the effects of ELF electric or magnetic fields over a wide range of field strengths and waveforms on metabolism, growth and development for mammals, amphibians and avian species. So far, sinusoidal ELF electric and magnetic fields in the range associated with the ELFCS have not been demonstrated to produce adverse metabolic, growth, or developmental effects in animal systems.

Reproductive Effects

Potential adverse reproductive effects of ELF electric and magnetic fields have been addressed in a large number of laboratory investigations and a few epidemiologic studies. A total of 21 references were found that were pertinent to the evaluation of reproductive effects of electric and magnetic fields. The 15 laboratory investigations provided mixed results, with a tendency toward negative studies across the different reproductive parameters and experimental systems. The data predominantly document the absence of reproductive hazard based on laboratory studies. Human studies included a paper suggesting an increased miscarriage risk among users of electric blankets and heated water beds, which falls short of convincing.

Overall, there are some clear suggestions that electromagnetic fields can affect reproductive processes, but several studies convincingly document the absence of pathological effects in several species. The most important suggestions of hazard come from the study of developmental delays in fish and miscarriage risk in human populations. The literature remains incomplete in documenting the presence or absence of reproductive hazards associated with ELF electromagnetic radiation.

The evidence accumulated since the time of the AIBS reports regarding reproductive effects of ELF fields has not changed markedly. Suggestive evidence of adverse effects continues to accumulate in parallel with selected high-quality negative studies. The empirical evidence that ELF fields pose a hazard to reproduction continues to be unconvincing.

Cancer Risk

The issue of cancer risk related to ELF electromagnetic fields has generated a great deal of interest and concern on the part of the general public. The laboratory studies included a suggestion that magnetic fields do not act to enhance chemical promotion of tumors [Lyle et al. (1985)], and a strong suggestion that power switchyard workers are prone to increased risk of chromosome breaks [Nordenson et al. (1984)]. The five papers on residential electromagnetic field exposures and cancer risk included only one actual new investigation with results [McDowall (1986)]. Though no effect was noted, the study was rather weak as a test of electromagnetic field exposure per se. The extensive number of papers concerning occupational exposures (20 citations) reflects a large number of letters to the editor and a few papers with an incidental finding of increased cancer risk among men in occupations entailing exposures to ELF electromagnetic radiation [Calle and Savitz (1986); Milham (1985); Pearce et al. (1985); Olin et al. (1985); Flodin et al. (1986); Stern et al. (1986); and Tornquist et al. (1986)]. Several papers and letters suggest that such workers are at enhanced risk of leukemia, and other papers presented suggested associations with brain cancer, neuroblastoma in the offspring of exposed workers, and chromosomal abnormalities.

The overall review of the most recent work on ELF electromagnetic fields and cancer risk represents the continued accumulation of suggestive but flawed studies. Several of the epidemiologic studies concerning occupational exposures and cancer risk are improvements on past work, though the severe limitation in exposure characterization precludes conclusive results. The conclusion that electromagnetic fields are causing leukemia and other cancers is not justified, but the conclusion that there is some nonrandom relationship between selected occupations and cancer risk is strengthened by several of the studies reviewed.

Behavioral Effects

Most of the citations reviewed were clustered about the 1984-86 time period. As a consequence, many of the findings were included in the 1985 AIBS Reports published in March 1985 and May 1985. There are no new findings that alter the AIBS Review Committee conclusion to the effect that "the apparent lack of consistent deleterious effects tempts one to conclude that exposure to an ELF field is a rather innocuous event and, other than possible mini-shocks, without hazard" [Lovely (1985)]. Most data leading to this statement were obtained from subjects exposed to 60 Hz, kV/m electromagnetic fields. A paradox facing both behaviorists and physiologists is that the significance to intact organisms of in-vitro responses to magnetic or electromagnetic fields (i.e., calcium efflux, altered neural function, etc.) has not been demonstrated [Lovely (1985); Winters et al. (1985)]. Cellular and biochemical changes which, in theory, might well influence behavior have not been shown to do so, leading to the suspicion that in vitro effects might be dampened by the homeostatic processes of the intact organism.

Ecological Effects

The body of knowledge published since completion of the 1985 AIBS Reviews (AIBS, March 1985, and AIBS, May 1985) is negligible and does not alter the conclusions of the AIBS committee that the ecological risk of operating the ELFCS is very low; that should ecological effects occur they will be subtle, not catastrophic; and that the effects will be difficult to distinguish from the effects likely to be associated with the modification of habitats through construction and maintenance of the Communications System.

In general, observed biological effects have been associated with ELF fields associated with electric power transmission lines, where electric and magnetic fields are 1-3 orders of magnitude greater than fields produced by the ELFCS. These studies reflect the concerns and primary sources of funding for research by the electric utilities and the Department of Energy. Biological studies in the vicinity of electric power transmission lines have not identified significant effects that are at once reproducible and unequivocal [Lee et al. (1977); Phillips (1979); Kavet (1982); Rish (1982); Rogers (1983); Lee (1984); Phillips (1985)]. With regard to the ELFCS "the literature fails to reveal any clear evidence for biological effects from exposure to air fields comparable in magnitude to those of the proposed antenna" [Carstensen (1985)]. The latter statement would appear to hold for small mammals, birds, bees, livestock, crops, grasses, and trees studied either in the laboratory or in the vicinity of electric power transmission lines.

1.3. Overall Conclusions

The detailed review of literature on the biological effects of extremely low frequency (ELF) electric and magnetic fields conducted by Research & Development Laboratories (RDL) during the past year has led to the following general conclusions:

- Extensive laboratory studies on animal growth, development, behavior, neuroendocrine parameters, hematology, immunology, and metabolism have not demonstrated deleterious effects of fields with intensities equal to those of an ELF Communication System (ELFCS). ELF pulsed fields with intensities significantly higher than the fields associated with ELF antennas have been demonstrated in clinical trials and laboratory studies to have a beneficial medical effect in the facilitation of bone fracture reunion.

- In vitro studies designed to elucidate the mechanisms of ELF field interactions with living tissues have demonstrated that fields with high intensities (more than two orders of magnitude greater than the fields associated with ELF antennas) can produce alterations in cell growth, metabolism, and DNA synthesis.

- There is no clear evidence for adverse ecological effects of ELF fields with intensities in the range of those associated with ELF antennas. Although evidence exists for the detection of ELF antenna fields by birds, there is no indication that this detection interferes significantly with long-range migratory patterns.

- Although cardiac pacemakers of the unipolar design are highly sensitive to electromagnetic interference from ELF electric and magnetic fields, the threshold field intensities required to produce pacemaker malfunctions are significantly higher than the intensities of ELF antenna fields.

- Reports on adverse reproductive effects of low-intensity ELF fields are generally unconvincing, although further studies are needed in this area.

- The possible correlation between human cancer risk and ELF field exposure has been supported by several new epidemiological studies that were, in general, flawed by poor design and deficiencies in the methods used for data collection and analysis. This issue remains the most controversial subject in the area of ELF field bioeffects. There is a clear need for additional epidemiological studies that characterize human exposure to ELF fields in a quantitative manner, and which use statistically powerful procedures for data acquisition and analysis.

Based on the review and evaluation of the available professional literature published in the period 1977-March 1986 containing scientific information relevant to biological and health effects of ELF electromagnetic radiation, the overall conclusion is that:

- It is unlikely that ELF electric and magnetic fields associated with the ELFCS have an adverse effect on human health or on animal systems in general.

Chapter II

LIBRARY DEVELOPMENT

The basic components of Library Development for the ELF Bioeffects Literature Evaluation and Assessment Program are: literature searches of appropriate information data bases, culling and indexing of retrieved relevant literature, translation of relevant foreign documents, entry of bibliographic and characterization information into a data base computer file, and storage of bioeffects literature in a permanent library. The specifics of each of these ELF Library components have been described in detail from their initial development through completion in the various monthly progress reports published by RDL beginning in December 1985. Following is a summary of the library components.

2.1. Literature Search and Retrieval

RDL began development of the bioeffects literature search strategy by identifying information data bases likely to contain the majority of literature related to the subject of interest. Through Dialog Information Systems, Inc. of Palo Alto, California, 26 data bases were initially identified as viable candidates. RDL then began consultations with Information on Demand, Inc. of Berkeley, California for development of an effective and comprehensive literature search strategy. Following a period of test, evaluation, and search refinement, RDL conducted literature searchs of twenty (20) information data bases for the period January 1985 to present (19 March 1986). They are:

- Aerospace Data Base
- Agricola
- Biosis Preview
- CAB Abstracts
- Compendex
- Conference Papers Index
- Dissertation Abstracts Online
- DOE Energy
- DTIC
- EI Engineering Meetings
- Electric Power Data Base
- Embase Excerpta Medica
- Energyline
- Enviroline
- Environmental Bibliography
- INSPEC
- LC MARC
- NIOSH
- NTIS
- Pollution Abstracts

The beginning of the search period was specified as January rather than April, to insure that no relevant literature was omitted between the conclusion of the previous bioeffects library development effort and the current effort. Approximately 400 citations were returned from the searches. Of those, fifty (50) percent were eliminated as not relevant, and an additional 25 percent were eliminated due to inter-data base redundancy. A net total of 144 relevant and new citations were realized during the February-March 1986 time frame.

As described in the progress report for August 1986, a continuation of previous literature searches was conducted for the time period March 1986-1 September 1986. As mentioned in that report, the period of search exceeded the 31 March 1986 cut-off point indicated in the Statement of Work to allow enough time for relevant literature within that period to be appended to the various information data bases (typically 30-90 days, or longer). The last search (after elimination of irrelevant and redundant citations) yielded 145 new and relevant citations. This resulted in a net total of 289 new and relevant citations for the period of this contract.

Actual retrieval of relevant documents has been accomplished through a variety of sources. Primary sources include the University of California, Los Angeles; California Institute of Technology; the Foreign Broadcast

Information Service; Joint Publications Research Service; various professional journals and publications in the field of bioelectromagnetics; as well as contributions from RDL's technical experts in the various fields associated with bioelectromagnetic effects and research.

2.2. Literature Culling and Indexing

All relevant bioeffects literature recovered from the literature searches was prepared for inclusion into a data base computer file (developed specifically for this program by RDL). In addition to all required bibliographic data, each document has been characterized by Subject Category, Subject Material, Issue Area, Electromagnetic Field Type, Electromagnetic Field Characterization, and Species Type. The specific key words and descriptors for each of these data fields were developed in cooperation with library specialists, RDL's experts in bioelectromagnetics, and with emphasis on the continuation of criteria established by the AIBS and the NAS. Lists of all key words in the various data fields were submitted for approval to the ELF Project Office. The characterizations and bibliographies of all retrieved bioeffects literature are resident within the RDL data base computer file for use by the ELF Project Office or their designates. Specific details of the data base computer file have been published in RDL monthly progress reports, and are summarized below in Section 2.4.

2.3. Foreign Literature Translation

For that literature identified as new and relevant from the search of information data bases and other sources, RDL employed a number of resources to acquire English translations of those documents that showed potential for "new and significant findings" as directed by the Statement of Work. The initial resource was the Foreign Broadcast Information Service (FBIS). The FBIS is a body of the Government's Joint Publications Research Service (JPRS). Both FBIS and JPRS regularly translate foreign publications of interest in a variety of defense, technical, and medical fields. In the event that documents of interest were unavailable from FBIS/JPRS, they were translated by competent RDL staff members, or independent translation services.

2.4. Database Computer File Development

Introduction

This document describes the ELF Bioeffects Library Data Base System. The system has been developed by RDL to facilitate the efficient storage and retrieval of ELF biological effects literature. The system has been developed with the following criteria in mind:

- o efficient data access
- o ease of use
- o minimal learning time
- o portability

RDL has developed a Dedicated Data Base Management System, specifically designed for performing bibliographic literature searches. In evaluating many commercially available data base management systems, we have found none that effectively meet this requirement. Following is a description of the ELF Library Data Base, the User Interface, and the Search and Display Module of the Data Base System.

Data Base Description

The ELF Library Data Base is divided into the following categories and data fields:

- ELF File Number;

- Bibliographic Data--Author(s), Title, Publication Date, Author Affiliation, Report Number, Publication, Language, Number of Pages, Number of References;

- Keyword Data--EM Field Type, EM Field Characterization, Subject Categories, Subject Materials, Issue Areas, and Species.

Physically, the ELF data base is stored as a keyed ASCII text file. Each data record (single bibliographic entry) is delimited by a single line with an exclamation mark, followed by the record data. Fields are lines of text beginning with a percent character "%" and a unique 2-character field key. This method of storage allows for variable length fields, each field taking up exactly as much storage as needed, with a 3-byte per line overhead of the field key. This scheme allows for multiple author and key-word fields per record, as well as title fields of arbitrary length; for example:

```
%FN 85500
%AU Bernhardt JH, Kossel F
%TI Recommendations for the Safe Use of NMR Equipment
%DA Feb 1985
%AA Inst. for Radiation Hygiene, Federal Health Office,
%AA D-8042 Neuherberg, FRG
%PU Clin. Phys. Physiol. Meas., 1985, Vol. 6 No. 1,
%PU p. 65-74
%LA english
%NP 10p
%NR  0
%FT magnetic, electromagnetic
%FC 10Hz to 15Hz, 0.5T to 2T
%SM general health, cardiovascular effects
%SC public health, in-vivo exposure
%IA health risk, cardiac pacemakers, epilepsy, current
%IA density, nuclear magnetic resonance (NMR) systems,
%IA tomography
%SP humans
!
%FN 85501
%AU Fuhr G, Hagedorn R, Muller TH
%TI Cell Separation by Using Rotating Electric Fields
%DA 1985
```

See the figure on the following page for an example of a completed record.

Since the data base is stored as a text file, modifications and additions may be made using any standard text editor or word processor. Data may be easily transferred to other systems since the data base is not in any special binary format.

In order to provide immediate retrieval of data, it is necessary to index some of the fields that are frequently accessed when searching the data base. This is accomplished by using B-Tree indecies (an efficient file indexing scheme) on the file number, author, and keyword fields. In a file

15. File Number: 85529

Author(s): Guy AW

Title: Hazards of VLF Electromagnetic Fields

Publication Date: Mar 1985

Author's Affiliation: Ctr. for Bioengineering RJ-30 Washington Univ., Seattle 98195

Report Number: AGARD-LS-138, CONF-8504179-

Publication: Impact of Proposed RF Radiation Standards on Military Operations (Italy), Apr 11 1985

Language: english   No. Pages: 20   No. References: 47

Field Type: electromagnetic

Field Characterization: 50Hz, 60Hz, 350kV

Subject Categories: ELF field dosimetry, exposure standards, health effects, transmission lines

Subject Materials: health hazards, human health, shock hazards

Issue Areas: occupational exposure, public exposure, body current, spark discharge, field intensity, contact current

Species: humans

with 160,000 records, an indexed search would require at most five disk accesses, as opposed to sequentially reading the entire data base.

User Interface

The ELF Library Data Base User Interface is designed for ease of use and requires minimal learning time. A menu-driven interface is used to provide quick and easy access to all ELF data base functions, at a single keystroke. The main menu provides the following functions:

```
-- Data Base: rdl  ** ELF Bio-Effects Library **  main.menu --
      * ELF Bio-effects Library Data Base - Main Menu *
                   Enter one of the following:
                     S. Search Commands Menu
                     C. Change Working Data Base
                     A. Add Records to Data Base
                     L. List Entire Data Base
                     E. Expert Command Mode
                     Q. Quit Elf Bio-Lib
Enter Menu Option Letter -- (?=Help, !=Main Menu) ->
```

Options are selected by pressing the letter on the keyboard corresponding to the function on the menu. Entering "S" will display the search commands menu, "C" will allow the user to use a different database, "A" will allow the user to add records to the current database, etc. The search commands menu allows the user to access most of the fields in the ELF data base:

```
-- Data Base: rdl   ** ELF Bio-Effects Library **   search.menu --
        * ELF Bio-effects Library Data Base - Search Menu *
                     Search on the Following:
     N. File Number                  E. EM Field Type
     A. Author Name                  F. Field Characterization
     T. Title                        S. Species
     M. Subject Materials            D. Publication Date
     C. Subject Categories           I. Author Affiliation
     I. Issue Areas                  Q. Quit Search Menu
Enter Menu Option Letter -- (?=Help, !=Main Menu) ->
```

An expert command mode is provided for users who are more experienced and prefer a command-driven interface to a menu interface. Searches that do not appear on the search command menu may be performed using the command-driven interface.

Searching and Displaying the Data Base

When a search is performed on the ELF data base, all records that are found in the search are displayed in a summary display mode. In this mode, four records are displayed on the screen in summary format. Summary format consists of the file number, authors (two lines at most), and the title (two lines at most). The user may display the next page of four lines (or previous), display detailed data on a single record, print the detailed data of all records found in the search, return to the first record found in the search, or quit summary display mode. The top line of the screen displays the name of the data ase, the number of records found in the search, and the number of records remaining to be displayed:

```
-- Data Base: rdl    -- Records Found:  42 --    38 More --

      9. File Number: 85508
         Author: Mercer HD
         Title: Biological Effects of Electric Fields on
                Agricultural Animals

     10. File Number: 85509
         Author: Ioale P, Guidarini D
         Title: Methods for Producing Disturbances in Pigeon
                Homing Behavior by Oscillating Magnetic
                Fields

     11. File Number: 85510
         Author: Watkins JP, Auer JA, Morgan SJ, Gay S
         Title: Healing of Surgically Created Defects in the
                Equine Superficial Digital Flexor Tendon:
                Effects of Pulsing....

     12. File Number: 85511
         Author: ANONYMOUS
         Title: Safety of NMR

Enter: D(isplay 9-12), B(ack), F(orw.), T(op), Q(uit),
       P(rint), or ? ->
```

When the display option is entered, the user will enter the number of the record to display, and that record will be displayed with all of its fields. Since the record is usually too large to display on one screen, a single screen full is displayed at one time, with the file number, authors, and title always being displayed. The user can then toggle through the rest of the display, print the current record, or return to summary display mode:

```
-- Data Base: rdl    -- Records Found:  42 --   38 More --

  11. File Number: 85510
      Author: Watkins JP, Auer JA, Morgan SJ, Gay S
      Title: Healing of Surgically Created Defects in the
             Equine Superficial Digital Flexor Tendon:
             Effects of Pulsing Electromagnetic Field
             Therapy on Collagen-Type Transformation
             and Tissue Morphologic Reorganization
      ============

      Pub. Date: Oct 1985
      Auth. Aff.: Dept. Large Animal Med. and Surgery, Col.
                  Vet. Med., TX A&M Univ., College Station,
                  TX 77843
      Publication: Am. J. Vet. Res., Oct 1985, Vol. 46 No. 10,
                   p. 2097-2103
      Language: English
      No. Pages: 7 p
      No. Refs.: 43
      Field Type: pulsed
      Field Char.: 1.5Hz, pulse duration 90 µsec

---More--- <SPACE> or <RETURN> to Continue, Q to Quit:
```

```
-- Data Base: rdl    -- Records Found:  42 --    38 More --

  11. File Number: 85510
      Author: Watkins JP, Auer JA, Morgan SJ, Gay S
      Title: Healing of Surgically Created Defects in the
             Equine Superficial Digital Flexor Tendon:
             Effects of Pulsing Electromagnetic Field
             Therapy on Collagen-Type Transformation
             and Tissue Morphologic Reorganization
      ============

      Subject Cat.: healing effects, in-vivo exposure
      Subject Mat.: physiology and biochemistry,
                    cellular and extracellular effects
      Issue Areas: tendon injury healing, bone healing
      Species: horses, large mammals, livestock, agricultural
               animals

Enter P(rint Record, Q(uit, or <RETURN> to re-display:
```

Conclusion

This is just a brief description of the RDL ELF Library Data Base System. It does not encompass all of the systems capabilities. The system has been designed, developed, and implemented on RDL's Digital Equipment Corp. VAX 11/780 running the Unix 4.2bsd operating system. This is a multiuser system, which allows the data to be available to several users at once.

Overall, the system has provided RDL with an easy and efficient means of creating and maintaining a data base of ELF biological effects literature.

Chapter III

LITERATURE REVIEW, EVALUATION, AND ASSESSMENT

3.1. General Outline

The process of literature review, evaluation and assessment consists of two basic tasks:

1. Literature examination and review.

2. Literature evaluation and assessment.

At the outset, all the relevant citations are examined and their contents are summarized according to the following items:

- main objective of the article,
- description of the findings,
- reported bioeffects (if any),
- relevance to the ELF Communications System (ELFCS).

The articles relevant to the ELF Communications Program, and containing potentially new significant findings, are further evaluated and assessed. The results are summarized in the Evaluation and Assessment Summary Sheet, where specific items such as description of findings, evaluation and assessment, relevance to the ELFCS, field exposure conditions, and conclusions are addressed for each citation. The following example demonstrates an actual summary sheet used in the process of literature evaluation and assessment.

1. Author:

   Ottani V, Monti MG, Piccinini G, Pernecco L, Zaniol P, Ruggeri A, Barbiroli B

2. Title:

   Pulsed Electromagnetic Fields Increase the Rate of Rat Liver Regeneration after Partial Hepatectomy

3. Source:

   Proc. Society of Experim. Biol. & Med., Vol. 176, pp. 371-377, 1984

4. Description of the Findings:

   The effects of a pulsed magnetic field on the regeneration of rat livers was studied by combined electron microscopic and biochemical techniques. Rats were partially hepatectomized and then subjected to pulsed magnetic fields for 30 min immediately afterwards and at 12-hr intervals thereafter for periods up to 7 days post-surgery. The field waveform consisted of a major sinusoidal half-wave (50 Hz, 6 mT) followed by 4 cycles of a 400-Hz, 0.6-mT sine wave. Control rats were sham-exposed to the field. The authors reported that the pulsed magnetic field exposure promoted a more rapid regeneration of partially resected livers as compared to the controls. They observed rapid increases in the ornithine decarboxylase levels (an enzyme used as an early marker of cell growth) and in DNA synthesis (based on the incorporation of tritiated thymidine). Glycogen depletion and the accumulation of lipid droplets, both of which occur in partially resected livers, were found to be diminished in the animals exposed to a pulsed magnetic field relative to control rats.

5. Evaluation and Assessment:

This study appears to have been carefully performed with proper attention to the use of appropriate sham controls. It demonstrates that a high intensity pulsed magnetic field can favorably influence the rate of liver regeneration following partial hepatectomy. However, it should be noted that the pulsed magnetic field waveform was quite unusual, and has not been used in previous laboratory studies or in clinical trials to determine the effects of pulsed fields on the rate of bone fracture reunion. The authors also made no effort to determine the threshold magnetic field parameters that could influence the rate of liver regeneration.

6. Relevance to ELFCS:

The pulsed magnetic field waveform had 50-Hz, 6-mT and 400-Hz, 0.6-mT components. Both of these have substantially larger intensities than the 72- to 80-Hz, 14-μT maximum magnetic fields present in air in the vicinity of an ELF antenna. The results are therefore not directly relevant to ELFCSs.

7. Field Exposure Conditions:

Rats were exposed to a pulsed magnetic field produced by a large Helmholtz coil. The pulsed field consisted of a 50-Hz, 6-mT component (1/2 cycle) followed by a 400-Hz, 0.6-mT component (4 cycles).

8. Specific Comments on the Criteria for Scientific Merit:

This paper appears to meet the established criteria of scientific merit.

9. Conclusion:

The authors have demonstrated by morphological and biochemical criteria that a high-intensity, pulsed magnetic field with an unusual waveform can facilitate liver regeneration in partially hepatectomized rats. The fields used in this research had intensities that were about 50-500 times greater than the sinusoidal magnetic fields present in air near an ELF antenna, and the results are not of direct relevance to the issue of potential biological effects of the fields associated with the ELFCS.

3.2. Technical Consultants

As stated earlier, the main tasks of this program include ELF bioeffects literature search, document retrieval, literature review, evaluation, and assessment. consultants. The following expert consultants participated in the literature evaluation and assessment.

Dr. Robert G. Lindberg, Laboratory of Biomedical and Environmental Sciences, UCLA, Los Angeles, CA 90024

Dr. Asher R. Sheppard, J.L. Pettis Memorial Veterans Hospital Loma Linda, CA 92373

Dr. Thomas S. Tenforde, Biology and Medicine Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720

Dr. David A. Savitz, Department of Epidemiology, School of Public Health, University of North Carolina, Chapel Hill, NC 27514

All of RDL's technical consultants are well recognized for their research activities in the bioelectromagnetics area and for their active participation in various bioelectromagnetics related events such as symposia, conferences, meetings, etc.

3.3. Literature Characterization and Classification

In order to provide a convenient access to the ELF bioeffects library, the reviewed and evaluated citations are characterized based on exposure field type such as electric, magnetic, geomagnetic, etc., and field category, which is indicative of a particular features of an exposure field, such as frequency, strength, etc. In addition, all documents are classified by subject material, subject category, and issue areas.

The developed subject categories, subject materials, and issue areas are a continuation of those developed by NAS and AIBS. Moreover, these are modified and augmented as appropriate to accomodate scientific development. Clearly, such a thorough classification and characterization of the literature permits one to directly access all data strictly pertinent to a particular and narrow area of interest, avoiding unnecessary time-consuming searches.

3.4. Criteria for Scientific Merit

Since reviewed literature inevitably exhibits considerable quality variation, criteria were established to evaluate scientific merits for each individual citation, and these criteria were used as guides in the process of literature evaluation and assessment. They are:

- Definition of the problem investigated:

  The objective of a study must be defined clearly and rigorously.

- Definition of environment:

  A given experimental or observational report should include all relevant environmental factors such as noise, temperature, vibration, light, electromagnetic fields, and chemical agents.

- Experimental method and protocol:

  The experimental techniques used avoid or control factors such as noise, vibration, microshocks and chemicals.

  The effective ELF field, voltage, or current applied to the organism should be measured.

The experimental and observational techniques, methods and conditions should be objective. Blind scoring should be used whenever there is a possibility of investigator bias; likewise, data analysis should be objective.

A given experiment should be internally consistent with respect to the effects of interest.

The results should be quantifiable and susceptible to confirmation by other investigators.

A given experiment should be supplemented by a protocol describing experimental setup, duration and level of field exposure, equipment used, and all particular features that could affect the experimental outcome. In addition, protocol should include complete information on object(s) under investigation such as age, sex description of control sham-exposed groups, and other relevant data.

o Sensitivity analysis:

The sensitivity of the experiment should be adequate to ensure a reasonable probability that an effect would be detected if it existed.

When possible, threshold values should be estimated for field intensities and frequencies for which there are noticeable changes in bioeffects.

Maximally sensitive procedures should be employed whenever possible.

- Statistical design and analysis:

  Proper statistical techniques should be used to establish the outcome.

- Models employed:

  If models are used, it is necessary to assess the degree to which they simulate the geometrical and physical characteristics of the biological object.

  Models should be appropriate to the experimental objectives and technique.

- Result interpretation and assessment:

  Biological and engineering methodologies should be scientifically sound and appropriate for the experiment(s) or study.

  The information reported should be adequate to permit judgements on the conclusions reached.

Data analysis techniques should be clearly described.

The conclusions drawn should not be of a speculative nature or extend beyond the limits of the available data.

These criteria represent a modified and more comprehensive version of the criteria used by AIBS Committee members in 1985 report on biological and human health effects of ELF electromagnetic fields.

3.5. Letter Reports

There are four letter reports prepared during the period of November 1985-October 1987. The first two reports present new significant findings in the literature pertinent to ELF electromagnetic field-related bioeffects in epidemiology. These reports were prepared based on a thorough evaluation and assessment of two documents (detailed descriptions of the documents follow) by Dr. David Savitz, a recognized expert in the area of epidemiology.

The second two reports present the highlights of two scientific symposia, which took place in the same time period. Report No. 3 highlights the proceedings of the 1986 National Council on Radiation Protection and Measurements (NCRP) Annual Meeting, which took place in Washington, D.C. on April 2-3. Report No. 4 summarizes results of the 8th Annual Bioelectromagnetics Society (BEMS) Meeting held in Madison, WI on June 1-5. Both symposia were concerned with biological effects associated with nonionizing radiation.

Letter Report No. 1

Author:

Lin R.S., Dischinger P.C., et al.

Title:

Occupational Exposure To Electromagnetic Fields and the Occurence of Brain Tumors. An Analysis of Possible Association.

Source:

J. Occup. Med., Vol. 27, No. 6, pp. 413-419, 1985.

Description of the Findings:

White male Maryland residents who died from brain tumors during the period 1969-1982 were found to be employed more frequently in electricity-related occupations (electrician, electrical engineer, utility company servicemen) than were controls. Aggregation of jobs into definite, probable, and possible exposure groups indicated a gradient of risk consistent with ELF fields causing the excess risk. Brain tumor deaths occurred at a younger age among the exposed men.

Evaluation of Scientific Merit:

This is a very well-designed study relative to the previous literature on occupational exposure to ELF fields and cancer. The strengths are a large case group, review of the accuracy of death certificate diagnosis, and systematic and blind coding of exposures. The results were evaluated to ascertain the likelihood of a casual association, and the enhanced risk for "cleaner" brain tumor diagnoses and for more highly exposed occupational groups are consistent with a casual association. The primary limitation is the reliance on job title on death certificates and expert opinion to characterize exposure rather than any sort of direct or indirect measurements. Also, it seems that hypothesis concerning exposure to ELF fields and brain tumor risk was not established prior to the study.

Relevance to ELFCS:

The health effects of low-level exposure ELF fields constitute the exposure of interest in this study which should be qualitatively generalizable to exposures from ELFCSs.

Evaluation and Assessment:

This study suggests that occupations in which ELF field exposures are presumed to occur carry an elevated brain tumor risk. The data are certainly consistent with such a conclusion and no obvious methodological errors are present. The confidence in their being a casual relationship is diminished by the absence of evidence that such occupations really result in excessive ELF field exposures. Men in those jobs do seem to have an increased risk of brain cancer, but the firm conclusion ELF fields are the cause is not warranted.

Conclusions:

This study makes a credible argument that occupations presumed to produce ELF field exposures increase brain tumor risk. In spite of limitations in exposure assessment, this is a very important contribution to the literature on health effects of ELF fields and warrants further research. Relative to surveys of proportionate leukemia mortality by occupational title, the extra care in establishing accurate diagnoses and the presence of a risk gradient with increasing exposure makes this study stronger than any of the preceding occupational cancer studies.

Letter Report No. 2

Author:

Broadbent DE, Broadbent MHP, Male JC, Jones MRL

Title:

Health of Workers Exposed to Electric Fields

Source:

British J. Industr. Med., No. 42, pp. 75-84, 1985

Description of the Findings:

This paper reports on an exposure and health interview survey of 390 electrical power transmission and distribution workers. It was found that measured exposure above the threshold of 6.6 kV-h/m were quite rare (<10 of the subjects) and was notably less than estimated exposure. The measured and estimated exposures were examined in relation to numerous measures of physical health (physician visits, prescriptions, headaches) and mental health (anxiety, obsessional symptoms, somatic symptoms, depression) with no evidence of adverse effects of electric field exposures.

Evaluation and Assessment:

This is by far the most thorough and convincing study of this issue in the literature given the number of subjects, exposure measurement methods, and health measures. The absence of any association, in spite of a thorough analysis, suggests that within this exposure range there are no general health effects of ELF fields. As the authors note, higher exposures may be harmful or there may be an effect on health components not examined in the study, but the results of the Soviet literature on "neurasthenic" effects are effectively negated by this report.

Relevance to ELFCS:

The exposure to 50-Hz electric fields is directly relevant to the ELFCS.

Field Exposure Conditions:

50 Hz electric fields from electricity generation and distribution.

Specific Comments on the Criteria for Scientific Merit:

The methods are specified in detail, the data were thoroughly and properly analyzed, and the conclusions are quite consistent with the data. The study is of very high quality and described thoroughly.

Conclusion:

This excellent study provides important evidence that: 1) power company workers receive surprisingly little exposure to substantial electric fields; 2) the electric field exposures received do not affect general physical or mental health functioning. These conclusions are far more certain than that provided by earlier positive studies.

Letter Report No. 3: Summary of the Twenty-Second Annual Meeting of the National Council on Radiation Protection and Measurements

The 1986 National Council on Radiation Protection (NCRP) Annual Meeting was on the subjects of nonionizing radiation and ultrasound. This was the first time in 22 years that these topics were chosen as subjects for the NCRP annual meeting, as discussed by George Wilkening in his introductory remarks.

The first session on the morning of 2 April consisted of five talks on the physical interactions, biological effects, and exposure criteria for radio-frequency (RF) radiation (300 kHz to 3000 GHz). In the first presentation, A.W. Guy described the fundamental energy absorption processes for RF radiation. He described "resonance" phenomenon in which bodies with dimensions comparable to the wavelength of the incident electromagnetic radiation absorb a maximum amount of the radiation. For adult humans this peak absorption occurs at 70-100 MHz, and for rodents and other small laboratory animals it occurs at frequencies approaching 1 GHz. For children the resonance peak falls in the 100-MHz to 1-GHz range, depending on body size. The sharpness of the resonant absorption peak depends upon the polarization of the incident RF radiation relative to the long axis of the body. Guy also discussed the infrared thermography technique for studying radiation absorption and for locating "hot spots". Boundary layers between regions of differing dielectric properties were also discussed in terms of their effect on RF energy absorption patterns. Finally, the current state of knowledge of RF "burns", especially in the frequency region below 30 MHz, was described. Guy pointed to the severity of this potential problem and the need for more data on RF burns in the frequency ranges both above and below 30 MHz.

The second presentation was by Donald Justesen, who described selected results from his laboratory work of the past two decades. First he discussed some confusing data on the response of thermophilic bacteria to RF radiation. Two strains were studied, with differing and contradictory effects of RF radiation being observed on the growth rate of these two types of thermophilic bacteria. No interpretation was given of the data. The second topic discussed by Justesen was totally unrelated to RF radiation. Robert Smith, a student in Justesen's laboratory, observed that short-term exposure to 16-Hz magnetic fields results in a slight depression (-0.12°C) of the mean daily core body temperature in mice, as detected by FM radiotelemetry. Higher and lower frequencies of ELF magnetic fields had no effect, suggesting a "windowed" response in the frequency domain. No interpretation was given of these unexpected observations.

The third presentation was by M.E. O'Connor, who gave a summary of the literature on behavioral effects of RF radiation. She described some of the vast differences in the results of studies in Eastern European countries, where neurasthenic effects were reported at very low incident RF power densities (on the order of hundreds of microwatts per square cm), and studies in the United States, where behavioral effects have generally not been seen, except at relatively high power densities greater than 10 mW/cm^2. Some of the results described were those from the laboratories of deLorge and Justesen and from O'Connor's own laboratory.

The fourth talk was by W.R. Adey, who described the theories that he and his colleagues have developed over the last decade on mechanisms by which extremely weak electromagnetic fields can influence cellular and tissue functions. Many of Adey's studies have used RF carrier fields that are amplitude-modulated in the ELf frequency range. In the mid-1970's, Adey and Bawin observed changes in calcium ion release from binding sites at nerve cell surfaces during exposure to RF fields that were amplitude-modulated at frequencies in the range of 7-16 Hz. Higher and lower modulation frequencies led to no effect on calcium ion binding. Similarly, observations were made on windows in the field intensity in the range of power densities from 1-10 mW/cm^2. These observations were confirmed by work in other laboratories, notably that of Blackman at the EPA. Adey also described a number of more recent studies in which membrane surface receptors and cyclic adenosine monophosphate were implicated in the response of cells such as lymphocytes and osteoblasts to RF fields with ELF amplitude modulation. He described some new results on the effects of these fields on ornithine decarboxylase metabolism, which he speculated could influence the production of cancer promoters such as phorbol esters. He showed some intriguing new in vitro data on the enhancement of neoplastic cell transformation by a combination of x-rays, phorbol esters, and microwaves.

The fifth and last talk in this session was given by Edward Alpen, who presented a preview of the contents of the 450-page report recently completed by NCRP Committee 53 ("Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Radiation") after nine years of work. The committee generally accepted the frequency-dependent RF exposure standards recently proposed by ANSI Committee C.95. This standard imposes a limit of 1 mW/cm^2 on incident power density over the frequency range of 30-300 MHz, which encompasses the resonant absorption region for adults and large children. The 1-mW/cm^2 level is ten times lower than the preceding standard that was in force in the 1970's. The limit on power density increases for frequencies below 30 MHz (as $900/f^2$ with f in MHz) and above 300 MHz (as f/30) up to 1.5 GHz. Above 1.5 GHz a flat limit of 5 mW/cm^2 is imposed. In the low frequency range below 3 MHz, a flat 100-mW/cm^2 limit is imposed, but this limit may lie above the threshold field intensities that produce RF burns (as described earlier by A.W. Guy). For the public at large, the NCRP Committee 53 recommendation is that the limit on incident power density be five times lower than for occupational exposures.

The second session on 2 April was a series of four talks on ELF field interactions with living systems. The first talk by William T. Kuane was a review of the fundamental physical principles underlying the dosimetry of ELF field interactions in humans and laboratory animals. He described the mechanisms by which a living object acquires a large surface charge in an external high-voltage electric field, while the internal field below the skin is attenuated by a factor of about 10^7 relative to the external field intensity. He also described field enhancement effects that led to large increases in the local field near parts of the body with small radii of curvature (for example, the local field at the top of the head is enhanced by approximately a factor of 20 relative to the electric field at a distance of several meters from the head). Conductive models of the human body have been used successfully for direct measurements of internal fields and current densities by several techniques, including those developed by Guy and by Kaune. He also described the internal field and current distributions resulting from exposure of humans to ELF magnetic fields. Kaune has used the "impedance network" approach of Gandhi to model the current distributions in the body, and finds a build-up of current in the groin and axillary regions similar to that found with ELF electric field exposure.

The second talk in the ELF session was by H.B. Graves, who gave an overview of ELF electric field bioeffects. He presented a summary of areas where there are established bioeffects, and areas in which it is now established that there are no effects. Several areas in which there is general agreement in the literature that biological effects result from the exposure of animals to high-voltage ELF electric fields include: (1) behavior (field perception and adaptation), (2) circadian rhythms (in pineal melatonin production), (3) nervous system (excitability of synapses in cervical ganglia), (4) hormone levels (increased steroid hormone levels indicative of stress), and (5) bone fracture repair. Graves also discussed the current controversy over the issue of whether human exposure to ELF electric and magnetic fields leads to an increased cancer risk. He also listed approximately 20 areas in which no clear biological effects have been observed as a consequence of ELF electric field exposure, including hematology, immunology, fertility, growth and development, and genetics (including mutagenesis).

The third talk in this session was by Thomas Tenforde, who described the interaction mechanisms and bioeffects of static and ELF magnetic fields. For static fields, the three primary mechanisms of interaction that have been demonstrated in careful laboratory studies are: (1) electrodynamic interactions (e.g., the induction of electrical potentials in the blood circulation); (2) magnetomechanical effects (e.g., the orientation of retinal rod outer segments in fields of 0.5-1.0 Tesla, and the translation of paramagnetic and ferromagnetic substances in strong magnetic field gradients); and (3) effects on electronic spin states in certain classes of charge transfer processes (e.g., the transfer of a photoexcited electron in photosynthesis). For time-varying fields in the ELF frequency range, the initial interaction involves the induction of electric fields and currents in tissue in accord with Faraday's law of induction. A growing body of evidence indicates that these induced currents exert secondary effects on cell membrane structures through one or more physiochemical processes, the exact nature of which have not as yet been elucidated. Tenforde described several well-established biological interactions of static and ELF magnetic fields with living organisms, including (1) the downward swimming movement of magnetotactic bacteria in response to the geomagnetic field; (2) the electromagnetic guidance system of elasmobranch fish (sharks, skates, and rays); and (3) the induction of a flickering illumination in the eyes of human subjects exposed to pulsed and sinusoidal ELF magnetic fields at intensities above 10 millitesla. He also summarized the relatively large number of tissue and organ functions in mammals that have been shown not to be affected by static magnetic fields in the range of 1-2 Tesla. Tenforde also discussed several areas of future research on static and ELF magnetic fields, including (1) studies of chronic exposure effects on the cardiac and central nervous systems; (2) studies on cell, tissue, and visual systems exposed to ultrahigh fields with intensities up to 10 Tesla (of interest in future medical imaging and in vivo spectroscopy based on magnetic resonance with static fields in the 2-10 Tesla range); and (3) mechanistic studies on the cell membrane substrates that have been implicated as possible targets for ELF field interactions. He closed his talk with a brief discussion of six applications of magnetic fields in medicine and biological research: (1) magnetic resonance imaging and in vivo spectroscopy, (2) the use of SQUID gradiometers for recording endogenous magnetic fields associated with the electrical activity of the brain and heart, (3) electromagnetic blood flow measurements, (4) the use of pulsed magnetic fields to facilitate bone fracture reunion, (5) magnetic separation techniques for biological materials, and (6) magnetic circular dichroism spectroscopy for in vivo studies of DNA secondary structure.

The fourth presentation was the Tenth Lauriston S. Taylor Lecture, given this year by Professor Herman P. Schwan on the subject of cellular interactions with electromagnetic radiation. He began with a discussion of the dispersion properties of tissue conductivity and dielectric constant as a function of the applied electromagnetic field frequency. He summarized the basic physical phenomena that underlie the alpha, beta, and gamma dispersions in the frequency ranges of <1 kHz, 10 kHz-10 Mhz, and >10 MHz, respectively. The gamma dispersion is associated with tissue water, the beta dispersion with the polarization of cellular membrane structures, and the alpha dispersion with counterion relaxation phenomena and changes in the electrical properties of cell membranes. As a result of these relaxation mechanisms, the dielectric constant of living tissue exhibits stepwise decreases as the electromagnetic field frequency increases, while the electrical conductivity exhibits stepwise increases. Schwan then proceeded to describe the coupling of electromagnetic fields to tissue and cellular structures as a function of frequency, including effects on cell membrane potentials. Finally, he discussed the biophysical basis of electric field force effects on cells, including orientation effects, dielectrophoresis (movement in electric field gradients), deformation, rotation, vesicle ejection, protoplasmic streaming, and cell fusion in high fields.

In the final scientific session on the morning of 3 April, the discussion of magnetic field effects was continued with a presentation by Thomas Budinger on safety and hazard evaluation in magnetic resonance imaging (MRI). Budinger began with a brief presentation of the physical principles of MRI and certain unique features of MRI relative to other imaging modalities. He also described the rationale for considering the use of static fields with intensities as high as 10 Tesla for in vivo spectroscopy, namely, the increased signal-to-noise ratio that would be achieved and the cleaner separation of resonance peaks due to an enhanced chemical shift. He described the need for biophysical studies on cardiovascular dynamics and nerve impulse conduction during exposure to these ultrahigh fields. Budinger discussed the epidemiological studies on human populations exposed occupationally to high magnetic fields (including his own study on 792 workers at accelerator facilities and a matched control group), and concluded that there was no evidence for adverse health effects at field levels up to about 1 Tesla. He next discussed time-varying magnetic fields that result from rapid switching of the static magnetic field gradients used for spatial localization of magnetic resonance signals. Very large time variations, on the order of 10^4 Tesla/sec, are required to influence the bioelectric properties of nerves and to produce neuromuscular stimulation. Budinger also described preliminary studies with rodents that indicated no adverse effects of rapidly time-varying magnetic fields on fetal development and growth. In the final subject covered in his talk, Budinger discussed the biological effects of the RF fields used in MRI, with frequencies below 100 MHz in the present generation of imaging units. He reviewed the issue of tissue heating, and the ANSI Committee C.95 whole-body exposure limit on absorbed power of 0.4 W/kg (or 2 mW/g for any gram of tissue). The present MRI exposure guidelines in the United States and Britain are consistent with this limit, whereas the whole-body limit in the West German guidelines is 1 W/kg (or 5 W/kg per kilogram of tissue except for the eyes). Budinger concluded his presentation by noting that the United States guidelines for MRI exposure to static fields (2 Tesla upper limit) and time-varying fields (3 Tesla/sec upper limit) were reasonable in the context of our present knowledge of potential health effects.

The final four talks on the morning of 3 April were on the subject of ultrasound, and consisted of 20-minute presentations on the dosimetry, medical uses, biological effects, and exposure limits for ultrasound. The first talk was by Paul Carson, who summarized the four known mechanisms through which ultrasound with frequencies of 1-10 Mhz (as used clinically) can interact with living tissues: (1) thermal effects, (2) direct field interactions, (3) force effects on molecules and cells, and (4) cavitation. Carson also described the various parameters used to characterize the absorbed power from ultrasound. These parameters include: (1) I_t = (total time-averaged acoustic power)/(transducer area); (2) I = time-averaged intensity for a CW plane-wave field = $p_o^2/2\rho c$, where p_o = pressure amplitude, ρ = tissue density, and c = velocity of sound in tissue; (3) i = instantaneous acoustic intensity = $p^2/\rho c$, where p = instantaneous acoustic pressure; and (4) I_m = $p_m^2/2\rho c$ = maximum intensity calculated over the largest half-cycle of the pressure wave form. The use of the parameter I_m is advocated by the NCRP. Carson also described the two frequently used conventions for calculating time averages of the intensity: (1) I_{SPTA} is based on the temporal average of p^2 at the spatial peak, and (2) I_{SPTA} is based on the temporal average calculated over a single pulse, which is used specifically for pulsed ultrasound sources.

The second talk in this session was by Marvin Ziskin, who described the many applications of ultrasound in medical diagnosis and therapy. Among the topics that he covered were (1) fetal monitoring devices, both for short-term and long-term observations; (2) pulsed sources for cardiac monitoring; and (3) pulsed and CW units for peripheral vascular monitoring by the Doppler ultrasound technique. He related diagnostic and therapeutic exposures to the American Institute of Ultrasound in Medicine standards, which provide limits on I_{SPTA} in tissue (or water) to the dwell time of the ultrasound exposure in seconds. Ziskin also described various clinical surveys on fetal monitoring with ultrasound in which the incidence of fetal abnormalities was recorded. For the largest sample size of 4500 studied to date, it can be concluded that the increase in the incidence of fetal abnormalities as a result of ultrasound scanning is less than 0.5 percent above the normal incidence level of 4.3 percent. The actual risk may be much less, but a significantly larger sample size than studied to date would be required to define a lower level of risk. Ziskin also discussed a large clinical study completed in 1972 involving 121,000 patients examined by ultrasound, in which no obvious adverse effects were noted.

The third talk on ultrasound was by Floyd Dunn, who discussed thermal and nonthermal mechanisms of ultrasound damage to biological tissues. Many of the laboratory studies with rodents have reported effects such as fetal abnormalities to arise only when the intensity of the ultrasound waves produced temperature elevations greater than 1°C.

Various nonthermal responses, i.e., at ultrasound intensities below levels that produce tissue heating, were also discussed. These effects include auditory (sensory) responses, pearl chain formation by red blood cells, and acoustic cavitation effects on trapped gases in tissue.

The final talk on ultrasound was by Wesley Nyborg, who discussed exposure recommendations. He described risk versus benefit considerations and the difficulties in quantitatively predicting thresholds for ultrasound damage. Nyborg described the AIUM (American Institute of Ultrasound in Medicine) recommendations that the I be limited to 100 mW/cm^2 for dwell times greater than 500 seconds, or that the product of I_{SPTA} and the dwell time be less than 50 J/cm^2 for dwell times less than 500 seconds. These recommendations limit tissue heating to less than 1°C in most circumstances. Diagnostic ultrasound techniques are generally well below the AIUM limits, while therapy procedures involving ultrasound are usually close to, or slightly above, the AIUM guideline. An example of treatments using ultrasound at intensities well above the AIUM guideline (as much as 100 times greater) is the therapy of focal lesions in organs such as the brain, eye, liver, and kidney. Nyborg concluded his talk with a discussion of cavitation effects, which can in some situations pose risks of tissue damage that are difficult to assess. He illustrated his remarks with a brief movie showing the cavitation of gas bubbles in plant cells during one-minute-"on"/one-minute-"off" exposures to ultrasound at progressively greater intensities. At the highest ultrasound intensities, extensive movements of components within the cell cytoplasm were seen, and the cell membranes eventually ruptured.

Letter Report No. 4: Summary of the Eighth Annual Bioelectromagnetics Society Meeting

The objective of this letter report is to highlight the proceedings of the 8th Annual Bioelectromagnetics Society meeting and also to report on any new significant findings relevant to biological and health effects of nonionizing electromagnetic radiation, primarily in the 1-300 Hz frequency range, germane to the Navy's ELFCS. The 8th Annual BEMS meeting was held at the University of Wisconsin, Madison, Wisconsin, on June 1-5, 1986.

The following report summarizes ELF bioeffects and dosimetry research activities presented at the 8th Annual BEMS meeting. The report includes only selective presented papers, which in our view, are most relevant to the ELFCS; however, full review, evaluation and assessment of all papers fitting the criteria supplied in the Statement of Work will be provided separately in the upcoming monthly progress reports. Selection of the following papers was done by Drs. Tenforde and Tatoian, both of whom participated in the meeting.

The opening session on "New Directions in Bioelectromagnetics" consisted of the presentation by Eberhard Neumann, who focused on interaction between membranes and electromagnetic fields. Neumann indicated that the experimental data on isolated membrane fragments suggest that the membranes along with the regions adjacent to the membrane surfaces are the targets of direct electric field effects. Theoretical studies reportedly show that the membranes and surface compartments are amplification units for the transformation of small external potentials (mV, V) in major changes (kV/cm) of the natural electric field (50-100 kV/cm) of the membrane. In addition, it was suggested that a superimposed external field does not primarily affect the electric part of the driving force (electrochemical potential) rather, induced ion accumulation increases the concentration gradient (e.g. for Ca^{2+}) which leads to an increase in the transport rate.

Session B consisted of four talks. The first presentation was by Howard Wachtel, who studied the ELF electric and magnetic field data from approximately 600 households. This study reportedly indicates (1) a correlation among the magnetic fields in different rooms within the population of houses studied ; (2) a wide dispersion of magnetic field intensities between different houses; (3) a similarity in the statistical distribution of magnetic fields under "high power" and "low power" conditions, and (4) no correlation between the average magnetic field and the level of "high power" used. The results suggest that the component of the field in a house adds to externally generated components, so that the average residential ELF field is determined mainly by outside sources.

The second presentation was by Frank Barnes, who examined the correlation between 60-Hz residential magnetic fields, transmission lines, and wiring configuration and calculated values of the magnetic field for expected transmission line currents. The initial results showed the same order between wiring classifications and the average measured values with high field configuration homes having the greatest average measured values; however a wide spread in the data is indicated.

The third presentation was also by Howard Wachtel. He discussed preliminary results of a study on the potential association between exposure to residential EM fields due to power distribution lines and risk of childhood cancer. The study consists of many phases. Interviews with residents and field measurements have been completed, but data analysis is still in progress. Subgroups of cancer cases to be analyzed include leukemia, brain tumors and lymphomas. No conclusive results were reported.

The fourth presentation was by John Zapotosky, who introduced an ecological program, funded by the Department of the Navy, to determine possible adverse bioeffects of the Navy's ELFCS on biota residing in the vicinity of the system. Biota being examined included: upland flora, soil microflora, slime molds, soil amoebae, soil arthropods, earthworms, pollinating insects, small mammals, birds, wetland flora and aquatic organisms. The program reportedly focuses on ecological studies and also includes monitoring for possible in situ organismal effects. Basic operational characteristics of two transmitters, one in Wisconsin and the other in Michigan, of the communications system were discussed. Preliminary reports indicate the absence of a consistent pattern of bioeffects from exposure at the Wisconsin antenna, which has been operational since 1969. Evaluation of a fully operational ELF system is planned for both sites.

Session D entitled "Interaction Mechanisms" consisted of four presentations. The first speaker was C.H. Durney, who has calculated the electromechanical response of a particle with an effective mass m and effective charge q and viscous damping using the Lorentz force term in the equation of motion. Analyses were restricted to very low frequencies. The applied field consisted of dc-ac magnetic fields and the electric field induced by an ac magnetic field. Solution of the equation exhibited helical motion for the particle, with strong resonance near the cyclotron frequency (qB/m), which, in the author's view, may correspond to the frequency windows observed experimentally. In addition, strong dependence on ac magnetic components suggests the relation to the amplitude windows.

The second presentation was by A. Chiabrera, who used the analytical model to study electric and magnetic field effects on ligand binding. It is assumed that in a hydrophobic environment, a charged ligand (ion, lectin, hormone) is drifted by the Lorentz force with no collisions with water molecules. The numerical integration of the Langevin equation has been performed for various field frequencies. The solutions were grouped into typical sets, which reportedly provide explanation of some experimental data.

The third speaker was Charles Polk, who examined the effect of magnetic field ramp functions on charge density at the cell surface. Experiments with cells embedded in a homogeneous fluid of "large" dimensions (dish radius

> 5 cm) and in small liquid drops (radius ~1 mm) showed that the rise or decay time of the charge density is primarily determined by the electrical conductivity and dielectric permittivity of the cell and the surrounding medium; however, the magnitude of charge density depends on the shape, size, and electrical properties of the surrounding environment.

The fourth presentation was by Bruce McLeod, who presented a method for an estimation of the magnitude of the damping factor for biological ions in low frequency electromagnetic fields. The damping modified conductivity tensor and the expression for the energy absorbed by ions under the influence of electric and magnetic fields are derived. One of the conductivities shows a resonance, where the resonance peak position is set by the ion charge to mass ratio q/m and the magnitude of the dc component of the magnetic field. The width of the resonance curve is reportedly controlled by the damping factor. By adjusting the value of the damping factor (using matching with experimental curves), an estimate for a mean collision time was obtained in the neighborhood of 23 msec.

Session F consisted of eight presentations, the last six of which will be highlighted here. The third talk was by Thomas Tenforde, who have introduced a power-frequency magnetic field personal dosimeter with data acquisition capabilities. The developed microprocessor-controlled dosimeter was designed to measure 60-Hz fields with an intensity range of 2 nT-60 μT. A digitized resolution of 0.25 nT is provided in the 2-nT to 1-μT range, and a 0.15-nT resolution in the 1-μT to 60-μT range. Contamination of the fundamental 60 Hz signal by harmonic fields is reported to be less than one percent.

The fourth presentation was by W.T. Kaune, who focused on induction of currents in animals and humans by ELF magnetic fields. The author used the so-called impedance-network method to calculate current densities induced by ELF magnetic fields in horizontal and vertical sections through the oodies of humans, rats, and swine. It was observed that current densities induced in humans and animals are highly nonuniform. Current enhancements were predicted in the neck area, axillae, and lower pelvic region. Current densities induced in rats and swine are reported to be much smaller than in humans.

The fifth presentation was by H.R. Chuang. His topic, "Interaction of ELF-LF Electric Fields With Human Bodies and Metallic Objects", dealt with the results of numerical calculations for quantifying the interaction of ELF-LF electric fields with a realistic model. The numerical method is based on the surface charge integral equation, and is reportedly both efficient and accurate. The developed method has been extended to determine the open-circuit potential and the short-circuit current induced in a human body with arbitrary posture and in metallic objects such as vehicles in the vicinity of a power transmission line. Possible shock currents were analyzed by using equivalent circuits.

The sixth talk was by D.L. Lessor, wh. presented a three-dimensional finite difference computation of electric current densities in inhomogeneous biological specimens from ELF fields. The computer code used a line successive over-relaxation. Current densities were reported to be higher in tissues of higher conductivity, contrary to the near uniformity reported from some modeling formulations. The author indicates that total currents through body cross sections are fairly insensitive to conductivity inhomogeneities and that they agree with measured values.

The seventh talk was by P.J. Dimbylow, who presented a method of calculation of current densities. The method is based upon the general analysis of properties of the interaction between animals and ELF electric fields by Kaune and Gillis (paper that appeared in Bioelectromagnetics in 1981). The field outside the body is obtained by solving Laplace's equation for the scalar potential. The solution for a perfect conductor is then related to actual tissue conductivity values to obtain the potential at the inner surface of the phantom. An iterative finite difference method was used in solving Laplace's equation. Values of current densities and short-circuit currents were presented and a comparison was made with some experimental values in a case of exposure to 60-Hz electric fields.

The eighth speaker was Koichi Shimizu, who presented a paper on the measurement of ELF electric field at biological body surfaces. The effect of using a thin and flexible field sensor was studied. The sensor was fixed at the top of a curved body which was part of conductive cylinder. The measurement results were then compared with theoretical calculations. In addition, Shimuzu reported on development of a new technique to reduce measurement error caused by field enhancement due to the sensor edge.

Session I entitled "ELF In Vitro Studies" had seven presentations (the presentation by R. Goodaman and A. Henderson was cancelled). The first talk entitled "60-Hz AC Electromagnetic Fields: Cellular Studies" by J. Reese presented systems for exposing cultured cells to 60-Hz electric and/or magnetic fields. Initial studies characterized these systems, and the conditions necessary for optimal cell growth were established. Presently the author's interest is in detecting any effects on growth and metabolism, differentiated cell function, cell transformation rates, and mutation frequencies. Indicator cells were selected for specific attributes allowing for membrane study, nuclear and cytoplasmic events that might be altered by EMF exposure. The results indicate that exposure to 10-V/m electric fields or 20-Gauss magnetic fields alone do not effect cloning efficiencies of CHO cells. Additional experiments reportedly show no significant differences in growth rate of either NIH 3T3 or CHO cells grown in 20-Gauss fields.

The second presentation was by A. Sheppard, who studied the interburst interval (IBI) of burst-firing Aplysia ganglion neurons (bursters) exposed in vitro to electric fields at 2 and 60 Hz over the range 0.025-10 mV/cm rms. The 60-Hz H-field-induced E-fields were at most 0.05 mV/cm rms in the shallow conducting medium. The results suggested that either bursting cells were more sensitive to weak E-fields or that the H-field was more potent. Ten minutes of exposure to E-fields of ascending strength showed long IBIs and/or changes in slope of IBIs versus time for both 2- and 60-Hz E-fields. The authors concluded that 1) burster E-field sensitivity can account for H-field observations; and 2) generally, bursters are more sensitive than beaters.

The third presentation was by C. Franceschi, who studied EMF effects on response to PHA of human lymphocytes obtained from: ten normal young doners, ten far aged normal donors, one homosexual man with LAS, and one subject with myotonic dystrophy and his five siblings. The lymphocytes from aged, LAS, and myodystrophic donors shared an impaired response to PHA. Peripheral blood lymphocytes were stimulated for three days and pulsed with 3H-thymadine for the last 6 hours of incubation at 37 °C. The cultures were exposed for 72 hours to 50-Hz, 2-mV pulses with impulse width of 3.3 msec. PHA concentrations of culture medium were tested. A stimulatory effect of the EMF was evident at PHA concentrations of 5 and 10 ul/ml in young donors and at 1,5 and 10 ul/ml in aged donors. A significant increase was evident testing the LAS donor's lymphocytes. In the case of the myodystrophic patient the increase was significantly higher than in his siblings. Data suggests that the effect of EMF is higher at optimal and high PHA concentrations and when the basal responsiveness to PHA is decreased.

The fourth talk was by D.B. Lyle, who examined the effect of a 60-Hz sinusoidal electric field (SEF) on the cytotoxicity of the murine normal lymphocyte cell line CTLL-1 against a specific allogeneic cancer target cell, MPC. No effect was reported at a field strength of 10 mV/cm applied only during the 4-hr cytotoxicity assay. Proliferation of CTLL-1 cells over a 48-hr period in response to the specific growth factor IL-2 was also unaffected by the SEF; however, when the 4-hr assay was conducted after a 48-hr pre-exposure, cytotoxicity was significantly reduced. Presently the author is actively involved in the field strength threshold determination using a weaker field. The obtained results, reportedly "... raise the possibility that sinusoidal electric fields might interfere with some immune cancer surveillance mechanisms.

Speaker number five was R. Cadossi from the University of Modena, Italy. Cadossi studied the effects of low frequency pulsing electromagnetic fields (PEMFs) on the response to the lectins of human normal and pathologic lymphocytes. PEMFs used consisted of a 75-Hz, 2.8-mT pulse train with an impulse width of 1.3 msec. Induced voltage ranged from 0.5 mV to 10 mV. The results of experiments indicate increase in lymphocyte response to the lectin stimulation in the different lymphocyte samples tested ($p < 0.01$). The author believes that the effect is at least in part mediated by release of soluble B-cell growth factors. The experiments suggest the presence of window effects, and that some values (i.e., 10 mV) inhibit lymphocyte response to lectins. An additional result reportedly shows that PEMFs favor lectin-induced proliferation.

The sixth talk was by A. Carsten, who investigated the possible induction, by exposure to 60-Hz electric and magnetic fields, of 1) dominant lethal mutations (DLMs); 2) multigeneration (MG) effects, as made evident by litter size, sex ratio, survival, and growth over three generations; and 3) the induction of bone marrow sister chromatid exchanges (SCEs) and retardation of average cell generation time (AGT). There were three identical exposure facilities operated at (0,0), (15,3), and (50,10) (kV/m, Gauss). DLM data showed no significant effects from EM exposure on the number of viable embryos, early or late embryonic deaths, or preimplantation loss. MG data studies on date of birth, litter size, sex ratio, weight gains and mortality also showed no obvious effects from EM fields. All SCE and AGT data analyses revealed no significant effect.

The seventh presentation was by W.D. Winters, who studied virus suppressor factors induced in cultured cells by exposure in vitro to 60-Hz AC magnetic fields. Sensitive host cell and virus assay systems were used to detect effects of exposures to uniform 60-Hz, 1-Gauss magnetic fields on virus infections. The author reported induction of a state of significant cellular resistance to virus challenge by Andenovirus type 5, Herpesvirus type 1, Coxsackievirus B3, and Vesicular Stomatitis Virus. In addition, the authors observed induction of the production of substances which suppress virus infections when transferred to unexposed cells. In vitro exposures lasted at least 24 hours.

Although the eighth talk by R. Goodman was cancelled, it seems that a brief description of the scheduled presentation, which is given in BEMS abstracts, should be made. Goodman's study reportedly analyzed data from a two-dimensional gel electrophoresis of polypeptides from Csiara salivary gland cells exposed to three types of pulsed asymmetric EM signals, as well as symmetric sine waves at 60 and 72 Hz. The author observed both quantitative and qualitative changes in the translational patterns of cells exposed to EM fields. Moreover, differences in the profiles of polypeptides are also reported. Three polypeptides found in exposed cells overlap those seen in cells following exposure to heat shock. The suppression of protein synthesis, however, was not observed in exposed cells. The heat shock proteins were found in addition to a large number of new and augmented polypeptides.

Session K was entitled "ELF Bioeffects In Vivo", and it consisted of six papers. The first presentation was by C. Blackman, whose paper entitled "Effect of Power-Line-Frequency Electric Fields on a Developing Organism" presents results of Gallus eggs exposure during their 21-day incubation periods to either 50-Hz or 60-Hz sinusoidal electric fields with an average intensity of 10 V/m. Cross-contamination between 50 and 60 Hz was below 45 dBV. Within 1.5 days after hatching, the chicks were removed from the apparatus and tested. The test consisted of examining the effect of 50- or 60-Hz electromagnetic fields at 15.9 V/m and 73 nT on efflux of calcium ions from the chick's brain tissue. For eggs exposed to 60 Hz electric fields during incubation, the brain tissue, reportedly showed a significant response to 50-Hz fields, but not to 60-Hz fields. In contrast, the brain tissue from chicks exposed in ovo to 50-Hz fields did not respond in a significant manner to either 50- or 60-Hz fields. The author suggests that exposure of a developing organism to ambient in-door levels of power-line frequency electric fields can alter the response of brain tissue to radiation-induced calcium-ion efflux. Blackman indicates that the physiological significance of his finding has yet to be determined.

The second talk was by W.J. Quinlan, who studied neuroendocrine response of cannulated rats to intermittent 60-Hz electric fields. Male Long-Evans rats were exposed to a 60-Hz, 80-kV/m electric field with 5-sec duration time and 30 sec intervals. Sequential sampling of blood from an undisturbed cannulated rat before, immediately after, and 15 minutes following exposure reportedly provides information on the beta-endorphin, prolactin, adrenocorticotropin (ACTH), and corticosterone response to intermittent electric fields. Results on the neuroendocrine response of rats to a known current stressor of 0.4, 0.8, and 1.6 μA will be presented in the future.

The third presentation was by John L. Orr, who studied threshold intensity for detection of 60 Hz electric fields. Using operant conditioning techniques, six baboons were trained to report the presence or absence of an electric field using an interface of three sensors. Psychometric functions for individual animals reportedly decreased monotonically with decreasing field strength. In January 1986, a field intensity of 32 kV/m supported highly accurate responses. The average detection threshold for baboons was 18 kV/m, and the range was 8-28 kV/m. More research in this area is in progress.

The fourth speaker was Richard Lovely, whose study was to identify the site of action of food and electric field aversion for rats exposed to 100-kV/m 60-Hz electric fields. Specifically, the role of rat's eyes, ears, vibrissae, and other body hair was evaluated. Apriori orthogonal comparisons on the combined data for the groups with altered facial features, such as removal of eyes, ears or vibrissae, revealed that altered facial features are a significant source of variance ($p=0.017$) in the rat's aversion of saccharin-flavored food placed in an intense 60 Hz electric field.

The fifth presentation was by Walter R. Rogers, who examined the aversion of electric fields by baboons. Six baboons were trained to press illuminated manipulandum to turn off a 60-kV/m electric field and cue light in order to receive a food pellet. Then the ability of three stimuli to control operant responding were investigated using a Latin square design. Presence of a 60-kV/m field did not affect appetitively motivated response, and termination of the electric field could not maintain responses in the absence of food rewards. Similar results were reported at 73 kV/m. The data suggest that electric fields might slightly increase resistance to extinction. The author concludes that apparently these relatively intense fields are not very averse to nonhuman primates.

The sixth paper was delivered by J. Silny from the Helmholtz Institute fur Biomedizinische Technic, Federal Republic of Germany. Silny studied short-term effects of a strong magnetic field in the range of 5-10000 Hz on the living organisms, including humans. An induced electric field in the inhomogeneous volume conductor was calculated using the finite element method. The first experiments were conducted on rats to study their behavior under 50-Hz, 20-mT exposure lasting one week. The stimulation threshold of the heart in dogs for 50-Hz and 1-kHz exposures was also investigated. Author reported on conducting more than 100 experiments in a magnetic field (100 Hz, $B < 100$ mT) in the head region, or in the magnetic field (50 Hz-10 KHz, $B < 4$ T) in the extremities. The stimulation thresholds of the nerves and muscles, and above all in the heart lie, reportedly, in the range of several 100 mT to some T magnetic induction.

A special symposium entitled " Joint Bioelectromagnetics Society Bioelectromagnetics Symposium", which was held on Thursday (June 5) morning, had six presentations, four of which will be highlighted here. The first speaker was A.A. Pilla, and the topic of the presentation was "In Vivo and in Vitro Dosimetry of Pulsating Electromagnetically Induced Current". Pilla discussed the characterization of electric fields and current densities induced by pulsating magnetic fields (PMF), both in vitro and in vivo. A review was given of prior work on characterization of the electrical response to PMF in plastic culture dishes containing physiological saline. The effect of living cells on the induced current was evaluated using cell impedance data. A theoretical model was proposed for this characterization and was empirically verified. Real-time measurement of the PMF induced current was obtained using a specially constructed porous tantalum electrode probe. Using available data on dielectric constants for different types of tissue, estimates of the current densities within the tissue were obtained.

The fourth presentation was by M. Blank, who studied concentration changes at sodium channels due to oscillating electric fields. Blank has presented the Surface Compartment Model (SCM) of membrane transport, derived from the first principles and taking into account ionic processes in the electrical double layers of membranes. Under a voltage clamp, the SCM yielded the currents shown by either sodium or potassium channels of squid axon. Oscillating voltages of various frequencies were applied to the sodium channel model and frequency-dependent ion concentration changes were obtained. The greatest changes were observed in those concentrations that normally control the activity of the ion pump, internal sodium and external potassium. The optimal frequency was around 200 Hz. The results indicate that: (1) the ionic currents in excitable membranes can be described by electrodiffusion theory; (2) the selectivity of an ionic channel is due to the kinetics of channel opening; and (3) the transient ion concentration changes due to oscillating fields provide the outline of a physical mechanism for the functioning of "ion pumps".

The fifth talk was by D.B. Jones, who presented the results of a study to determine low frequency electromagnetic field effects on cAMP and cAMP dependent protein kinase activity in melanoma cells. Low frequency EMF was shown to induce differentiation in Cloudman melanoma cells, as monitored by the activity of the rate limiting enzyme in melanin biosynthesis, tyrosinase. Reportedly, this induction is similar to the natural regulatory hormone, melanocyte stimulating hormone (MSH). Applied EMF signals consisted of 21 pulses having 200-μsec main and 20-μsec opposite polarity duration, respectively. The burst was 5 msec long and repeated at 15 Hz. The rate of change of the magnetic flux (dB/dt) was measured to be 0.1 Gauss/μsec, corresponding to an induced electric field of 1 mV/cm. The early response of melanoma cells showed a decrease in the cAMP protein kinase activity. Addition of MSH stimulated both cAMP and cAMP-dependent protein kinase activity by five-fold. When MSH and EMF were applied simultaneously, a decrease in the later parameters was observed, suggesting an inhibition of the MSH stimulation. To further verify these results, the authors added NaF. The EMF again inhibited the NaF stimulation, indicating a possible inhibition of the receptor-cyclase signal at the level of the GTP binding regulatory protein.

The sixth paper was delivered by J.T. Ryaby, who has studied the effects of low frequency electromagnetic fields on protein phosphorylation and synthesis in melanoma cells. Electromagnetic field stimulation has been shown to induce differentiation in melanoma cells. The EMF consisted of a 5-msec burst containing 21 pulses having 200-μsec main and 20-usec opposite polarity resulting at 15 Hz. dB/dt in the main polarity was 0.1 Gauss/μsec, which corresponded to an induced electric field of 1 mV/cm. 32PO4 and 35S-methionine labeled proteins were analyzed by one- and two-dimensional electrophoresis and subsequent autoradiography. The results showed quantitative differences between control, melanocyte stimulating hormone (MSH-) and EMF stimulation. At 5 min, both EMF and MSH decreased phosphorylation of 60- and 75-kilodalton (kd) protein class, the increase phosphorylation of a 52-kd class. At 15 min, both EMF and MSH continued to show increased phosphorylation of a 52-kd class. At 30 min, no changes were observed. At 72 hours, protein synthesis was reportedly affected. The author concludes that EMF can regulate cellular phosphorylation mechanisms.

Session N was entitled "Growth and Rehabilitation", and it consisted of six presentations. Highlights from three of them follow. The first speaker was S. Fitton, who studied the effect of pulsed electromagnetic fields (PEMFs) and dexamethasone on tendon cells in culture. A double-blind clinical trial of PEMFs therapy of chronic rotator-cuff tendonitis was reportedly observed to cause a significant reduction in pain and increased mobility in the previous experiments by Binder et al. (1984) (Lancet 8379: 695-674). The author intended to examine factors involved in such interactions, and test the effects of simultaneous use of PEMFs and dexamethasone, a drug used to modify connective tissue destruction. Exposure consisted of both a single pulse, or pulse train waveforms, with a 15-Hz repetition rate. Produced magnetic flux density was measured at 1.6 mT. The results indicated that, at the highest dose of dexamethasone, cellular proliferation on the 20th day of culture is suppressed in controls by 20 percent when pulse train was used, and is elevated by some 15 percent when a single pulse was used. In addition, the author has reported the reduction of the glucuronidase activity by some 50 percent for both wave trains.

The second presentation was by L-M Liu, who studied ELF electric field effects on tendon fibroplasia in vitro. Chicken sublims tendon explants were exposed in vitro to 96-hour ELF unipolar pulsed electric fields to determine effects on cell proliferation and collagen and noncollagen protein synthesis. At a pulse repetition rate of 1 Hz and a pulse duration of 1 msec, fibroblast proliferation and collagen synthesis were not increased during exposure at a peak current density of 355 $\mu A/cm^2$; whereas, there was a general enhancement of cell proliferation, but no apparent effect on collagen synthesis in explants exposed to 710 $\mu A/cm^2$. Exposure to 710 $\mu A/cm^2$ modulated at 16 Hz resulted in suppression of cell proliferation with no effect on collagen synthesis. No effect on cell proliferation or protein synthesis were detected after exposure to a 16-Hz field with a pulse duration of 5 msec and a peak current density of 355 $\mu A/cm^2$.

The third presentation was by G. Poli from Orthopedico Rizzoli, Bologna, Italy. Poli reported his experience in the treatment of congenital pseudarthrosis with surgery alone and surgery combined with electromagnetic stimulation. Twelve patients were operated on with excision of the pseudarthrosis focus, reduction, and fixation by endomedullary nail. All patients received the same orthopaedic treatment. Applied field's parameters were: 72 Hz, 1.3-msec impulse width, and 2.8-mT field strength. The imbalance between healthy and affected limbs worsened in three patients in the control group and in one patient in the exposed group. The overall conclusions are that PEMF stimulation with proper surgery significantly improves the patients prognosis.

The following reviews are associated with Poster Presentations - papers presented on boards and commented on by respective representatives/authors. Presentation X1, entitled "Residential ELF Magnetic and Electric Fields Measured Over Twenty-Four-Hour Periods", was presented by W.T. Kaune et al. The authors built a magnetic- and electric-field data acquisition system for ELF field characterizations in residences in the state of Washington. The system consists of five units: a central data acquisition and control unit, three magnetic field-sensitive probes, and one probe for vertical electric-field measurements. The responses of the probes and associated analog electronics could be set to be linear in the range 20-2000 Hz.

Presentation X2, also by W.T. Kaune et al, dealt with the introduction of a new device for generating ELF magnetic fields in biological exposure systems, where field leakage is greatly reduced. The approach has the advantage that exposed and control preparations can be located close together. Device made of three 40 cm x 40 cm x 1.3 cm - thick copper plates, placed in a parallel configuration with an interplate spacing of 7.6 cm. A current I is directed through the central plate, and a current I/2 is returned through each of the two outer plates. Up to eight 2.5-cm-diameter cylindrical exposure chambers, located between the plates, can be exposed to uniform (3 percent) magnetic fields from 0 to 1 mT. ELF electric fields from 0 to 50 V/m can be directly generated in the chambers by introducing current through graphite electrodes located in their ends.

Presentation X8 was by C.D. Cain et al, who designed the agar-bridge system for cell exposure in a tissue culture. The system is designated for the ELF fields in such a manner that field strengths 0.1-10 mV/cm and current densities 2-200 $\mu A/cm^2$ are fairly uniform and are measurable in the tissue culture medium. In addition, the agar-bridge system allows biochemical assays to be done quickly and efficiently. Composition of the glass bridge includes two concentric hemi-cylindrical glass tubes with diameters of 28- and 41-mm, so that 1% agar solution (10 ml) can be poured between the tubes. The electric field is generated by a constant current amplifier and Wavetek wave-generator modulator. Since ornithine decarboxylase (ODC) activity has proven to be sensitive to ELF fields, the effects of 60-Hz fields on ODC activity in various cell types are studied.

Presentation X12, entitled "Exposure of Chick Forebrain to ELF: Relation of Effects of Treatment, Experimental Replicates and Side of the Brain", was given by J.S. Brand et al, whose study was intended to replicate and extend the original observations regarding ELF effects on calcium efflux from chick cerebral hemispheres. Fields of 6, 10, 25, 40 and 56 V/m at both 6 and 16 Hz were tested. Significant stimulation of calcium efflux was observed in one out of three trials at 10 V/m and 6 Hz and inhibition at 56 V/m and 16 Hz in two out of three trials. In subsequent experimental series, either 1) control samples were all left- or all right-halves in a given trial, or 2) the left- and right-halves were distributed equally within treatment and control groups. The data from all such trials were subjected to a three way analysis of variance to test for effects of day to day variation on ELF treatment of brain sidedness. Day to day variation was not a significant factor. In ten out of ten trials efflux from the left brain half was greater than the right, and the difference was significant in three trials. The authors conclude that sidedness of the chick brain can be an important factor in this type of experiment.

Presentation X13 was by G.J. Niemi et al, who studied the potential effects of an ELF antenna system on breeding bird community density and richness and on the densities of specific breeding species. Experimental sites were in northern Wisconsin and northern Michigan. The authors report on insufficiency of sample sizes to make statistically reliable statements. It was determined that at least 40 500-m transects were necessary to sample in control and in treatment areas. Several statistically significant differences between control and exposed groups were found, however, no consistent pattern of differences were detected. These results were presented earlier at the ELFCS's ecological review held on April 15-16 at Escanaba, Michigan.

Presentation X14, entitled "Effects of 76-Hz Fields on Peatland Ecosystems in Wisconsin" was by the science team from the University of Wisconsin, Milwaukee, headed by F. Stearns, whose studies were undertaken to examine peatland systems for potential effects of intermittent 76-Hz fields. Ecosystem level functions mediated by cell membrane activity, including decomposition, foliar cation concentration and leaf diffusion resistance, were chosen for study. The eleven sites chosen differed in electromagnetic field exposure by approximately two orders of magnitude providing a gradient from high levels (treatment) to low or ambient levels (control). Statistical analyses have indicated no significant differences among treatment means for decomposition rates for most foliar uptake parameters.

Presentation X15 was given by G. d'Ambrosio et al from the University of Napoli, Italy, who tested the possible chromosomal abnormalities caused by a 50-Hz electric field. Bovine lymphocytes from peripheral blood were cultured in RPMI medium supplemented with 20 percent autologous plasma, antibiotics, and mitogen PHA-M. The exposure to a 50-Hz, 1-mA/cm^2 current density revealed a 12 percent of anomalous caryotypes in the unexposed samples versus 21 percent in the exposed ones. The data reportedly suggests that a truly 50-Hz, 1-mA/cm^2 current density can induce chromosomal damage.

Presentation X16, given by J.E. Morris et al., was focused on studies to evaluate the response of lymphocytes exposed to 60-Hz electric and magnetic fields, separately and in combination. Mitogen stimulation responses of spleen lymphocytes were used to measure membrane interactions and subsequent DNA synthesis initiation. The experimental results showed marked reduction in mitogen response. The presense of a contaminating magnetic field of some 0.05 Gauss caused the authors to conduct additional studies using either an agar bridge electrode system or a separate magnetic field system. No consistent changes have been observed in the response of lymphocytes exposed to either 60-Hz electric (< 10 V/m) or magnetic (20-Gauss) fields.

Presentation X17 was entitled "Effects of 60-Hz Electric Fields on the Daily Rhythms of Biogenic Amines" and was given by B.J. Vasquez et al. In this study male albino rats were exposed to a 39-kV/m, 60-Hz electric field for 20 hours a day for four weeks, in order to detect and quantify the possible effects of EMFs on the brain circadian rhythms. This was a double-blind experiment with a code to be broken only after all tissues had been processed. Two way analysis of variance (ANOVA) tests done on the data expressed as pg/mg wet tissue indicated significant changes over time of day for the levels of amines and metabolites in the striatum, and highly significant interaction between types of treatment (sham or exposed) and time of day occurred for NE in the hypothalamus.

Presentation X18, entitled " A Comparison of Electric Field Detection for Two Waveforms", was given by M.E. Stell et al., who attempted to demonstrate detection of a pulse modulated 100-kHz electric field. The results of the detection experiments at 60 Hz and 100 kHz were discussed in terms of the behavioral effects of electric fields and the putative mechanisms that could underlie these effects.

Presentation X28 was entitled "Electromagnetic Fields Induced In a Person Near a Video Display Terminal". It was presented by W.J. Ross Dunseath, who made a qualitative evaluation of the electric and magnetic fields induced at selected points inside a person due to external electric and magnetic fields generated by video display terminals (VDTs). The evaluation was made within the DC to 1-MHz range using amplitude and phase measurements of external electric and magnetic fields near the VDT with the person absent. Evaluations having increasing accuracy and complexity are developed in four stages: 1) The person is modeled as a prolate spheroid; 2) internal fields are determined when the prolate spheroid model is above a conducting floor and beside a conductive wall; 3) prolate spheroids with an appropriate shapes are used to model the head, torso, arms and legs of a person; and then 4) each part of the model is is replaced by equivalent electric dipole moment. By using closed form solution, the complete set of equations for the electric and magnetic fields are programmed and analyzed.

Presentation X62 was given by M.G. Shandala from the Marzeev Research Institute of General and Communal Hygiene, USSR. The author discusses various impacts of electric fields near high voltage transmission lines. Specifically, discussion focuses on direct impact, taking place when a person is staying within the electric field area; impact from spark discharges, when a man touches constructions insulated from the ground; impact of currents passing through the body that is in contact with and insulated from earth objects. The degree of each factor increases with the strength of the field. To secure high voltage power transmission line siting and exploitation, population protection from 330 kV and more AC industrial frequency lines are needed. The basic demand lies in strict observation of the established guidelines for designing and operating these lines.

Chapter IV

DISCUSSION OF THE LITERATURE

Physical Hazards, Including Electric Shocks and Effects on Electronic Medical Devices

The two principal issues related to this topic are: (1) ELF field effects on medical electronic devices, especially cardiac pacemakers; and (2) electric shock phenomena. These issues will be discussed separately, and analyzed for relevance to ELF Communication Systems (ELFCS).

Pacemakers

Modern microprocessor-controlled pacemakers operate in a "demand" mode, in which electrical stimuli are delivered to the heart only if it fails to exhibit intrinsic activity. Two different configurations of electrode leads are used in modern pacemakers: the "bipolar" design in which both electrodes are implanted in the heart with a separation of less than 3 cm, and the "unipolar" design in which the cathode lead is implanted in the heart and the pacemaker's case serves as the anode. Only the "unipolar" design has been found to be sensitive to electromagnetic interference (EMI) with pacemaker functions. This interference results from the significant separation of the anode and cathode in a "unipolar" pacemaker, which provides a large antenna for the reception of EMI. Of the approximately 500,000 individuals in the United Sates who have implanted pacemakers, about 50 percent have the "unipolar" variety.

Demand pacemakers exhibit two characteristic malfunctions in response to EMI. The first type of malfunction is characterized by an aberrant pacing rate, with either irregular or slow pacing. The second type of malfunction results from the modern pacemaker's noise detection circuitry, which that causes the pacemaker to revert to a fixed-rate pacing mode (the "reversion" mode) when EMI is sensed. In this mode, the cardiac stimuli provided by the pacemaker can be competitive with the heart's own endogenous signals. Only a few types of commercially available pacemakers have sophisticated noise rejection circuitry that can circumvent the two types of malfunctions described above. The great majority of modern pacemakers (greater than 90 percent) are responsive to EMI with differing degrees of sensitivity.

Several papers dealing with the sensitivity of demand pacemakers to EMI from ELF electric and magnetic fields have been reviewed by RDL during the past year [Formanek et al. (1977); Bridges et al. (1978); Butrous et al. (1982, 1983); Irnich (1984); Moss and Carstensen (1985)]. All of these reports were concerned with 50- and 60-Hz electric and mangetic fields characteristic of power transmission lines, as well as machinery and appliances. The results can be extrapolated, however, to 72- to 80-Hz fields from ELF communication systems. Based on the data in the above-referenced reports, the lowest value of 50/60-Hz electric fields that produced pacemaker malfunctions is 1.5 kV/m (rms). This field intensity induces a body current in a human subject of approximately 25 μA. The lowest value of 50/60-Hz magnetic fields that produced pacemaker malfunctions is 21 μT (rms) [= 21 gauss (rms)]. Since the maximum 72- to 80-Hz electric and magnetic fields in air in the proximity of an ELF antenna are 160 V/m and 14 μT, respectively, the findings described above indicate that no pacemaker-related problems should result from human exposure to the fields associated with and ELFCS.

Electric Shocks

The phenomena of electric contact currents and spark discharges from ungrounded (or poorly grounded) metal objects in the vicinity of a high-voltage source have been extensively studied and are reasonably well understood. Several reports on this subject have been reviewed by RDL [Olsen and Jaffa (1984); Anonymous (1984); Anonymous (1985); and Tenforde (1985)], and in all cases it has been concluded that adherence to the National Electrical Safety Code (NESC) is sufficient to avoid any significant hazard to humans from electric shock phenomena. Specifically, the NESC limits contact currents at 50/60 Hz to 5 mA. Currents of this magnitude are very unlikely to arise due to the charging of objects in the vicinity of an ELF antenna. One report that is noteworthy, however, is that of Frazier et al. (1978). These investigators observed that electric fields in air with intensities as low as 60-140 V/m can induce sufficient charge on an ungrounded tractor-trailer or camper van to create a hazard if the vehicle is contacted by an ungrounded person wearing the most vulnerable model of unipolar pacemaker. Thus, caution should be taken by a person wearing a unipolar pacemaker primarily near power transmission lines and also near ELF communications antennas, where field strengths exceed 60 V/m.

Two other topics on which papers have been reviewed by us are concerned with the effects of electric shocks on bees and livestock. Honeybees experience shocks from "step potentials" created in a hive exposed to the fields from a high-voltage ELF source [see, for example, Greenberg et al. (1985)]. This phenomenon can be lethal to bees, because it produces aberrant behavior such as stinging and the propolization of hive entrances. The threshold field level above which sufficient charging currents are produced in beehives to elicit this behavior is about 2 kV/m, and so the topic is not relevant to ELFCSs that produce maximum electric fields in air of 160 V/m.

A second shock phenomenon that was reviewed is the hazard to livestock resulting from neutral-to-earth voltages and ground currents present on farmsteads [Gustafson and

Albertson (1982)]. These voltages are produced by inadequate neutral-to-earth grounding of the primary and secondary electrical distribution system on farms. Dairy cows can perceive 50- to 60-Hz fields with contact voltages as low as 1 V, and this can lead to decreased milk production, mastitis, etc. The problem can be mitigated by improved grounding practices on farmsteads, and it is not directly relevant to ELFCSs. The extremely high sensitivity of farm animals to weak ELF voltages and currents, however, indicates the need to minimize the currents injected into the earth near ground terminals associated with ELF antennas.

Therapeutic Effects

During the last two decades the efficacy of pulsed magnetic fields for stimulating the reunion of bone fractures has been tested extensively in clinical trials. Compared to earlier procedures in which electrodes were inserted directly into bone tissue to inject electrical currents that accelerate fracture healing, the use of pulsed magnetic fields has several distinct advantages: (1) the fields are applied external to the body surface by Helmholtz coil applicators, and so there is no risk of surgical trauma or infection; (2) there is no problem with electrode polarization or the release of toxic products into tissue; and (3) the induced field in bone tissue is reasonably uniform. Beginning in the early 1970's, several clinical trials by

C.A.L. Bassett and his colleagues indicated considerable promise for the promotion of bone fracture healing by the application of pulsed magnetic fields with repetition frequencies in the ELF range.

In the last year we have reviewed thirty reports of clinical studies on the facilitation of bone fracture reunion by ELf pulsed electromagnetic fields [Silin et al. (1979); Grigorieva et al. (1980); Cheng and Mulier (1981); Sedal et al. (1981); Mitbreit et al. (1981); Kraus et al. (1982); Wahlstrom (1982); Cadossi et al. (1982); Rakshit (1982); Asherl et al. (1982); Delport et al. (1982a); Caullay and Mann (1982); Bassett et al. (1981, 1982a, 1982b, 1984); Haimovici (1982); Wiendl (1982); Dunn and Rush (1984); Sharrard (1984); Simonis et al. (1984); Harrison and Bassett (1984); Haupt (1984); Marcer et al. (1984); Nahoda (1984); Simmons (1985); Chvojka (1985); Rinaldi et al. (1985); Poli et al. (1985); and Fontanesi et al. (1985)]. These publications appeared in the worldwide literature subsequent to 1980, and all reported success in accelerating fracture reunion by the application of pulsed fields. In 15 reports, quantitative estimates of the success rate in the clinical trials was given. These estimates ranged from a 63-91 percent success rate, with most of the values ranging from 80-90 percent. The results of these studies therefore support the earlier claims by Bassett and others of the efficacy of ELF pulsed field treatment in the healing of bone fractures.

The frequencies of the fields used in the above-referenced clinical studies ranged from 1-75 Hz, and the magnetic field intensity was generally in the range of 0.2 to 2 mT (2 to 20 gauss). These field intensities are approximately 15-150 times greater than the maximum 72- to 80-Hz magnetic fields present in air in the vicinity of an ELF communication system antenna (B = 14 μT). This topic is therefore only of marginal relevance to the issue of potential bioeffects of the fields associated with an ELFCS.

A total of 19 reports were also reviewed on animal studies in which ELF pulsed fields were used to treat bone fractures and various types of injuries to nonosseous tissues. Of the 11 reports on treatment of bone fractures in various animal species (rats, dogs, and rabbits), nine claimed success in accelerating bone fracture healing by exposure to pulsed fields [Blumlein et al. (1978); Bassett et al. (1979); Shim (1981); Stuermer et al. (1981); Schubert et al. (1982); Chen et al. (1982); Harrington et al. (1982); and Kahanovitz et al. (1984)]. Two reports of no beneficial effects were also reviewed [Enzler et al. (1984) and Miller et al. (1984)]. Of seven reports on the use of pulsed fields to treat injuries to skin, ligaments, tendons, and nerves, five claims were made of beneficial effects [Bentall (1981); Franc et al. (1981); Orgel et al. (1984);

Raji (1984); and Jackson et al. (1985)]. There were two reports of no beneficial effects on the healing of nonosseous tissues [Cockshutt et al. (1984) and Watkins et al. (1985)]. One report of an inhibitory effect of ELF pulsed fields on the growth of rodent tumors was also reviewed [Pilla et al. (1982)]. Overall, the laboratory animal studies on bone fracture treatment with pulsed ELF fields yielded results that were generally consistent with the results of human clinical trials. There is also a suggestion that ELF pulsed fields may be beneficial for the treatment of ligament, tendon, and nerve injuries, but the number of literature reports on this subject is small and several negative findings have been reported.

A total of ten reports on the effects of ELF pulsed fields on the growth of biochemistry of cells grown in tissue culture were also reviewed by RDL staff and consultants. Six of these reports were concerned with cultured bone cells from rats and chickens [Archer and Ratcliffe (1981); Norton (1981); Laub and Korenstein (1982); Hanley et al. (1982); Noda et al. (1982); and Korenstein et al. (1984)]. In general, these reports suggest that pulsed field treatment leads to an enhanced growth rate and increased DNA synthesis rate in cultured bone cells. Variable effects on protein synthesis, especially collagen, have been reported. These differences in experimental findings may result from (1) differences in the types of bone cells studied, (2) differences in the growth state of these cells at the time the pulsed fields were applied, (3) differences in the tissue culture medium and procedures used by various investigators, or (4) some combination of the first three factors. Four reports were also reviewed in which increased growth rate and/or DNA synthesis rate was observed in various nonosseous cells grown in tissue culture, including fibroblasts and dorsal root ganglia [Liboff et al. (1982); Sisken and McLeod (1982); Loyd et al. (1982); Cleary and Liu (1985)]. Overall, the results of in vitro studies designed to elucidate the mechanisms by which pulsed ELF fields facilitate bone fracture reunion are consistent in the observation that DNA synthesis rate is increased and bone cell growth is stimulated.

In Vitro Cellular Studies Including Membrane and Extracellular Interactions

In Vitro Studies with Pulsed Fields

One half (29/58) of the cited literature on cellular effects studied by in vitro techniques involved the influence of pulsed magnetic fields, often in tests with bone cells or cells of connective tissues. An additional five citations involved work with pulsed electric fields. In the overwhelming majority of cases the authors report changes in cellular functions, often involving either cell proliferation, DNA synthesis, or other protein synthesis. Often, cell proliferation was found to be unaffected, while changes in protein synthesis were more common. Both inhibitory and stimulatory changes in protein synthesis were found, even in the same system. Such findings are only superficially contradictory because of differences among the various experimental conditions, and because the complex cellular regulatory mechanisms can direct both upward and downward changes in chemical rates.

Many of these studies inquired into the mechanism of the field influence. The pattern of results was to support the concept of a cell membrane mediated effect involving calcium (see below), cyclic AMP [Jones (1982)], and other factors of intracellular second messenger systems. None of the research reviewed during 1986 investigated thresholds for these phenomena, and generally experiments were done with one or a few field conditions. The pulsed magnetic fields usually had peak intensities of the order of 10-50 gauss (1-5 mT) and fast rise times capable of inducing electric fields of the order of 1 or 10 mV/cm in current paths about a centimeter in diameter. Unfortunately, detailed dosimetric data for the pulsed fields were rarely given. However, Fitton-Jackson (1982) reported that 15-Hz was the most effective pulse frequency.

Conti et al. (1985) provided detailed evidence that a pulsed magnetic field (50 gauss, 3 Hz square wave) inhibits

DNA synthesis by an effect on calcium-dependent biochemical processes. Dihel et al. (1985) found increased cell division rates among Paramecia exposed to a pulsed magnetic field with parameters typical of the clinically used waveform: 5.4 mT peak, 325-μs/5.2-ms asymmetrical pulse, 72-Hz repetition rate. In this case too, the field effects involved a calcium dependent mechanism, and changes in membrane potential and fluidity were reported. Similar evidence for PEMF effects on cell biochemistry were reported by Archer and Ratcliffe (1981) and by Rodan and Johnson (1981). In the latter report, the authors gave the then new finding that PEMF acts on bone cells similarly to hormones and noted the need for a minimum five hours of exposure to observed changes in biochemical endpoints. Hanley et al. (1982) found effects on DNA synthesis in one class of bone cells (osteoblasts) but not another (periosteal cells), only for the stronger of two waveforms, and they observed either growth stimulation or inhibition depending upon the addition of serum to the medium. Other reports also detailed cell membrane related, calcium-dependent biochemical processes [Colacicco et al. (1984); Greenbaum et al. (1985)].

Evidence for an effect on the transcription process (by which the genetic information of the chromosomal proteins is read) was reported by Goodman et al. (1981, 1982). The fields in vitro were reported to be in the range 1-10 mV/cm. At the antenna site, ELFCSs may produce fields within one order of magnitude of the fields found to affect transcription, and the threshold for effects on transcription is unknown. Thus, this finding may be directly relevant to the ELFCS in the region of maximum magnetic fields near the antenna. A physiological change, which may be directly related to the alteration of transcription by ELF fields, has not yet been reported on, but, in principle, effects on transcription may profoundly affect biological systems.

Numerous studies found stimulatory effects on protein synthesis in various cell systems, including fibroblasts, bone cells, connective tissue cells, and white blood cells of the immune system [Jolley et al. (1982); Delport et al. (1982); Murray (1982); Goodman (1982); Noda et al. (1982); Loyd et al. (1982); Murray and Farndale (1985); Hellman et al. (1985)]. A number of papers report significant changes in intracellular enzymes and biochemical messengers following PEMF exposure. Cain et al. (1985) found changes in cyclic AMP and ornithine decarboxylase in cultured bone cells. Otani et al. (1984) found altered levels of this latter enzyme and in thymidine uptake in a study in which rats were exposed in vivo to a PEMF of unusual waveform. They also (1984) found corresponding physiological evidence in the changes of liver weight and protein content, glycogen content and volume lipid droplets.

Biochemical synthesis of hormonal or other protein products was reported to be influenced by pulsed magnetic fields in studies of noradrenaline production by neural tissue [Rein and Dixey (1982)], and prostaglandin synthesis of bone cells [Johnson and Rodan (1982)].

Cell growth and development during stages of neurite extension were studied in neurons from chick dorsal root ganglia exposed to PEMFs [Sisken (1982)]. The PEMF enhanced neurite outgrowth in a way that depended on exposure duration.

If, as many researchers reported, PEMFs affect fundamental cellular mechanisms, it is reasonable to inquire into possible effects on the cancer process in vitro. Lyle and Kamin (1985) reported that a PEMF did not act as a primary or secondary tumor promoter, nor did the PEMF synergize the actions of a phorbol ester tumor promoting agent.

Other research involved very strong pulsed electric fields. In a typical report, Porschke (1985) used a 20-kV/m, 200-ms pulse to convert DNA from condensed to free conformations. Research activities with such large fields [see also Westfall et al. (1984); Korenstein et al. (1982); Laub and Korenstein (1982)] are far removed from the issues attending environmental exposure to ELFCS fields. Epidemiological reports of chromosomal changes in workers exposed to strong electric fields and coincidental spark discharges led to an in vitro study [Nordenson (1984)] that demonstrated chromosomal changes from pulsed (3 us) high strength

(3.5 kV/cm) pulses of current. This finding is also irrelevant to ELFCS.

<u>In Vitro Studies with Sinusoidal Electric and Magnetic Fields</u>

The studies with sinusoidal electric and magnetic fields involved diverse experimental designs, field applications and outcomes. Often, the results from one or more aspects of these studies were positive and indicated electric or magnetic field influences on cellular processes and often appeared to involve events at the cell membrane. A number of important indications of no field effect were reported.

Most studies with sinusoidal fields are related to power line health issues and have a variable degree of relevance to ELFCS issues, depending upon the strength of the applied electric field. The 50- or 60-Hz frequency is considered relevant to ELFCS which employs a 72- to 80-Hz signal. The literature reviewed also included research with strong static electric fields, but these are irrelevant to ELFCS and are omitted from this summary.

Nordenson et al. (1984) found no chromosome changes in lymphocytes exposed for 3 hr to a strong current density (1 mA/cm^2). Stevenson and Tobey (1985) found small effects on membrane ion transport properties using very strong

(2.5 V/m) 60-Hz fields in the medium surrounding the tissue. Winters et al. (1985) reported on lymphocytes exposed to combined electric and magnetic fields at levels relevant to ELFCS fields. They found no significant effects in a number of exposure protocols and in tests for blastogenic responses to mitogens and antigens, and no effects on cell proliferation.

Sheppard et al. (1986) reported direct electrical effects on nervous system preparations at very much lower levels (to 2 mV/cm) and at much lower frequencies (about 1 Hz) suitable for the test system (Aplysia neurons). These field conditions are not directly relevant to ELFCS.

ELF field effects on calcium ions have been the focus of considerable interest because of the nearly ubiquitous physiological importance of calcium, the very low field levels at which effects are found, and the evidence for distinct "windows" for effective field parameters. Blackman et al. (1985a, 1985b, 1985c) reported on several aspects of the calcium ion efflux from chick brain tissue, which appear relevant to ELFCS issues. Related papers on calcium ion efflux from brain tissues [Bawin et al. (1977a, 1977b); Blackman et al. (1977); Myers and Ross (1981)] were also reviewed. The most significant findings involve an apparent harmonic relation among the frequencies that cause positive effects, which indicate an important role for the static geomagnetic field of about 40 μT (0.4 gauss) and for ELF magnetic fields as weak as 65 nT. These data suggest a resonance phenomenon, but quantitative details are incomplete.

Liboff (1985) proposed a cyclotron resonance behavior for ions subjected to ELF magnetic fields in the presence of the static geomagnetic field. This model attempts to account for the harmonic relationship between effective frequencies in the calcium efflux data. In the literature reviewed, this model was at an early stage of development and appeared to ignore important physical interactions that may require alterations in the model. Liboff et al. (1982) also reported stimulation of DNA synthesis in fibroblasts that was independent of the frequency of the applied magnetic field and therefore presumably involved another mechanism.

A number of studies [e.g., Zhang et al. (1984), and Bustos et al. (1978)], involve applied electric fields many orders of magnitude greater than could be realized by environmental exposure to an ELFCS, and these reports were held irrelevant for the purposes of this summary.

In Vivo Physiological Studies, Including Neural and Neuroendocrinological Effects

Of the literature reviewed in 1986, 18 citations not otherwise categorized as "metabolic" studies concerned physiologic and neuroendocrine effects in animals exposed in vivo to ELF electromagnetic fields. These studies most often involved neural and neuroendocrine responses to electric and magnetic fields, and some involved lengthy exposure periods. Of the research reviewed, eight citations were from East European countries, especially the USSR. These eight studies are proportionately a larger fraction of the research than in other areas, which may reflect the emphasis on such research in Eastern Bloc scientific work. In the West, there appeared to be relatively less interest in pursuing research in this direction as a result of the absence of disruptive effects in the neuroendocrine system. Nonetheless, there have been significant positive findings in research with various ELF electromagnetic fields that show influences on this important element of the body's response to environmental conditions and physiological status.

A number of experiments conducted at Battelle Pacific Northwest Laboratory show a marked change in the rhythmically varying levels of melatonin and related metabolites in the rat pineal gland [Anderson, 1982)]. Rats were exposed for several weeks or more to 60-Hz electric fields of about 40 kV/m, and in one study, 1 kV/m. Wilson et al. (1985) reported a follow-up study that shows corresponding changes in tryptophan, serotonin metabolites, free serotonin, and methoxyindole-specific enzymes of the pineal. Although such effects may be physiologically significant and could be related to harmful effects, at present the physiological significance is unknown. The role of the pineal gland in circadian rhythmicity and reproductive physiology is a new and currently active research interest of many laboratories. While considerable information has been obtained, the neurophysiological and biochemical knowledge in this area is incomplete. The additional influence of fields adds still more questions. It is possible that the observed changes are of little importance under realistic exposure conditions. To date, there is no demonstration of a lower threshold for the effects on pineal metabolism, and the role of ELF magnetic fields, if any, is unexplored.

A screening study of rat serum chemistry was conducted throughout a 120-day period in which rats were exposed to an 80-kV/m electric field (21 hr/day). Seto et al. (1984) found no significant effects on blood serum components of the exposed rats. The tested 60-Hz field was about 50 times stronger than the electric field associated with an ELFCS, suggesting that an ELFCS electric field would be likewise ineffective in changing serum chemistry. The data specifically indicate no evidence for chronic stress that would be reflected by changes in endocrine functions. In related research, Seto et al. (1985) examined selected organs, including the adrenal, thymus, pituitary, and testes, as well as heart, liver, kidneys, etc. They found "no specific evidence of histopathologic differences between field-exposed and sham-exposed animals at the light microscope level." Immune system responses in mice exposed for 30 to 120 days (21 h/day) to 60-Hz fields at 100 kV/m (unperturbed) were found unaffected [Morris (85046)]. The tests conducted involved both mitogen (con A, PHA, PWM, etc) responses of spleen cells and tests of cytotoxicity. Graves et al. (1979) exposed mice to 60-Hz electric fields of 0, 25 or 50 kV/m for up to 6 weeks and found no changes in blood cell counts and body weight. Adey et al. (1979) conducted studies of activity and general physiology (measuring body weight, food and water consumption, urine output) in rats exposed to relatively weak environmental 60-Hz electric fields up to 1000 V/m. Nocturnal activity was slightly reduced in amount and duration at the highest field level of only 1000 V/m. The largely negative findings on blood chemistry and blood cell counts in strong 60-Hz electric fields indicate that ELFCS electric fields, which are never more than 160 V/m, would also have no effects. These findings further suggest that the disruption of pineal melatonin rhythms is not broadcast throughout the neuroendocrine system to cause widespread disturbances, but these negative findings on blood factors do not diminish the importance of further understanding of the pineal effects.

In contrast, Shandala et al. (1981) conducted a number of experiments at 15 or 20 kV/m (50-Hz), which were continued for four months. As reviewed by Shandala, such chronic exposures (for 80 to 300 minutes per day) produced statistically significant changes in various serum chemistry endpoints as well as changes in blood cell counts, enzyme activities, motor reflexes, and immunological responses. In most instances, repeated examinations conducted two months after the end of exposure found a return to control levels. Histopathological studies of organs and tissues were negative. There was evidence from the few data obtained with 10-kV/m exposures of a threshold lying above 10 kV/m. The role of field perception in these studies cannot be determined, but may be significant. If these results were due to perception, it would be clear that no similar effects could occur for ELFCS fields which are well below the level of perception. Yevtushenko et al. (1981) reviewed a two studies of rats. In the first, rats exposed chronically to 10 kV/m electric fields for periods of up to 6 months of daily exposures lasting 20 to 320 min showed metabolic and somatosensory changes for 15- and 20-kV/m exposures, but no effects for 10-kV/m fields. Chronic (4 months) exposure to magnetic fields of 94 gauss (50-Hz) produced changes that suggested deleterious effects on the nervous, hematoimmunological, and cardiovascular systems and on tissue metabolism. Rats exposed at 9.4 gauss however had no such effects, indicating a threshold between 9.4 and 94 gauss.

The third study discussed by Yevtushenko et al. involved human subjects exposed for 20 days to 10 kV/m for 2 hr per day. These experiments gave evidence for reversible alterations in cardiovascular function and skin temperature. The foregoing studies from the USSR are to one degree or another in contradiction with similar studies elsewhere in which chronic exposures with stronger fields, but with more nearly continuous exposure periods, gave little or no evidence for functional changes in major organ systems. It cannot be determined if the different results are due to exposure parameters, caging designs, different animal species, imperfect controls or other factors. Research with human subjects at Midwest Research Institute however [Graham et al. (1984)] did find an alteration in heart rate that may be related to the finding reported by Yevtushenko et al.

Carmaciu et al. (1977) reported a large (2.7 fold) increase in antidiuretic hormone and reduced urine output among rats exposed for 2 or 6 hr to a 50-Hz 100-kV/m electric field. The authors noted "hyperactivity" among the exposed animals, which may indicate an arousal response [illegible] perceptible field influences. Sensory events may [illegible] some or all of the findings, but the study did [illegible] the mechanism for the effect.

Marsakova (1983) reported that [illegible] netic fields (1.1 gauss, [illegible] interfered with thyroid [illegible]

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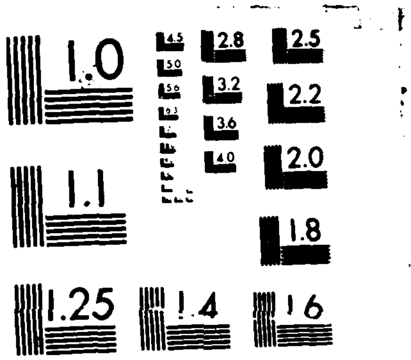

MICROCOPY RESOLUTION TEST CHART
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thyroid iodine levels. The proposed mechanism for effects was a magnetic field influence on the pituitary-hypothalamic axis, which is central to neuroendocrine functions. Ponomarev et al. (1984) studied human subjects repeatedly exposed to strong, localized 50-Hz magnetic fields (10 or 20 mT, 100 or 200 gauss), which are intended to have a therapeutic effect. They found increased cortisol levels and decreased aldosterone levels. The finding, if confirmed, would indicate potential health risks from such exposures to the public, but the fields are at least 100 times those associated with the ELFCS. Buiavykh (1984) reports a similar therapeutic utilization of a 30 mT magnetic field with reported beneficial effects on lipoprotein levels and benefits to hypertensive patients.

Changes in the genome would be a significant indication of a potential for deleterious health effects. Thus, studies were undertaken to test for chromosome alterations causing dominant lethal mutations in mouse embryos, or producing sister chromatid exchanges in bone marrow cells. Mice were exposed to combined electric and magnetic 60-Hz fields in the ranges 0, 15 and 50 kV/m and 0, 3, 10 gauss, respectively. Carsten et al. (1985) studied embryos from 7000 female mice exposed during impregnation and for up to 17 days of gestation with no evidence of excess mutation rate in the exposed group. Likewise, the chromosome study in which exposure periods extended up to 28 weeks found no field-related effects.

An important technique to determine the potential for a change in the genetic material of cells involves examination of peripheral white blood cells for quantitative information on chromosome aberrations. Interpretation of chromosome aberrations is not straightforward, but their occurrence indicates that the agent under investigation has the potential to alter the genome in both somatic and germ cells and points to the need for more detailed consideration of cancer and birth defects in relation to the agent. Nordenson et al. (1984) presented data that show a five-fold greater incidence of chromosome breaks and an increased incidence of chromatid breaks in workers at electric power switchyards. In the absence of more thorough data on mechanisms and exposures, it is unknown if this finding is related to either the electric field, the magnetic field, the spark discharges received in regions of high electric field strength, or to collateral (non-field) exposures. Because of in vitro data indicating similar chromosome aberrations in blood exposed to electric discharges (akin to spark discharges), the authors leave open the possible role of spark discharges in causing the observed aberrations.

The very large magnetic fields associated with magnetic imaging devices were tested for effects on cardiac function by Willis and Brooks (1984). They found no effects on heart electrical performance (ECG) and blood pressure for exposures lasting up to 90 minutes. Fields included a 0.16-T static field and sinusoidal, triangular, and square-wave fields at low frequency (1- or 2-Hz). The sinusoidal magnetic fields tested are relevant to the issues of ELFCS.

In summary, the reviewed articles are consistent with the present status of the literature on ELF field influences on the neuroendocrine functions of animals exposed in vivo. Thus, acute exposures to strong electric fields may have effects related to field perception, and there is little evidence of deleterious effects from such acute changes. Relatively fewer studies explore chronic exposure to fields greater than 10 kV/m, 50 or 60 Hz, and there is some contradiction between results obtained in various laboratories. Slight or moderate effects on blood cell counts have been reported by many investigators, but the effects appear too small to be of health significance in and of themselves. In other studies (not reviewed in 1986), 60-Hz fields of 40 kV/m (effective level) had no statistically reliable effects on blood cell counts [Ragan et al. (1981)]. Positive effects of strong electric fields may be related to sensory effects or direct field influences on tissues, but the mechanisms are undetermined. Magnetic fields have been studied less extensively, and it is not possible to draw conclusions from the few reports. Many reports of magnetic field-related neuroendocrine effects involve field levels above 0.1 mT and ranging to 20 mT, far in excess of ELFCS magnetic fields.

Metabolism, Growth, and Development

Since the normal growth and development of a living system is brought about by a complex series of interrelated genetic, morphologic, and biochemical events occuring in a precise temporal sequence, any substantive interference with these events may have serious consequences such as birth defects, embryonic or fetal death, failure to reproduce, and many others. The interference with these events is known to be produced by drugs, disease, chemicals, etc. The following review focuses on those studies in which living systems were exposed to ELF electric and magnetic fields to assess effects on growth and development. There were 34 such studies cited.

Grissett et al. (1977) investigated possible developmental effects on primates exposed for one year to electric and magnetic fields characteristic of the ELFCS. The most significant finding of this study was the difference in rate of weight gain between exposed and control males. The exposed males gained weight at a slightly faster rate than the control males and at the end of one year were approximately 11 percent heavier than the controls. The difference in weight however was not accomplished by an increase in bone length measurements. The most agreement with the growth rate difference was observed in chest circumference. Serum triglycerides and respiratory quotient in exposed females is reported to be "slightly lower" than in female controls. Analysis of more than two years of data, including complete endocrinologic profiles, led the authors to conclude that "there is no indication that these findings have any adverse clinical significance, and both groups of animals appear quite healthy".

Mathewson et al. (1977a,1977b) studied bioeffects of ELF vertical electric fields on exposed rats, where the emphasis was on growth, food consumption, and blood metabolite alterations. Results of this study showed no effects from exposure to fields in the range of 0-100 V/m on growth, food and water consumption, nor the blood concentrations of total protein, globulin, glucose, cholesterol, triglycerides, or total lipid. In addition, necropsy and histopathological examination of tissue from 15 organ systems did not reveal any changes.

In their study of the effects of a pulsed magnetic field on the growth of chick embryos exposed to 70 to 320-gauss field strengths, Saha et al. (1981, 1982) reported field strength-dependent increases in both the weight and length of embryos. Fertilized chicken eggs were used in the experiments, and exposure pulse width and repetition rate were 2 msec and 200 Hz, respectively. Exposure field characteristics, such as field strength and waveform, differ from those associated with the ELFCS. Somewhat similar results were reported by Rooze et al. (1982), where in vivo study of skeletal modifications of chick embryos exposed to pulsed electromagnetic field for 100-150 hours appears to indicate enhancement of bone growth in chick embryos, however, the authors fail to specify exposure field characteristics such as frequency and field strength. No statistically significant ELF-related bioeffects were reported by Archer et al. (1981) in their study of the effects of a pulsed magnetic field (15 mT, 1 Hz) on the development and metabolism of chick bone embryos. Studying possible embryotropic effects of 50-Hz electric and magnetic fields, Pafkova (1985) reports no effects on the early embryonic development of chick embryos exposed to 100- and 200-kV/m electric fields; the author states: "the occurrence of developmental anomalies was not increased, nor was there any retardation of growth in the period till day 8 of embryonal development". Reed et al. (1985) studied exposure of avian embryos to 60-Hz electric fields with intensities up to 100 kV/m. After three years of investigation that utilized more than 20,000 embryos, no direct effect on the growth, development, or overall health and well being of avian embryos was observed. Moreover, Portet et al. (1984) reported no modifications in the biological and structural parameters pertinent to animal growth and development as a result of the exposure of a small number of newborn rabbits to an intense (50 kV/m) electric field 18 hours a day for a period of 6 weeks.

Growth and developmental effects of ELF electric and/or magnetic fields were also reviewed by Florida Department of Environmental Regulations (1985), by Chernoff (1985), Mercer (1985), McRobbie (1985), Raleigh (1985) and Phillips (1985). None of these reviews found convincing evidence for a pattern of adverse growth or developmental effects in either mammalian or avian species exposed to 50/60-Hz sinusoidal fields in the range 1 to 10 kV/m.

Maffeo et al. (1984) made an attempt to verify the biological and physical aspects of the "controversial" experiments by Delgado et al. (1982), in which a total of 212 fertilized chicken eggs were incubated for 48 hours while exposed to pulsed trains of square wave magnetic fields of 0.5 msec duration and pulse repetition frequencies of 100-1000 Hz at a magnetic field density flux of 1.2 and 12 μT. In contrast to Delgado's findings of significant birth defects, no significant differences were observed between exposed, sham-exposed and control eggs.

Ehret et al. (1979) studied exposure of rats and mice to 60 Hz horizontal and vertical electric fields at intensities ranging from 8 to 100 kV/m, where investigation of ELF electric fields effects on ultradian, circadian, and infradian rhythms in several metabolic variables was carried out.

The authors report evidence that older animals exhibit increased locomotor activity and metabolic activity (general arousal response). Based on later research [Rosenberg et al. (1983)], the average threshold field intensity for this effect in rodents is about 50 kV/m. The reported response is transient, lasting for an hour or less even in the continued presence of the electric field. After two to three applications of 60-Hz electric fields with intensities up to 100 kV/m at hourly intervals, the arousal response disappeared, which is indicative of rapid habituation to the presence of a high-intensity, power-frequency electric field. The ELF electric field intensities observed to produce transient disturbances in metabolic and behavioral variables in rodents are more than 300 times larger than the maximum fields in air (160 V/m) in the vicinity of an ELFCS antenna. No such effects would therefore be anticipated in humans or wildlife near the ELF antenna.

As the result of the exposure of rats and humans to 50-Hz, 10-kV/m electric and 9.4- and 94-gauss magnetic fields, Yevtushenko et al. (1981) report on some metabolic changes of the tissue; however the authors have failed to present the experimental procedures, and no attempt was made to determine the threshold electric field intensity required to produce these effects in humans. The electric and magnetic field intensity levels were well above the 160-V/m and

0.14-gauss maximum field levels in air near the ELF Communications antenna.

Shandala et al. (1981) report significant biological effects on some metabolic parameters in rats chronically exposed to a 50-Hz electric field at intensities of 15 and 20 kV/m, while no effects were observed at the field intensities of 10 kV/m and less. The authors fail to assess many important experimental parameters, such as threshold field level above which the various metabolic and physiologic indices began to exhibit statistically significant changes. The effective field intensities used in the experiments far exceed (100 times) those produced in the vicinity of an ELFCS. Later on, Shandala et al. (1983) studied the effects of a 50-Hz, 15-kV/m electric field on metabolic processes in the human organism. Based on the results of exposure of 40 men 90 minutes daily for a period of 20 days, the authors found no significant effects on metabolic processes, nor were there any cumulative effects on the blood indices.

Seto et al. (1983) report no statistical differences in food and water intake between controls and rats exposed to an unperturbed, vertical 60-Hz, 80-kV/m electric field. Statistically significant differences were observed observed in growth pattern from four to eight weeks of age, however, suggesting a slight initial development delay in growth rate. The reported effect is small, and disappears by the eighth week. Whether the delay in growth might produce some latent effect to be expressed later in life (i.e., learning ability, survivability, etc.) was not explored. Exposure field strength by far exceeds that produced by the ELFCS.

Effects of 60-Hz electric and magnetic fields on rat cerebellar development are briefly discussed in the abstract by Gona et al. (1985). The authors report no changes in Purkinje cells in the majority of animals (rats) exposed to a 60-Hz, 100-kV/m, 10-gauss electromagnetic field; however, some of the exposed animals reportedly showed clusters of degeneration in the cerebellum. Exposure to the electromagnetic field lasted 21 days, and details of experimental conduct are not available. Although the results suggest a possible effect of intense electric and/or magnetic field on neurological *development*, the implications for lower exposures or other species is unclear. Electric and magnetic field strengths are several orders of magnitude greater than those measured in the vicinity of an ELFCS.

Dodge et al. (1985) studied the effects of low level pulsed electromagnetic fields (PEMFs) on growth and behavior of hatchling turtles. Twenty four hr/day continuous exposure for three months to 50-msec bursts of bipolar pulses (250-μsec positive and 5-μsec negative) at a 2-Hz repetition rate resulted in an increase in weight and growth compared to litter paired, sham-exposed controls. This document lacks sufficient data for thorough evaluation and assessment. Exposure field characteristics differ from those associated with an ELFCS, so that the relevance to the ELF antenna is doubtful.

Retardation of embryogenesis by a 60-Hz magnetic field applied to fertilized Medaka fish eggs for 48 hours was reported by Cameron et al. (1985). Specifically, the authors reported developmental abnormalities and developmental delay when eggs were exposed to a 1-gauss magnetic field. A close inspection of the data indicates three problems: (1) the number of embryos per group was very small (typically 6-8 specimens), (2) no single experimental condition was tested in a replicate experiment, and (3) the procedure used to calculate the developmental delay was not properly performed. Reported exposure magnetic flux density was seven times larger than the maximum field present near the ELF antenna. The authors did not establish the threshold field level at which developmental effect occurs in fertilized fish eggs.

Finally, in their review of bioeffects resulting from a 400-kV transmission line, Algers et al. (1983) and Morgan et al. (1985) report no new significant findings on metabolism, growth, or development in humans and vertebrates in general.

Reproductive Effects

Potential adverse reproductive effects of ELF electric and magnetic fields have been addressed in a large number of laboratory investigations but in very few epidemiologic studies. The literature citations over the past year indicate that there is continued interest and research pertinent to this potential hazard, with a primary emphasis on laboratory studies as opposed to investigations of exposed human populations. The concern with reproductive effects as a potentially sensitive endpoint for environmental exposures is well justified, in that the fetus is highly vulnerable to toxic agents. Given past suggestive findings from laboratory studies, the paucity of epidemiologic studies is unfortunate.

A total of 21 references were found that were pertinent to the evaluation of reproductive effects of electric and magnetic fields. Of these 21, 15 were laboratory investigations [Jones (1985); Dodge et al. (1982); Freimark et al. (1985); Saha et al. (1981); Saha et al. (1982); Cameron (1985); Gona et al. (1985); Ueno et al. (1985); Pafkova (1985); Reed et al. (1985); Rooze et al. (1982); Carsten and Bentz (1985); Seto et al. (1984); Maffeo et al. (1984); Serdyuk (1985)], one was a field study of exposed cows [Algers and Hennichs (1985)], three concerned human populations [Wertheimer and Leeper (1986); Schaefer and Silny

(1977); Logue et al. (1985)], and two were reviews of the literature [Albert et al. (1985) and Chernoff (1985)]. Most of the reports of laboratory studies were incomplete, in that they were based on abstracts. As the results of these studies are documented in more detail, they will be more contributory to a scientific understanding of the risk posed by electromagnetic fields.

The 15 laboratory studies that were reviewed addressed a variety of reproductive health indices (e.g., fertility, congenital defects, fetal growth) in a wide variety of experimental systems (e.g., rats, fish, chickens, humans). These investigations provided mixed results, with a tendency toward negative studies across the different reproductive parameters and experimental systems. Specifically, high-quality negative studies were done on development of chick embryos [Reed et al. (1985)] and on neural development in rats [Gona et al. (1985)]. Several studies reported enhanced skeletal development due to electric field exposure in avian species. Data suggesting adverse effects of electromagnetic fields were noted in studies of developmental abnormalities and delays in fish [Cameron (1985)], but the results are not conclusive. The data predominantly document the absence of reproductive hazard based on laboratorty studies.

The one field biology study of fertility among cows exposed to electric fields also showed no adverse effect

[Algers and Hennichs (1985)]. Human studies included a letter speculating on electromagnetic fields and sudden infant death syndrome, but with no presentation of supporting data [Schaefer and Silny (1977)]. A report indicating that occupational exposures to nonionizing radiation among physical therapists had no effect on risk of congenital defects among their offspring [Logue et al. (1985)], which was limited in relevance by the consideration of non-ELF exposures and some serious methodological limitations. The most interesting paper indicated increased miscarriage risk among users of electric blankets and heated waterbeds [Wertheimer and Leeper (1986)]. The latter study is a suggestive preliminary analysis, especially because of a seasonal pattern in risk consistent with adverse effects in winter when such devices are in use. The pattern of results is not, however, precise, and there are methodological limitations that make the study unconvincing of a reproductive hazard from using electric blankets and heated waterbeds. The review papers by Albert et al. (1985) and Chernoff (1985) indicate the methodological shortcomings of past literature and the difficulties of reseach on reproductive effects of ELF electromagnetic fields.

Overall, there are some clear suggestions from studies of several different species that imply that electromagnetic fields can adversely affect reproductive processes. Many of these are uncorroborated and potentially the result of methodological flaws. There are also several studies that convincingly document the absence of pathological effects in several species. The most important suggestions of hazard come from the study of developmental delays in fish and miscarriage risk in human populations.

Cancer Risk

The issue of cancer risk related to ELF electromagnetic fields has generated a great deal of interest and concern on the part of the general public. Past epidemiologic studies have produced evidence suggestive of increased cancer risk among workers exposed to environments in which electric and magnetic fields are present, as well as suggestions of an increased risk of childhood and adult cancers among persons living in proximity to certain types of electrical distribution lines associated with elevated magnetic field levels. Laboratory studies have been less supportive of potential carcinogenic effects of power frequency electromagnetic fields. Recent literature pertinent to the relationship between extremely low frequency electromagnetic radiation and cancer risk was assembled by RDL and reviewed in the monthly progress reports. This summary will describe the literature considered and provide conclusions regarding the current status of evidence.

The number and types of citations covered during the year are informative about the type of research activity. A total of 32 items were selected as being relevant to the assessment of cancer risk. These included only two laboratory investigations directly concerned with carcinogenesis, five papers concerned with studies of humans exposed from power transmission and distribution lines, twenty papers addressing possible carcinogenic effects of occupational exposures, and four review papers. The predominance of letters, articles, and commentaries regarding exposures and cancer risks in the workplace is noteworthy. Also, the imbalance between reports on human effects in contrast to the dearth of information produced through laboratory studies of carcinogenesis is significant. Papers concerned exclusively with public perceptions or concerns regarding a potential health hazard were not included in this tabulation.

The laboratory studies included a suggestion that magnetic fields do not act to enhance chemical promotion of tumors [Lyle et al. (1985)] and a strong suggestion that power switchyard workers are prone to increased risk of chromosome breaks [Nordensen (1984)]. Although neither study is definitive, they illustrate the potential value of further laboratory investigations of the postulated carcinogenic processes by which ELF electromagnetic fields might initiate or promote human cancers.

The five papers on residential electromagnetic field exposures and cancer risk [Wachtel et al. (1986); Barnes et al. (1986); Savitz et al. (1986); Crocetti (1983)] included only one actual new investigation with results. The others were abstracts concerning work in progress or reviews of earlier work. McDowall (1986) presented a study of persons living in proximity to power substations or overhead power lines. Though no effect was noted, the study was rather weak as a test of electromagnetic field exposure per se.

The extensive number of papers concerning occupational exposures (20 citations) reflects a large number of letters to the editor and several papers with an incidental finding of increased cancer risk among men in occupations entailing exposures to ELF electromagnetic radiation. Several papers and letters suggest that such workers are at enhanced risk of leukemia [Calle & Savitz (1986); Milham (1985); Pearce et al. (1985); Olin et al. (1985)], including surveys of occupational mortality and more thorough case-control [Flodin et al. (1986); Stern et al. (1986)], and cohort studies [Tornqvist et al. (1986); Olin et al. (1985)]. None of the more detailed studies were intended to assess this particular exposure (most were initially concerned with ionizing radiation), so that there is little detail regarding exposure. Other papers presented suggest associations with brain cancer (Lin, et. al. (1985), neuroblastoma in the offspring of exposed workers [Spitz & Johnson (1985)], and chromosomal abnormalities [Nordensen (1984)]. Among these, the report by Lin et al. (1985) was most significant in that some effort was made to categorize workers by presumed exposure level. The overall pattern of results (stronger effects among men most likely to be exposed to electromagnetic fields and stronger effects for primary as opposed to potentially metastatic brain cancers) was consistent with an effect of electromagnetic fields.

The review papers [Sheikh (1986); Wertheimer (1982); Liburdy (1982); Barker (1984)], of course, do not present new data concerning electromagnetic fields and cancer. Instead, depending on the author's particular viewpoint, the compilation of suggestive findings may be emphasized or the methodological weaknesses in all existing literature. The basis for both suggestions is valid, but the author's perspective tends to produce an imbalance in interpretation.

Studies of residential exposures were rarer in this recent literature. The one negative study was not of great value due to the lack of evidence that "exposed" persons had, in reality, been exposed.

The laboratory studies of carcinogenesis were scarce, though other literature addressed the basic biological effects presumed to underlie carcinogenesis (e.g., endocrine changes, immune responses). The lack of high-quality laboratory studies of carcinogenesis leaves the interpretation of human data more uncertain in that the plausibility of carcinogenesis from electromagnetic fields is so uncertain.

The overall review of the most recent work on ELF electromagnetic fields and cancer risk represents the continued accumulation of suggestive but flawed studies. Several of the epidemiologic studies concerning occupational exposures and cancer risk are improvements on past work, though the severe limitation in exposure characterization precludes conclusive results. Job titles remain the primary mode of exposure characterization, which is clearly an imperfect proxy for the true exposures to electromagnetic fields. Nonetheless, the growing evidence for an association between some aspect of working in "electrical occupations" and cancer risk should not be ignored. The conclusion that electromagnetic fields cause leukemia and other cancers is unwarranted, but the conclusion that there is some nonrandom relationship between selected occupations and cancer risk is strengthened by several of the studies reviewed.

It is useful to contrast the evidence reviewed above with that available at the time of the 1985 AIBS report. In the area of nonspecific effects of electric field exposures, Broadbent's et. al. study is quite thorough in evaluating psychological and medical symptoms, and finds no associations. There has been little new information on residential exposures to electromagnetic fields and cancer, but the occupational literature has grown. The addition of several more tentative suggestions that "electrical" occupations are associated with increased leukemia and possibly brain cancer strengthens the conclusion that some aspect of such occupations (not necessarily electromagnetic fields) are associated with carcinogenic risks. The pattern is more convincing of some nonrandom associations than at the time of the earlier report.

Behavioral Effects

Most of the citations reviewed dealt with behavioral effects observed in animals exposed to 50- to 60-Hz, kV/m EM fields, either in the vicinity of electric power transmission lines or produced in the laboratory. Measured effects included vocalization, activity patterns, psychomotor tests, adversive behavior, and alteration of circadian rhythms.

Sophisticated studies of swine chronically exposed to 30 kV/m EM fields below transmission lines failed to reveal significant reproducible changes in behavior [Phillips et al. (1977); Mahmoud et al. (1983); and Lovely et al. (1985)]. In some cases vocalization was greater within the field, and there was a tendency to avoid the EM field when at rest. The authors were reluctant, however, to attribute the observations entirely to the presence of the EM field. There does appear to be evidence, at least for detection of the 30 kV/m field, which is reinforced by observations that there is reduced grazing by cattle beneath activated transmission lines [Rogers et al. (1983)]. On balance, the conclusion that there are no significant adverse effects of EM fields produced by power transmission lines appears valid [Phillips et al. (1985)].

In laboratory experiments with rats, mice, and chicks exposed to 45- to 60-Hz EM fields varying from 30-500 kV/m, no effects were detected on food and water consumption, growth, activity, or learning [Mathewson et al. (1977a); Mathewson et al. (1977b); Graves (1977); Creim et al. (1984); Reed et al. (1985); and Blackwell et al. (1985)]. Conversely, one paper reports alteration of activity patterns in mice exposed to 60-Hz, 1-kV/m fields [Adey et al. (1979)], and magnetic fields of 100-150 μT were reported to influence behavior in rats [Liboff et al. (1985) and Miller et al. (1985)].

The search for mechanisms whereby EM fields are detected continues. In general, it appears that "detection of power line EMF occurs reliably within and across species, with a common threshold near 2 kV/m" [Maler (1985)]. The threshold for detection in rats is reported to be 3-10 kV/m [Stern et al. (1985)]. Pigeons can detect 60-Hz, 5-kV/m fields [Graves (1981)]. Baboons can detect 60 Hz at 8-28 kV/m [Orr et al. (1986)], but 60 does not produce aversive behavior [Rogers et al. (1986)]. The mechanism of detection is unclear. Rat vibrissae are credited with detection of 60-Hz, 75- to 100-kV/m fields [Lovely et al. (1985)], but in an experiment intended to confuse such a mechanism, rats detected 60-Hz fields even in a moving air stream [Sagan et al. (1985)]. Detection of EM fields through induced body currents does not appear to be a viable mechanism [Creim et al. (1985)], and magnetic fields are probably not involved [Gould (1984)]. While not directly relevant to ELF, electroreceptors have been confirmed and described in the lamprey eel [Akoev et al. (1984) and Muraveiko (1984)]. Unfortunately, many of the more recent citations were abstracts that did not allow thorough evaluation.

With regard to detection of magnetic fields, magnetite particles have been described in pigeons and more recently in bacteria [Frankel et al. (1979) and Blakemore et al. (1980)], as well as iron-containing cells in honey bees [Kuterbach et al. (1982)], ferric iron in the human sphenoid sinuses [Baker et al. (1983)], and magnetic crystals in the sinuses of yellow-fin tuna [Walker et al. (1984)]. Whether these inclusions play a role in the survival of the species or are simply evolutionary artifacts is not clear. There is reportedly no evidence of magnetic sensitivity in humans [Fildes et al. (1984)]. Gould suggests that magnetic induction is a feasible strategy for aquatic organisms such as sharks and rays, but that magnetic induction is ruled out on theoretical and empirical grounds for terrestrial animals [Gould (1984)]. Thus, if magnetic fields are detected by terrestrial animals, it is likely through magnetically sensitive materials or molecules. Two studies suggest that the earth's magnetic field may influence biochemical reactions: specifically the formation of melatonin [Cremer-Bartels et al. (1983) and (1984)]. Melatonin in turn is known to influence biorhythms and reproductive cycles. Unfortunately, the latter two studies are flawed, and the finding should be viewed with caution.

Circadian systems are most commonly considered within the field of regulatory biology, since the integrity of the internal timing system is paramount to the normal functioning of organisms. Circadian rhythms can be studied at almost any level of organization from cells to the intact organism. The overt evidence of a change in the circadian system is most commonly reflected in behavioral changes, including increased amounts of activity or rest or activity or arousal at an unusual time (phase shifts). Phase shifts, transitory in nature, have been reported in mice exposed to 60-Hz, 50-to 100-kV/m fields [Ehret et al. (1979a) and (1979b) and Groh et al. (1985)]. On-going studies are searching for a threshold of exposure to produce effects on the circadian system [Sagan (1985)]. On balance, there is evidence of circadian systems being perturbed by 60-Hz, kV/m EM fields [Sulzman (1985)]. In most cases, however, the effects have been produced in animals maintained in constant dark away from the normal day-night photoperiod known to dominate phasing of the circadian system. As a consequence, it appears unlikely that operation of the ELFCS system will adversely affect circadian systems. More encompassing, none of the citations reviewed suggest adverse behavioral effects to result from operation of the ELFCS

Ecological Effects

Eighty five citations judged to be relevant to either ecology or behavior were reviewed, since behavioral changes are likely to be reflected in ecological changes. Only 39 of the citations were issued after completion of the 1985 AIBS Reviews [AIBS, March (1985), AIBS, May (1985)]. Of these, 10 citations were chapters from the AIBS Reviews; 13 citations reported research previously evaluated in Chapter 10 of the AIBS (March 1985) report, which dealt with the effects of ELF transmissions on the natural biota [Lindberg (1985)]; and 7 citations were abstracts describing ecological studies in progress at the Michigan and Wisconsin ELF communication sites, Thus, the body of knowledge relevant to ecological effects has apparently not significantly changed since 1985, and the general conclusions put forth by the AIBS Review Committee remain valid.

For the purpose of this review "ecology" is interpreted rather broadly, since few if any studies dealt with such typical ecological subjects as population dynamics, community structure, food chains, or energy flows. Similarly lacking is information specific to the sensitivity of native species to ELF nonionizing radiation. A possible exception may be the honeybee studies by Bindokas et al. (1984); Greenberg (1985a, 1985b); and Fischer (1985). Considering the difficulty in attempting to extrapolate responses from one species to another, let alone to heterogeneous systems; the lack of dose response information for exposures to ELF radiation; and the lack of understanding of mechanisms to account for observed responses, one must conclude that there is no scientific evidence for or against ecological effects occurring at ELFCS sites. The ongoing ecological studies in Michigan and Wisconsin are intended to alleviate this deficiency [Zapotosky (1984), Burton, et al. (1985), Stearns et al. (1985), Larkin (1985), Niemi et al. (1986)]. Parodoxically, the probability of proving the null hypothesis (that no ecological effects have occurred as a result of exposure to the operating ELFCS) is very low, because the responses may be undetectable at the ecosystem level. A National Academy of Sciences evaluation [NAS (1977)] identified ecosystem effects as particularly important, because, in theory, they should represent an integration of all changes. The NAS also recognized however that the observed changes could be caused by "most anything". The accepted implication, with which we agree, is that the reported effects of ELF radiation are subtle, not catastrophic, and typically are effects not specific to ELF. The same kind of responses might be anticipated from a variety of environmental stressors. The ecosystem is a complex of biological species and physical factors that paradoxically is always in a state of flux while presenting an illusion of stability and demonstrating resiliancy to environmental stressors. Such a system may indeed mask or buffer subtle changes introduced by ELF transmission, leading to a false conclusion that no effect had occurred [Lindberg (1985)].

From an ecological perspective, the most dramatic changes in an ecosystem would occur if plants were adversely affected by ELF fields. Studies in the vicinity of high voltage lines did not show evidence of ELF fields below about 20 kV/m affecting plants [Rogers et al. (1984), Rogers et al. (1983) and Schwan (1984)]. Interpretation of data was sometimes confounded by environmental variables such as climatic factors. Results of the studies, however, gain credence when compared with the results of laboratory experiments. Several thousand plants representing 85 different species were chronically exposed to 60-Hz electric fields of 10-to 50-kV/m intensity in growth chambers under carefully controlled conditions [McKee (1985)]. Except for limited damage to leaf tips from coronal discharge, even the maximum field strength of 50 kV/m failed to affect overall growth, viability, or reproduction of exposed plants. Although the evidence suggests that plants will not be affected by operation of an ELFCS, there is a paucity of information regarding possible effects on lower plants or species occurring at the ELF communications sites.

Experiments with honeybees have shown that the abherrent behavior and reduction in honey yields observed in hives maintained in transmission line right-of-ways is attributable to step-currents from electromagnetic fields induced in the hive at the electric field intensities above 2 kV/m in air [Bindokas et al. (1984), Greenberg et al. (1985a, 1985b)]. This phenomenon can be alleviated by electrically shielding the hive. There is a reduction in foraging activity and queen-loss in electromagnetic fields above 5 kV/m. No adverse effects were observed in native bees near the operating ELF antenna in Wisconsin [Fischer (1985)]. A Russian investigator working with frequencies not relevant to ELF has reported wasps to be more sensitive than bees to electromagnetic fields and suggests that bee keepers use electromagnetic fields to stimulate foraging activity and swarming [Eskov (1982)]. On balance, the literature supports the position that honeybees will not be adversely affected by operation of the ELFCS.

Studies of migrating birds have reported changes in flight direction to occur as birds pass over an operating ELF antenna [Williams et al. (1977)]; however, there is no evidence that this phenomenon interferes with migratory success. A method of monitoring bird flight with mobile radar gear was described by Males (1985), and studies of migratory birds are in progress at the Michigan ELF communications antenna site [Larkin (1985)]. The question of whether or not birds really do depend on the earth's geomagnetic field for navigation is not resolved, but dependence is supported in the report by Bookman (1977) and challenged in a good overview of bird navigation in the report by Gauthreaux (1985). Possible mechanisms for detection of electromagnetic fields is briefly reviewed under the topic "Behavior". On balance, it appears that some migratory birds may sense ELF fields above the communications antenna, but because the navigational system of birds uses so many environmental clues, it is not clear that detection of the fields interfere with migratory success.

LITERATURE CITED

Adey W.R., Bawin S.M. et al. 1979. Effects of 60 Hz Environmental Electric Fields on the Mammalian Central Nervous System. Final Report to ONR by Veterans Admin. Med. Center Loma Linda, April.

Akoev G.N. and Muraveiko V.M. 1984. Physiological Properties of Lateral Line Receptors of the Lamprey. Neuroscience Letters, No. 49, pp. 171-173, August 1984.

Albert E.N., Yoshioka A. et al. 1985. Modulation of Fetal Rat Neurite Growth by Pulsing Electromagnetic Fields. Seventh Annual BEMS Meeting, June 1985.

Algers B. and Hennichs K. 1983. Biological Effects of Electromagnetic Fields on Vertebrates. A Review. Vet. Research Communications, Vol. 6, pp. 265-279.

Algers B. and Hennichs K. 1985. The Effect of Exposure to 400 kV Transmission Lines on the Fertility of Cows. A Retrospective Cohort Study. Preventive Veterin. Med., 3, pp. 351-361, 1985.

American Institute of Biological Sciences (AIBS). 1985a. Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields. Report of the Committee on Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields. AIBS, Arlington, Va., March 1985.

American Institute of Biological Sciences (AIBS). 1985b. Assessments and Viewpoints on the Biological and Human Health Effects of Extremely Low Frequency (ELF) Electromagnetic Fields. Compilation of Commissioned Papers for the ELF Literature Review Project. Washington, D.C., May 1985.

Anderson L.E. 1982. Neurochemical Effects of 60-Hz Electric Fields. U.S. Department of Energy Contractors Review.

Anonymous 1. 1985. Biological Effects of 60-Hz Power Transmission Lines. Florida Department of Environmental Regulations, March 1985.

Anonymous 2. 1984. Environmental Effects of Electric Fields Near Power Transmission Networks. Electra, No. 94 (CIGRE Working Group 01 of Study Committee 36, Interference) pp. 97-109.

Archer C.W. and Ratcliffe N.A. 1981. The Effects of Pulsed Magnetic Fields on Bone and Cartilage in Vitro. Trans. 1st Annual BRAGS, Phila., PA, USA, Nov. 9-11.

Asherl R., Vonfinkenstein A. et al. 1982. Changes and Problems of the Supplementary Treatment of Congenital Pseudarthrosis of the Tibia With Electric and Magnetic Fields. Trans. 2nd Annual BRAGS Meeting, September.

Barker B. 1984. Cancer and the Problems of Risk Assessment. Electric Power Research Institute, pp. 26-35, 1984.

Barnes F.S., Wachtel H. et al. 1986. Magnetic Fields and Wiring Configurations. Eighth Annual BEMS Meeting, Madison, WI, p. 7, June 1-5, 1986.

Baroncelli P., Battisti S. et al. 1986. A Health Examination of Railway High-Voltage Substation Workers Exposed to Extremely Low Frequency Electromagnetic Fields. Amer. J. Ind. Med., Vol. 10, No. 1, pp. 45-56.

Bassett L.S., Tzitzikalakis G. et al. 1979. Prevention of Disuse Osteoporosis in the Rat by Means of Pulsing Electromagnetic Fields. Electrical Properties of Bone and Cartilage: Experimental Effects and Clinical Applications, Grune and Stratton, pp. 311-331.

Bassett C.A.L. 1982a. Non-Surgical Treatment of Ununited Fractures by Specific Pulsed Electromagnetic Fields. Z. Orthop., Vol. 120, No. 4, pp. 493-496, 1982.

Bassett C.A.L., Mitchell S.N. et al. 1982b. Treatment of Therapeutically Resistant Non-Unions With Bone Grafts and Pulsing Electromagnetic Fields. J. Bone and Joint Surg., Inc., Vol. 64-A, No. 8, pp. 1214-1220.

Bassett C.A.L. 1984. The Development and Application of Pulsed Electromagnetic Fields (PEMFs) for Ununited Fractures and Arthrodeses. Ortop. Clinics of North Amer., Vol. 15, No. 1, pp. 61-87.

Bassett C.A.L., Caulo N. et al. 1981. Congenital "Pseudarthroses" of the Tibia: Treatment With Pulsing Electromagnetic Fields. Clinical Orthop. and Related Research, No. 154, pp. 136-149.

Bawin S.M., Sheppard A.R., et al. 1977a. Possible Mechanisms of Weak Electromagnetic Coupling in Brain Tissue. The Physical Basis of Electromag. Interac. With Biol. Sys.; Univ. Maryland, pp. 75-90.

Bawin S.M., Sheppard A.R., et al. 1977b. Models of Long-Range Order in Cerebral Micromolecules: Effects of ELF, VHF, and UHF Fields in Calcium Binding. USNC/URSI Internat. Meet., p. 100.

Bentall R.H.C. 1981. Effect of a 15-Watt Pulsed 27.12-MHz and a 2-mWatt Pulsed 3-MHz Device on the Tensile Strength of Rat Abdominal Wall Incisions. Trans. 1st Annual BRAGS Meeting, p. 23, November 1981.

Bindokas V. and Greenberg B. 1984. Biological Effects of 765 kV, 60 Hz Transmission Line on Honey Bees (Apis Mellifera L.): Hemolymph as a Possible Stress Indicator. Bioelectromagnetics Vol. 5, No. 3, pp. 305-314.

Blackman C.F., Elder J.A. et al. 1977. Two Parameters Affecting Radiation-Induced Calcium Efflux from Brain Tissue. USNC/URSI Internat. Meet., p. 101.

Blackman C.F., Benane S.G. et al. 1985a. A Pattern of Frequency-Dependent Responses in Brain Tissue to ELF Electromagnetic Fields. Bioelectromagnetics Society 7th Annual Meeting.

Blackman C.F., Benane S.G., et al. 1985b. Effects of ELF (1-120 Hz) and Modulated RF Fields on the Efflux of Calcium Ions from Brain Tissue in Vitro. Bioelectromagnetics, Vol. 6, pp. 1-11.

Blackman C.F. 1985c. The Biological Influences of Low-Frequency Sinusoidal Electromagnetic Signals Alone and Superimposed on RF Carrier Waves. U.S. Dept. Commerce, NTIS, PB 85-161248.

Blumlein H., McDaniel J. et al. 1978. The Effect of Low-Frequency Magnetic Fields on the Healing of Pseudarthroses in Animal Experiments. Zeitschrift Fuer Orthopaedie und Ihre Grenzgebiete, Vol. 116, No. 4, pp. 603-604.

Bookman M.A. 1977. Sensitivity of the Homing Pigeon to an Earth-Strength Magnetic Field. Nature, Vol. 267, pp. 340-342, May.

Bridges J.E., Frazier M.J. et al. 1978. The Effect of 60 Hz Electric Fields and Currents on Implanted Cardiac Pacemakers. IEEE Internat. Symp. on Electromag. Compatibility, pp. 258-265.

Broadbent D.E., Broadbent M.H.P., et al. 1985. Health of Workers Exposed to Electric Fields. Brit. J. Indust. Med., No. 42, pp. 75-84.

Buiavikh A.G. 1984. Effects of Low-Frequency Magnetic Fields on the Blood Lipoprotein Spectrum in Hypertension Patients. Vrach. Delo, No. 9, pp. 75-77, September 1984.

Burton T.M., Merritt R.W. et al. 1985. ELF Communications System Ecological Monitoring Program Annual Report for Aquatic Ecosystems - Tasks 5.8, 5.9, 5.10, June.

Bustos G., Roth R.H. et al. 1978. Tyrosine Hydroxlase Activation and Transmitter Release from Central Noradrenergic Neurons by Electrical Field Stimulation. Archives of Pharmacology, No. 301, pp. 149-156.

Butrous G.S., Barton D.B. et al. 1982. Effects of High-Intensity Power- Frequency Electric Fields on Implanted Modern Multiprogrammable Cardiac Pacemakers. J. Royal Soc. Med., Vol. 75, pp. 327-331.

Butrous G.S., Male J.C. et al. 1983. The Effect of Power Frequency High Intensity Electric Fields on Implanted Cardiac Pacemakers. Pace, Vol. 6, pp. 1281-1292, November-December 1983.

Cadossi R., Giancecchi F. et al. 1982. Low Frequency Pulsing Electromagnetic Fields in the Treatment of Delayed Unions and Acquired Pseudo-Arthrosis. Trans. 2nd Annual BRAGS Meeting, p. 71, September 1982.

Cain C.D., Luben R.A. et al. 1985. Pulsed Electromagnetic Field Effects on Responses to Parathyroid Hormone in Primary Bone Cells. Bioelectromagnetics Society 7th Annual Meet.

Calle E.E. and Savitz D.A. 1985. Leukemia in Occupational Groups With Presumed Exposure to Electrical and Magnetic Fields. New Engl. J. Med., Vol. 313, No. 23, pp. 1476-1477, 1985.

Cameron I.L., Hunter K.E. et al. 1985. Retardation of Embryogenesis by Extremely Low Frequency 60 Hz Electromagnetic Fields. Physiol. Chem. Phys. Med. NMR (USA), Vol. 17, No. 1, pp. 135-138.

Carmaciu R., Groza P. et al. 1977. Effects of a High-Tension Electric Field on the Secretion of Antiduretic Hormone in Rats. Revue Romaine De Morphologie, D'Embryologie, Et De Physiologie, Serie Physiologie, Vol. 14, No. 2, pp. 79-84.

Carsten A.L. and Benz R.D. 1985. Genetic, Cytogenetic and Somatic Effects of 60 Hz Electric and Magnetic Fields in Mice. Seventh Annual BEMS Meeting, June 1985.

Carstensen E.L. 1985. Studies of Plants and Animals Exposed to ELF Electric and Magnetic Fields. Assessments and Viewpoints on the Biological and Human Health Effects of Extremely Low Frequency (ELF) Electromagnetic Fields. AIBS Report, pp. 33-139, May.

Caullay J.M. and Mann T.C. 1982. Pulsing Electromagnetic Fields in Treatment of Non-Union Fractures. J. Royal College of Surgeons of Edinburgh, pp. 102-107, March 1982.

Chen T., Harrington D.B. et al. 1982. An In-Depth Scanning Electron Microscopy Study of Electronically Stimulated Bone Growth. Trans. 2nd Annual BRAGS Meeting, p. 48, September 1982.

Cheng N. and Mulier J.C. 1981. Treatment of Non-Union of the Tibia With a Pulsed Electromagnetic Field. Trans. 1st Annual BRAGS Meeting, p. 41, November 1981.

Chernoff N. 1985. Reproductive and Developmental Effects in Mammalian and Avian Species from Exposure to ELF Fields. Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields: AIBS Report, Chapter 8, March 1985.

Chvojka J. 1985. Pulsatile Magnetic Field and Its Effect on Healing of Fractures and Pseudarthroses. Acta Chir. Orthop. Traumatol. Cech., Vol. 52, No. 1, pp. 36-46.

Cleary S.F. 1978. Investigation of the Biological Effects of Pulsed Electrical Fields. Virginia Commonwealth University, Annual Progress Report.

Cockshutt J.R., Binnington A.G. et al. 1984. Effects of a Low Frequency Pulsating Magnetic Field on the Healing of Rat Skin Wounds. Veterin. Surg., No. 46, 13.3, p. 149.

Colacicco G. and Pilla A.A. 1984. Electromagnetic Modulation of Biological Processes: Influence of Culture Media and Significance of Methodology in the Ca Uptake by Embryonic Chick. Calcified Tissue Internat., No. 36, pp. 167-174.

Conti P., Gigante G.E., et al. 1985. A Role for Ca2+ in the Effect of Very Low Frequency Electromagnetic Field on the Blastogenesis of Human Lymphocytes. FEBS Letter, Vol. 181, No. 1, pp. 28-32.

Crocetti A.M. 1983. Report on Conferences With Dr. Nancy Wertheimer, and Wertheimer Response. New York Dept. of Health Power Lines Project, February.

Delport P.H., Cheng N. et al. 1982. The Effects of Pulsed Electromagnetic Fields on Protein Synthesis and Membrane Transport in Rat Skin. Trans. 2nd Annual BRAGS, p. 34.

Delport P.H., Mulier M. et al. 1982a. Treatment of Non-Union of Femur With Pulsed Electromagnetic Fields. Trans. 2nd Annual BRAGS Meeting, p. 76, September 1982.

Dihel L.E., Smith-Sonneborn J. et al. 1985. Effects of an Extremely Low Frequency Electromagnetic Field on the Cell Division Rate and Plasma Membrane of Paramecium Tetraurelia. Bioelectromagnetics, Vol. 6, pp. 61-71.

Dodge C.H., Helman K.B. et al. 1985. Effects of Low Level Pulsed Electromagnetic Field on Growth and Development of Hatchling Turtles. Bioelectromagnetics Society 7th Annual Meeting.

Dunn A.W. and Rush G.A. 1984. Electrical Stimulation in Treatment of Delayed Union and Nonunion of Fractures and Osteotomies. Southern Med. J., Vol. 77, No. 12, pp. 1530-1534, February 1984.

Ehret C.F., Sacher G.A. et al. 1979. Biomedical Effects of Energy Transmission: Effect of Extremely Low Frequency Fields on Ultradian, Circadian and Infradian Functions in Rodents. Argonne Nat. Lab., Div. Biol. and Med. Research Annual Rep. for 1979, ANL-80-90, pp. 37-38.

Enzler M.A., Sumner-Smith G. et al. 1984. Treatment of Nonuniting Osteotomies With Pulsating Electromagnetic Fields. Clinical Orthop. and Related Research, No. 187, pp. 272-276, July-August 1984.

Eskov E.K. 1982. Ethnological Anomalies in Bees and Wasps Caused by the Effect of Electric Fields. Ekologiya O, No. 6, pp. 76-78.

Fischer R.L. 1985. ELF Communications System Ecological Monitoring Program - Biological Studies of Pollinating Insects: Megachilid Bees. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program, Vol. 2, Tab F, IIT Research Institute Report E06549-17, June.

Fitton-Jackson S., Marsland T.P., et al. 1982. Physical Factors Involved in Biological Responses to Pulsed Magnetic Fields. Trans. 2nd Annual BRAGS, p. 31.

Flodin U., Fredriksson M. 1986. Background Radiation, Electrical Work, and Some Other Exposures Associated With Acute Myeloid Leukemia in a Case- Referent Study. Arch. Environ. Health, Vol. 41, pp. 77-78.

Florida Electric and Magnetic Fields Science Advisory Commission (FEMFSAC). 1985. Biological effects of 60 Hz power transmission lines. Tampa, Fla,; Florida Electric Power Coordinating Group.

Fontanesi G., Giancecchi F. et al. 1985. Pseudarthrosis Treatment With Cancellous Bone Grafts and Low-Frequency Pulsing Electromagnetic Fields. J. Bioelectricity, 4(1), pp. 163-170.

Formanek V.C., Gauger J.R. et al. 1977. Susceptibility of Cardiac Pacemakers to Modulated ELF Magnetic Fields. IITRE Report E6357-5, June.

Franc C., Schachar N. et al. 1981. The Electromagnetic Stimulation of Ligament Healing in a Rabbit Model. Trans. 1st Annual BRAGS Meeting, November 1981.

Frazier M.J., Bridges J.E. et al. 1978. Internal Body Potentials and Currents From ELF Electric Fields and Household Appliances. IEEE Intern. Symp. on Electromag. Compatib., pp. 266-272, June 1978.
.sp Freimark S.J., Salzinger K. et al. 1985. Effects of 60 Hz Electric and Magnetic Fields on the Response Rate of Adult and Pre/Perinatally Exposed Rats. Seventh Annual BEMS Meeting, June 1985.

Gauthreaux S.A. 1985. Electromagnetic Influences on Birds. Assessments and Viewpoints on the Biological and Human Health Effects of Extremely Low Frequency (ELF) Electromagnetic Fields; AIBS Report, pp. 141-153, May.

Gona A.G., Yu M.C. et al. 1985. Effects of 60 Hz Electric and Magnetic Fields on Rat Cerebellar Development. Bioelectromagnetics Society 7th Annual Meeting.

Goodman R., Henderson A.S. et al. 1981. The Effect of Pulsing Electromagnetic Fields on Transcription in Polytene Chromosomes. Trans. 1st Annual BRAGS, p. 83.

Goodman R., Bassett C.A.L. et al. 1982. Selected Electromagnetic Field Effects on Cellular Regulatory Processes. Trans. 2nd Annual BRAGS, p. 42.

Graham C. 1984. Influence of 60 Hz Fields on Human Behavior, Physiology, and Biochemistry. Final Report, July 1, 1982 to July 31, 1984, for New York State Department of Health, Albany.

Graves H.B., Long P.D. et al. 1979. Biological Effects of 60 Hz Alternating-Current Fields: A Cheshire Cat Phenomenon? Hanford Life Sciences Symposium, 18th DOE Symposium, Series 50, pp. 184-197.

Greenbaum B., Goodman E.M. et al. 1985. Cell Surface Effects of Pulsed Electromagnetic Fields on Physarum Amoebae. Bioelectromagnetics Society 7th Annual Meet.

Greenberg B., Bindokas V.P. et al. 1985a. The Effects of High-Voltage Transmission Lines on Honeybees. EPRI Report EA-3898, May.

Greenberg B., Bindokas V.P. et al. 1985b. Extra-High Voltage Transmission Lines: Mechanisms of Biological Effects on Honeybees. EPRI Report EA-4218, August.

Grigorieva, V.D., Tsarfis P.G. et al. 1980. Use of a Low-Frequency Permanent Magnetic Field in Patient With Deforming Osteoarthrosis and Rheumatoid Arthritis. Voprosy Kurortol., Fizioterapii I Lechebn. Fizichesk. Kultur., No. 4, pp. 29-35.

Grissett J.D., Kupper J.L. et al. 1977. Exposure of Primates for One Year to Electric and Magnetic Fields Associated With ELF Communications System. Naval Aerospace Med. Research Lab. Report NAMRL-1240.

Gustafson R.J. and Albertson V.D. 1982. Neutral-To Earth Voltage and Ground Current Effects in Livestock Facilities. IEEE Trans. Power Appar. and Sys., Vol. PAS-101, No. 7, pp. 2090-2095.

Haimovici N. 1982. Influence of the Neoformation of Bone Tissue by Means of Low-Frequency Pulsed Magnetic Fields. Biomed. Thermology, pp. 247-255.

Hanley K.J., Norton L.A. et al. 1982. The Effects of Pulsed Electromagnetic Fields Upon Periosteal and Osteoblast-Like Cells Grown in Culture. Trans. 2nd Annual BRAGS Meeting, p. 46.

Harrington D., Walter J. et al. 1982. The Efficacy of Electrical Stimulation on Experimentally Induced Non-Union Fracture of Canine Tibia. Trans. 2nd Annual BRAGS Meeting, p. 84, September 1982.

Harrison M.H.M. and Bassett C.A.L. 1984. Use of Pulsed Electromagnetic Fields in Perthes Disease: Report of a Pilot Study. J. Pediatric Orthoped., Vol. 4, No. 5, pp. 579-594.

Haupt H.A. 1984. Electrical Stimulation of Osteogenesis. Southern Med. J., Vol. 77, No. 1, pp. 56-64, January 1984.

Hellman K.B., Fowler A.K. et al. 1985. The Effect of Electromagnetic Fields on Lymphocyte Function: Enhancement of Mitogenic Stimulation. Seventh Annual BEMS Meeting, June.

Irnich W. 1984. Interference in Pacemakers. Pace, Vol. 7, Part 1, pp. 1021-1048, November-December 1984.

Jackson S.F., Hickman J. et al. 1985. Effects of Pulsed Magnetic Fields on Acute Tendon Injuries. Seventh Annual BEMS Meeting, June 1985.

Johnson D.E. and Rodan G.A. 1982. The Effect of Pulsating Electromagnetic Fields on Prostaglandin Synthesis in Osteoblast-Like Cells. Trans. 2nd Annual BRAGS Meet., p. 7.

Jolley W.B., Knierim K., et al. 1982. Effects of Pulsed Electromagnetic Fields on Cellular Infiltration and Collagen Formation in Implanted Viscose Sponges. Trans. 2nd Annual BRAGS Meet., p. 32.

Jones D.B. 1982. The Effect of Pulsed Magnetic Fields On cAMP Metabolism in Chick Embryo Tibiae. Trans. 2nd Annual BRAGS, p. 29.

Kahanovitz N., Arnoczky S.P. et al. 1984. The Effect of Postoperative Electromagnetic Pulsing on Canine Posterior Spinal Fusions. Spine, Vol. 9, No. 3, pp. 273-279, April 1984.

Kavet R. 1982. Biological Effects of Electric Fields: EPRI's Role. IEEE Trans. Power Appar. Syst., Vol. PAS 101, No. 7, pp. 2115-2121.

Korenstein R., Somjen D. et al. 1982. Primary Induced Cellular Changes and Cell Specificity in Pulsed Capacitive Stimulation of Bone Cells In Vitro. Trans. 2nd Annual BRAGS Meeting, p. 5.

Korenstein R., Somjen D. et al. 1984. Capacitive Pulsed Electric Stimulation of Bone Cells - Induction of Cyclic AMP Changes and DNA Synthesis. Biochemica et Biophysica Acta, Vol. 803, No. 4, pp. 302-307.

Kraus W., Lechner G. et al. 1982. On the Treatment of Loosening of Endroprostheses by Means of Pulsing Electromagnetic Fields. Trans. 2nd Annual BRAGS Meeting, p. 15, September 1982.

Larkin R.P. 1985. ELF Communications System Ecological Monitoring Program: Field Studies of Effects of ELF on Migrating Birds. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program, Vol. 2, Tab J., IIT Research Institute.

Laub F. and Korenstein R. 1982. Actin Polymerization Induced by Pulsed Electric Stimulation of Bone Cells in Vitro. Trans. 2nd Annual BRAGS Meeting, p. 43, September.

Laub F. and Korenstein R. 1984. Actin Polymerization Induced by Pulsed Electric Stimulation of Bone Cells In Vitro. Biochemica Et Biophysica Acta, No. 803, pp. 308-313.

Lee J.M., Bracken T.D. et al. 1977. Electrical and Biological Effects of Transmission Lines; A Review. Bonneville Power Administration, BPA-BIO-78-1, June.

Lee J.M. 1984. Status of Research on Biological Effects of Transmission Line Electric and Magnetic Fields. Right of Way, Vol. 31, No. 1, pp. 4-12, February.

Liboff A.R., Williams T. et al. 1982. Alternating Magnetic Fields Enhance DNA Synthesis in Fibroblastic Cells. Trans. 2nd Annual BRAGS Meet., p. 6.

Liboff A.R. 1985. Cyclotron Resonance Mechanism for Electromagnetic Energy Transfer to Cells. Bioelectromagnetics Society 7th Annual Meeting.

Liburdy R.P. 1982. Carcinogenesis and Exposure to Electrical and Magnetic Fields (Letter to the Editor). New Engl. J. Med., p. 1402, 1982.

Lin R.S., Dischinger P.C. et al. 1985. Occupational Exposure to Electromagnetic Fields and the Occurrence of Brain Tumors. An Analysis of Possible Association. J. Occup. Med., Vol. 27, No. 6, pp. 413-419.

Lindberg R.G. 1985. Potential Effects on Natural Biota in Operating an Extremely Low Frequency Communications System. Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields; AIBS Report, Chapter 10.

Logue J.N., Hamburger S. et al. 1985. Congenital Anomalies and Paternal Occupational Exposure to Shortwave, Microwave, Infrared, and Acoustic Radiation. J. Occup. Med., Vol. 27, No. 6, pp. 451-452., June 1985.

Loyd R.D., Mathews J.L. et al. 1982. Pulsing Electromagnetic Field Effects on Cultured Fibrocytes. Trans. 2nd Annual BRAGS Meeting, p. 95.

Lyle D.G., Kamin G.W. et al. 1985. T-Cell Growth Factor Production and (+3)H-Thymidine Incorporation by the Myeloid Leukemia Cells M1 and U-937 in the Presence of 12-O-Tetradecanoylphorbol-13-Acetate (TPA) Are Unaffected by 60-Hz Pulsed 20 Gauss Magnetic Field. Bioelectromagnetics Society 7th Annual Meeting.

Maffeo S., Miller M.W., et al. 1984. Lack of Effect of Weak Low Frequency Electromagnetic Fields on Chick Embryogenesis. J. Anatomy, No. 139, Part 4, pp. 613-618.

Males R. 1985. Assessing the Impact of Power Lines on Birds. EPRI Journal, Vol. 10, No. 4, pp. 48-51, May.

Marsakova H.B. 1983. The Influence of Variable Magnetic Field (VMF) on Central Nervous System (CNS) and Change of Amount of Iodine in Organs and Tissues. Kosmicheskaya Biologia I Aviakosmicheskaya Meditsina, Vol. 17, No. 4, pp. 90-92, July-August 1983.

Marcer M., Musatti G. et al. 1984. Results of Pulsed Electromagnetic Fields (PEMF's) in Ununited Fractures After External Skeletal Fixation. Clinical Orthop. and Related Research, No. 190, pp. 260-265, Nov. 1984.

Mathewson N.S., Oosta G.M. et al. 1977. Extremely Low Frequency (ELF) Vertical Electric Field Exposure of Rats: A Search for Growth, Food Consumption and Blood Metabolite Alterations. Armed Forces Radiobiology Institute.

Mathewson N.S., Oosta G.M. et al. 1977. Effects of 45 Hz Electric Field Exposure on Rats. Biological Effects of EM fields- Selected Papers of the USNC/URSI Annual Meeting, Vol. 1, pp. 460-471.

McDowall M.E. 1986. Mortality of Persons Resident in the Vicinity of Electricity Transmission Facilities. Brit. J. Cancer, No. 53, pp. 271-279.

McKee G.W. 1985. Effects of 60 Hz Electric Fields on Living Plants Exposed for Extended Periods. EPRI Report EA-4159, July

McRobbie D. and Foster M.A. 1985. Pulsed Magnetic Field Exposure During Pregnancy and Implications for NMR Foetal Imaging: A Study With Mice. Magn. Resonance Imag., Vol. 3, pp. 231-234.

Mercer H.D. 1985. Biological Effects of Electric Fields on Agricultural Animals. Vet. Hum. Toxicol. (USA), Vol. 27(5), pp. 422-426.

Milham S. 1985. Silent Keyes: Leukemia Mortality in Amateur Radio Operators (Letter to the Editor). The Lancet, p. 812, April 1985.

Miller G.J., Burchard H. et al. 1984. Electromagnetic Stimulation of Canine Bone Grafts. J. Bone and Joint Surg., Vol. 66-A, No. 5, pp. 693-698, June 1984.

Mitbreit I.M., Lavrishcheva G.I. et al. 1981. Changes in Peripheral Circulation of the Extremities During Reparative Regeneration of the Bone Under the Effect of Low-Frequency Magnetic Field. Vopr. Kurortol. Fizioterap. Lechebn. Fizichesk. Kult., Vol. 4, pp. 24-28, July-Aug. 1981.

Morgan M.G., Florig H.K. 1985. Power-Line Fields and Human Health. IEEE Spectrum, February.

Morris J.E. 1985. Immune System Responses and 60 Hz Electric Fields. Seventh Annual BEMS Meeting, June.

Moss A.J. and Carstensen E. 1985. Evaluation of Effects of Electric Fields on Implanted Cardiac Pacemakers. EPRI Report No. EPRI-EA-3917.

Murray C. 1982. Stimulation of Connective Tissue Protein Synthesis in Fibroblast Cultures by Pulsed Magnetic Fields. Trans. 2nd Annual BRAGS Meeting, p. 9.

Murray J.C. and Farndale R.W. 1985. Modulation of Collagen Production in Cultured Fibroblasts by a Low-Frequency, Pulsed Magnetic Field. Biochemica Et Biophysica Acta, No. 838, pp. 98-105.

Myers R.D. and Ross D.H. 1981. Radiation and Brain Calcium: A Review and Critique. Biobehavioral Reviews, Vol. 5, pp. 503-543.

Nahoda J., Koudela K. et al. 1984. Healing of Pseudarthroses of the Long Bones by Means of a Pulsating Electromagnetic Field. Acta Chir. Orthop. Traumatol. Cech., Vol. 51, No. 2, pp. 38-44, April 1984.

National Academy of Sciences (NAS). 1977. Biologic Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer. Report of the Committee on Biosphere Effects of Extremely-Low-Frequency Radiation. Washington, D.C.; National Research Council.

Niemi G.J. and Hanowski J.M. 1986. Assessing the Effects of the ELF Antenna System on Breeding Bird Communities. Eighth Annual BEMS Meeting, Madison, WI., 1-6 June.

Noda M., Sato A. et al. 1982. Effects of Pulsed Electromagnetic Fields on Cultured Chick Embryonic Femora. Trans. 2nd Annual BRAGS Meeting, p. 57.

Nordenson I., Hansson-Mild K. et al. 1984. Clastogenic Effects in Human Lymphocytes of Power Frequency Electric Fields: In Vivo and In Vitro Studies. Radiation and Environm. Biophysics, Vol. 23, No. 3, pp. 191-201.

Norton L.A. 1981. Effects of Electromagnetic Perturbation on Mixed Culture of Chondroblasts and Fibroblasts. Trans. 1st Annual BRAGS Meeting, p. 30, November 1981.

Olin R., Vagero D. et al. 1985. Mortality Experience of Electrical Engineers. Brit. J. Indust. Med., Vol. 42, No. 3, pp. 211-212.

Olsen R.G. and Jaffa K.C. 1984. Electromagnetic Coupling From Power Lines and Magnetic Field Safety Analysis. IEEE Trans. Power Appar. Sys., Vol. PAS-103, No. 12, pp. 3596-3607, December 1984.

Orgel M.G., O'Brien W.J. et al. 1984. Pulsing Electromagnetic Therapy in Nerve Regeneration: An Experimental Study in the Cat. Plastic and Reconstructive Surg., Vol. 73, No. 2, pp. 173-182. February 1984.

Ottani V., Monti M.G. et al. 1984a. Pulsed Electromagnetic Fields Increase the Rate of Rat Liver Regeneration After Partial Hepatectomy. Proc. Society for Experim. Biol. and Med., Vol. 176, No. 4, pp. 371-377.

Ottani V., Monti M.G. et al. 1984b. Influence of Pulsed Electromagnetic Fields on Regenerating Rat Liver After Partial Hepatectomy. J. Anatomy, No. 139, Part 2, pp. 253-263.

Pafkova H. 1985. Possible Embryotropic Effect of the Electric and Magnetic Component of the Field of Industrial Frequency. Pracov. Lek., 37, No. 5, pp. 153-158.

Pearce N.E., Sheppard A.R. et al. 1985. Leukemia in Electrical Workers in New Zealand (Letter to the Editor). The Lancet, April 1985.

Phillips R.D. 1985. Biological Effects of Electric Fields. U.S. Dept. of Commerce, NTIS, PB 85-243267.

Pilla A.A., Norton L. et al. 1982. Pulsatile Electromagnetically Induced Currents Synergize With Polymer Immunomodulating Drugs in the Inhibition of Growth of Murine Malignant Melanoma. Trans. 2nd Annual BRAGS Meeting, p. 16, September 1982.

Poli G., Dal Monte A. et al. 1985. Treatment of Congenital Pseudarthrosis With Endomedullary Nail and Low Frequency Pulsing Electromagnetic Fields: A Controlled Study. J. Bioelectricity, 4(1), pp. 195-209.

Ponomarev Y.T., Sorokina E.I. et al. 1984. Hydrocortisone and Adolsterone Content in the Blood of Patients With Coronary Heart Disease in the Treatment With Magnetic Fields. Vopr. Kurortol. Fizioterap. Lecheb. Fiz. Kult., No. 2, pp. 33-35, March-April 1984.

Porschke D. 1985. Short Electric-Field Pulses Convert DNA from "Condensed" to "Free" Conformation. Biopolymers, Vol. 24, No. 10, pp. 1981-1993.

Portet R., Cabanes J.,et al. 1984. Development of Young Rabbits Exposed to an Intense Electric Field. C.R. Societe de Biologie, Vol. 178, No. 2, pp. 142-145.

Ragan, A., Buschbom R.L., Pipes M.J., Phillips R.D. and Kaune W.T. 1981. Hematologic and Serum Chemistry Studies in Rats and Mice Exposed to 60-Hz Electric Fields. Interim Report, 1 October 1979-31 March 1981. DOE/RL/01830-T7 (DE82002426). Available from NTIS, Springfield, VA 22161.

Raji A.M. 1984. An Experimental Study of the Effects of Pulsed Electromagnetic Field (Diapulse) on Nerve Repair. J. Hand Surg., Vol. 90B, No. 2, pp. 105-112, June 1984.

Rakshit A.K. 1982. A Pilot Study of a Case of Long Standing Degenerative O.A. (Osteoarthritis) of Both Hips. Trans. 2nd Annual BRAGS Meeting, p. 42, September 1982.

Raleigh R.J. 1986. Joint HVDC Agricultural Study: Annual Progress Report for the 1985 Study period. DOE, Boneville Power Administration.

Reed T.J., Barnick J.S., et al. 1985. Effects of 60-Hz Electric Fields on Embryo and Chick Development, Growth, and Behavior. EPRI Report No. EPRI-EA-4161.

Rein G., Dixey R. et al. 1982. Electromagnetic Induction of Neurotransmitter Release from a Neuronal Cell Line in Tissue Culture. Trans. 2nd Annual BRAGS Meet., p. 39.

Rinaldi E., Negri V. et al. 1985. Treatment of Infected Pseudarthrosis of the Inferior Limb With Low-Frequency Pulsing Electromagnetic Fields: Report of 16 Cases. J. Bioelectricity, 4(1), pp. 251-264.

Rish W.R. 1982. Characterizing Uncertainty in Estimating Impacts from Energy Systems: Two Case Studies. Carnegie Mellon University Report, December.

Rodan G.A. and Johnson D.E. 1981. The Effect of Electromagnetic Fields on Alkaline Phosphatase in Osteoblast-Like Cells in Culture. Trans. 2nd Annual BRAGS Meet., p. 2.

Rogers L.E., Warren J.L. et al. 1983. Environmental Studies of a 1000 kV Prototype Transmission Line. Bonneville Power Administration CEA Project 78-95, July.

Rogers L.E., Beedlow P.A. et al. 1984. Environmental Studies of a 1000 kV Prototype Transmission Line - An Annual Report for the 1983 Study Period. Batelle Pacific Northwest Lab. Report, DOE/BP-371, November.

Rooze M, Hinsenkamp M, et al. 1982. In-Vivo Skeletal Modifications of Chick Embryos Induced by Electromagnetic Fields. Trans. 2nd Annual BRAGS Meet., Oxford, U.K., p. 73, Sept.20-22.

Rosenberg R.S. et al. 1983. Bioelectromagnetics, 4, pp. 181-191, 1983.

Saha S, Pal A., et al. 1981. Accelerated Growth of Chick Embryo Stimulated by a Pulsing Electromagnetic Field. Trans. 1st Annual BRAGS Meeting, p. 76.

Saha S, Pal A, et al. 1982. Growth of Chick Embryos Modulated by Pulsed Electromagnetic Stimulation. Trans. 2nd Annual BRAGS Meeting, p. 59.

Savitz D. A., Wachtel H. 1986. Case-Control Study of Childhood Cancer and Residential Exposure to Electromagnetic Fields. Eighth Annual BEMS Meeting, Madison, WI, p. 7, June 1-5, 1986.

Schaefer H. and Silny J. 1977. Sudden Infant Death Syndrome and Electromagnetic Fields: Point of View (Critique of E.E. Ekert). Medizinische Klinik, Vol. 72, No. 19, pp. 871-872, 1977.

Schubert T., Kleditzsch J. et al. 1982. Fluorescent Microscopic Investigations Into the Bone Healing Under Stimulation With Bipolar Pulse Currents and Interference Currents in the Animal Experiment. Trans. 2nd Annual BRAGS Meeting, p. 68, September 1982.

Schwan H.P. 1984. Electrical and Acoustic Properties of Biological Materials and Biomedical Applications. IEEE Trans. Biomed. Engin., Vol. BME-31, No. 12, pp. 872-878, December.

Sedel L., Christel P. et al. 1981. Acceleration of Repair of Non-Unions by Electromagnetic Fields. Revue De Chirurgie Orthop., Vol. 67, No. 1, pp. 11-23, 1981.

Serdyuk A.M. and Andrienko L.G. 1985. Effect of Electromagnetic Energy on Animals Reproductive Function. Seventh Annual BEMS Meeting, June 1985.

Seto Y.J., Hsieh S.T., et al. 1983. Food Consumption, Water Intake and Growth Data on Rats Chronically Exposed to a High Intensity 60 Hz Fields. J. Bioelectricity, Vol. 2, No. 2 and 3, pp. 197-205.

Seto Y.J., Fox F.T. et al. 1984. Chronic 60 Hz Electric Field Exposure Induced Subtle Bioeffects on Serum Chemistry. J. Environ. Science and Health, Vol.A 19, No. 8, pp. 865-885.

Seto Y.J., Majeau-Chargois D. et al. 1985. Histologic Study of the Internal Organs of Rats Chronically Exposed to a High-Intensity Electric Field. J. Environ. Science and Health, Vol.A 20, No. 1, pp. 73-85.

Shandala M.G., Dumanskiy Y.D., et al. 1981. Biological Effects of Industrial Frequency (50 Hz) Electric Fields. US-USSR Workshop on Physical Factors, Microwaves and Low Frequency Fields, pp. 253-264.

Shandala M.G., Dumanskiy Y.D., et al. 1983. Functional State of the Human Body During the Effect of Electric Field of Industrial Frequency. Vrachebnoye Delo, No. 6, pp. 102-104.

Sharrard W.J.W. 1984. Treatment of Congenital and Infantile Pseudarthrosis of the Tibia With Pulsing Electromagnetic Fields. Orthop. Clinics of North Amer., Vol. 15, No. 1, pp. 143-162, January 1984.

Sheikh K. 1986. Exposure to Electromagnetic Fields and the Risk of Leukemia. Arch. Environ. Health, Vol. 41, No. 1, pp. 56-63.

Sheppard, A.R. 1983. Biological Effects of High Voltage AC Transmission Lines with Reference to the Colstrip Project: Garrison-Spokane HVTL. Helena: Montana Department of Natural Resources and Conservation. Reprinted. NTIS No.PB83 207241. Springfield, Va.

Sheppard A.R. 1986. Effects of Extracellular ELF Electric Fields on Bursting Pacemaker Neurons of Aplysia. Eights Annual BEMS Meeting, p. 28 June 1-5.

Shim S.S. 1981. Effect of Electromagnetic Pulses Application on Fracture Healing With Emphasis on Vascularization. Trans. 1st Annual BRAGS Meeting, p. 19, November 1981.

Silin L.L., Brovkin S.V. et al. 1979. Low-Frequency Variable Magnetic Field as a Cure for Deforming Arthritis of the Knee Joint. Vopr. Kurortol. Fizioterap. Lecheb. Fizich. Kult., No. 2, pp. 41-43, March-April 1979.

Simmons J.W. 1985. Treatment of Failed Posterior Lumbar Interbody Fusion (PLIF) of the Spine With Pulsing Electromagnetic Fields. Clinical Ortop. and Related Research, No. 193, pp. 127-132, March 1985.

Simonis R.B., Good C. et al. 1984. The Treatment of Non-Union by Pulsed Electromagnetic Fields Combined With a Denham External Fixator. Injury, Vol. 15, No. 4, pp. 255-260, January 1984.

Sisken B.F. and McLeod B. 1982. The Effect of Orientation of Helmholtz Coils on Neurite Growth of Nerve Ganglia in Vitro. Trans. 2nd Annual BRAGS Meet. p. 90.

Spitz M.R. and Johnson C.C. 1985. Neuroblastoma and Paternal Occupation (A Case-Control Analysis). Amer. J. Epidem., Vol. 121, No. 6, pp. 924-929.

Stearns F., Guntenspergen G. et al. 1985. ELF Communications System Ecological Monitoring Program: Wetland Studies. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program, Vol. 2, Tab I, IIT Research Institute Report E06549, June.

Stern F.B., Waxweiler R.A., et al. 1986. A Case-Control Study of Leukemia at a Naval Nuclear Shipyard. Amer. J. Epidem., Vol. 123, No. 6, 980-992.

Stevenson A.P. and Tobey R.A. 1985. Potassium Ion Influx Measurements on Cultured Chinese Hamster Cells Exposed to 60-Hz Electromagnetic Fields. Bioelectromagnetics, Vol. 6, pp. 189-198.

Stollery B.T. 1986. Effects of 50 Hz Electric Currents on Mood and Verbal Reasoning Skills. Brit. J. Indust. Med., Vol. 43, pp. 339-349.

Stuermer K.M., Schmitt-Neuerberg K.P. et al. 1981. The Quantity of New Bone Formation in Cancellous Bone Grafts Under Electromagnetically Induced Alternating Current. Trans. 1st Annual BRAGS Meeting, p. 12, November 1981.

Swicord M.L. 1985. Possible Biophysical Mechanisms of Electromagnetic Interactions With Biological Systems. Biological and Human Health Effects of Extremely Low Frequency Electromagnetic Fields; AIBS Report, Chapter 3.

Tenforde T.S. 1985. Physical Properties of High-Voltage ELF Electromagnetic Fields and Their Interaction With Living Systems. Lawrence Berkeley Lab. Rep. 19710.

Tornqvist S. Norell S., et al. 1986. Cancer in the Electric Power Industry. Brit. J. Indust. Med., No. 43, pp. 212-213.

Ueno S., Kitahara T. et al. 1985. The Effects of ELF Magnetic and Electric Fields on the Embryonic Development of Frogs. Seventh Annual BEMS Meeting, June 1985.

Wachtel H., Barnes F. et al. 1986. The Predominant Statistical Influence of Outside Sources in Producing Non-Appliance ELF Fields in Homes. Eighth Annual BEMS Meeting, Madison, WI, June 1-5.

Wahlstrom O. 1982. Electromagnetic Fields Used in the Treatment of Fresh Fractures of the Radius. Trans. 2nd Annual BRAGS Meeting, p. 16, September 1982.

Watkins J.P., Auer J.A. et al. 1985. Healing of Surgically Created Defects in the Equine Superficial Digital Flexor Tendon: Effects of Pulsing Electromagnetic Fields Therapy on Collagen - Type Transformation and Tissue Morphological Reorganization. Amer. J. Vet. Res., Vol. 46, No. 10, pp. 2097-2103, October 1985.

Wertheimer N. 1982. Cancer and Alternating Magnetic Field Exposure. Amer. Assoc. Advancement of Sci., 148th National Meeting.

Wertheimer N. and Leeper E. 1986. Possible Effects of Electric Blankets and Heated Waterbeds on Fetal Development. Bioelectromagnetics, Vol. 7, pp. 13-22, 1986.

Westfall T.C., Meldrum M.J. et al. 1984. Noradrenergic Transmission in the Isolated Portal Vein of the Spontaneously Hypertensive Rat. Hypertension, Vol. 6, No. 2, pp. 267-274.

Wiendl H.J. 1982. Clinical Experience With Postoperative Electromagnetic Stimulation of Pseudarthroses. Aktuel Traumatol., Vol. 12, No. 6, pp. 287-293, 1982.

Williams T.C., Williams J.M. et al. 1977. A Radar Investigation of the Effects of Extremely Low Frequency Electromagnetic Fields on Free Flying Birds. Office of Naval Research Final Report, January.

Willis R.J. and Brooks W.M. 1984. Potential Hazards of NMR Imaging. No Evidence of the Possible Effects of Static and Changing Magnetic Fields on Cardiac Function of the Rat and Guinea Pig. Magnetic Resonance Imaging, Vol. 2, pp. 89-95, 1984.

Wilson B.W., Chess E.K. et al. 1985. Alterations in Pineal Tryptophan Metabolism in Rats Exposed to 60 Hz Electric Fields. Seventh Annual BEMS Meeting, June.

Winters W.D., Guest G.F. et al. 1985. Human Leukocyte Responses After Exposure to 60 Hz Electromagnetic Fields In Vitro. Bioelectromagnetics Society 7th Annual Meeting.

Yevtushenko G.I., Kalyada T.V. 1981. A Study of Biological Effects of Static and Low-Frequency Electromagnetic Fields. US-USSR Workshop on Physical Factors, Microwaves and Low Frequency Fields. pp. 265-272.

Zapotosky J.E., Abromavage M.M. et al. 1985. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program; Summary of 1983 Progress. Naval Electronics Systems Command, IIT Research Institute Tech. Report E06549-9, July.

Zhang S.Q., Butler J.M. et al. 1984. Sensory Neural Mechanisms in Contraction of the Rabbit Isolated Sphincter Pupillae: Analysis of the Responses to Capsaicin and Electrical Field Stimulation. Experim. Eye Research, Vol. 38, No. 2, pp. 153-163.

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