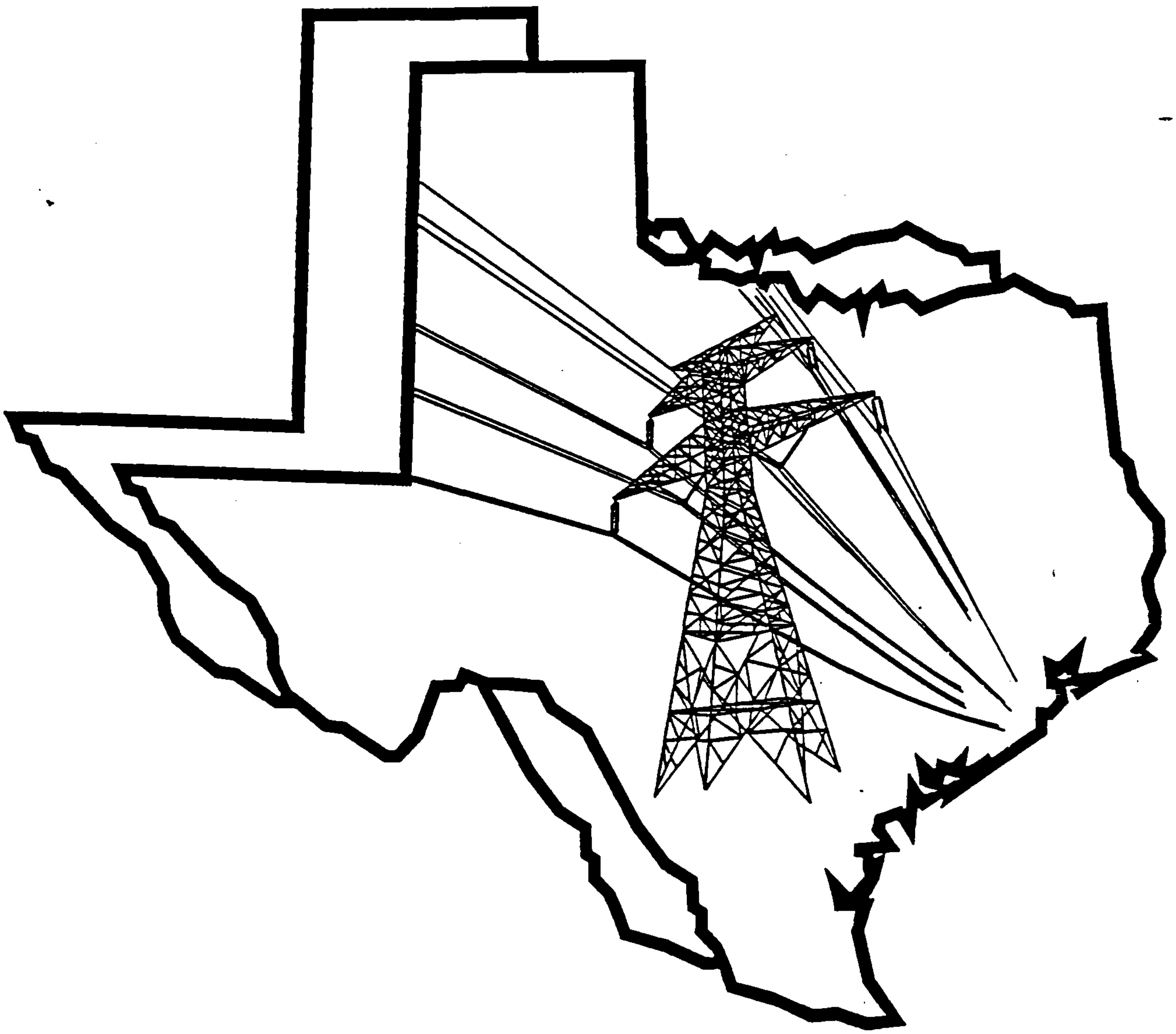
HEALTH EFFECTS OF EXPOSURE TO POWERLINE-FREQUENCY ELECTRIC AND MAGNETIC FIELDS

ELECTRO-MAGNETIC HEALTH EFFECTS COMMITTEE



PUBLIC UTILITY COMMISSION OF TEXAS

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PREFACE

The Electro-Magnetic Health Effects Committee has completed its initial examination of the literature and research involving electric and magnetic fields (EMF) and public health. This report is the result of three years of work by the Committee and represents a thorough study and analysis of the EMF issue. This report contains the Committee's review of EMF engineering and exposure assessment, epidemiologic studies, experimental studies, judicial issues, regulatory issues, and policy issues, and includes the Committee's recommendations to the Public Utility Commission of Texas. The conclusions and recommendations in this report represent the consensus of the Committee, and do not necessarily reflect the opinions of the Commission or the Commission Staff.

The Committee was originally proposed by a Commission task force that was organized to review the rules, practices, applications, and forms concerning transmission line certification in Texas. The task force identified numerous on-going studies concerning EMF and public health and believed that this issue required additional monitoring by qualified individuals. In February 1988, the task force recommended that the Commission appoint a Committee to study the EMF issue and report its findings annually to the Commission. The Committee met for the first time in January, 1989.

The Public Utility Commission of Texas recognized the increase in concerns regarding exposure to EMF and its potential effects on human health. The Commission agreed with the task force recommendations and on April 18, 1988, resolved that a Committee be appointed to study the literature and monitor the research concerning the possible health effects of exposure to electric and magnetic fields.

The Commission originally selected seven members and added an eighth member in September 1989. The members of the Committee represent the research community, the public health community, and electric utilities. They hold credentials in medicine, epidemiology, biology, engineering, health physics, bio-statistics, and public policy. The Committee members have served as volunteers and have not been reimbursed by the Commission for travel expenses or for the significant amount of time each member has devoted to this project. The Public Utility Commission of Texas owes the Committee members its sincere thanks and appreciation for the exceptional effort and commitment to this project.

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1. Introduction and Background

On April 18, 1988, the Public Utility Commission of Texas (PUC) established the Electro-Magnetic Health Effects Committee for the purpose of addressing the possible health effects of powerline-frequency electric and magnetic fields. The Committee was charged with the responsibility for researching the literature, monitoring on-going research, and reporting their findings annually to the Commission. This Committee was established as an independent review body which has served without compensation. Committee members were drawn from the research community, the Texas Department of Health, and suppliers of electric services. They are familiar with the scientific literature on electric and magnetic fields (EMF) and the methodology employed in this area. This report is the result of their efforts.

The report is divided into this Overview and major sections on the following topics: (1) Introduction and Background, (2) Engineering and Exposure Assessment, (3) Epidemiology of Health Effects and Exposure to EMF, (4) Experimental Studies, (5) Judicial Issues, (6) Regulatory Issues, and (7) Policy Issues and Options. In addition, appendices to the text are included.

Before the 1970's, health issues associated with electricity were limited to safety issues related to electrical shock. Then writers of a few reports from Eastern Europe suggested certain health effects in individuals exposed to electric and magnetic fields. In the mid-1970's, the State of New York began a 5-year, $5-million EMF research program. By the late 1980's, the scientific literature contained many EMF reports. The uncertainty inherent in such work has caused public concern because of the suggestion of cancer and other health effects.

Although public concern over EMF health effects has focused principally on transmission lines, such fields are produced by all electrical devices in everyday use.

Electric and magnetic fields are produced by voltage differences and current flow changes in electric transmission lines. Electricity generation and transmission is accomplished in three stages: (1) generation and passage through a step-up transformer, (2) transmission through high-voltage lines, and (3) passage through a step-down transformer and transfer to lower-voltage distribution lines. Alternating current (60 Hertz, or cycles per second) is standard in North America.

Electric and magnetic fields have been the subject of scientific study since the 19th century. Energy content from EMF is much lower than that from ionizing radiation (such as x rays) and is too low to cause heating effects. Even so, observations of some biological effects combined with findings from epidemiologic studies have increased the public's concern about possible human health effects. It is not clear which properties of the EMF environment among many should be measured, e.g., field intensity, duration of exposure, etc. In addition, it is clear that home appliances can produce magnetic fields as strong or stronger than those from transmission lines. Nonetheless, the public generally views involuntary exposure to be more of a health hazard than voluntary exposure. Research into this important issue is continuing largely through the efforts of the U.S. Department of Energy and the Electric Power Research Institute. Many uncertainties remain. This report concentrates on scientific, regulatory, and judicial aspects of EMF.

2. Engineering and Exposure Assessment

Demonstration of a cause-and-effect relationship between observed health effects and exposure to EMF is basically dependent on the accurate assessment of exposure to EMF and the resulting absorbed dose to cells, organs, and body. The electric and magnetic fields resulting from the everyday use of alternating current are complex, varying in properties such as wave shape, frequency, harmonic content, and transients (spikes). In vivo laboratory studies on animals and in vitro studies on cells, as well as epidemiologic studies, have failed to clearly identify any single field exposure parameter as a major agent in the induction of adverse health effects. The usual problems associated with applying data obtained from laboratory animals to humans are particularly important in the evaluation of EMF health effects. Furthermore, field measurements of exposure to electric and magnetic fields are by necessity limited to a determination of basic environmental properties. Most exposure assessments to date have been based on long-term average exposure rates. In this process, important data may not be recorded, and effects of exposure (dose) rate may be missed.

The Institute of Electrical and Electronic Engineers (IEEE) has established standards for methods used in measurement of EMF from power transmission lines. Development of standard methods for measuring EMF in other environments, such as residences, is needed. Various instruments to measure EMF are available commercially. These are capable of reliable measurement of individual EMF parameters, but no one measurement system exists for completely characterizing EMF in the environment.

Regardless of the imperfect (and perhaps inaccurate) nature of current exposure assessment methods, data so obtained are essential to the scientific evaluation of possible health effects. In the laboratory, conditions of EMF exposure can be carefully controlled. Assessing the exposure of the public to EMF is, however, beset by a multitude of complicating factors that determine the effect of the fields as well as actual exposure. This situation causes confusion when an effort is made to apply causal relationships established in controlled laboratory studies to human populations.

In situations where it is difficult or impossible to make actual EMF measurements, exposure rate estimates can be generated by appropriate computer calculations. Reliable programs exist for calculation of EMF in the vicinity of power transmission lines, and more capable programs designed to calculate magnetic fields in the more complex residential indoor environment are under development.

When potential health effects of EMF from transmission lines are evaluated, background EMF needs to be considered. The average natural magnetic field of the earth at Texas latitudes, which is static in contrast to such fields in most "technologically enhanced" environments, is around 500 milliGauss (mG).

The natural electric field in the atmosphere is 130 volts per meter near the earth's surface. As in the case of the natural magnetic field, the natural electric field is essentially static, while electric fields due to use of electricity in the home or proximity to power transmission lines are alternating at a rate of 60 Hertz.

The magnetic field (flux density) directly beneath a 345-kV transmission line carrying an average load is about 130 mG. Design of transmission lines can strongly affect the magnitude of the EMF generated by the lines. Generally speaking, raising the height of a line above the ground reduces the strength of EMF outside the rights-of-way. Burying transmission cables, however, does not assure a significant reduction in the exposure to magnetic fields.

It has recently been found that the average magnetic field intensity within a U.S. home ranges from 0.5 to 1.0 mG and that average residential electric fields range from 5 to 20 volts per meter. Operating electric appliances, for example, an electric can opener, may generate a magnetic field up to 20,000 mG nearby. The normal combination of distance from an appliance and infrequent use reduces the possible significance of this source of EMF exposure.

3. Epidemiologic Studies of EMF Exposure

Epidemiology is the study of the incidence and distribution of human disease and injury. Epidemiologists organize the study of the complex process of disease causation in terms of the disease agent, the environment, and the host. Epidemiologic studies are organized into two types: descriptive and analytic. Descriptive epidemiologic studies explore patterns of disease in whole populations (correlational studies) or specific subgroups in a population (cross-sectional studies). Analytic studies characterize subjects that do or do not have a specific disease (case-control studies) or subjects who share a common risk factor for a disease (cohort studies). Of major concern in all types of epidemiologic studies is the potential for bias and confounding factors. Bias is avoided by stringently defining subject selection criteria and maintaining quality control over measurement procedures. Confounding factors are accounted for by understanding the complex interrelationships between exposure and disease.

In epidemiologic studies of EMF and cancer, scientists have attempted to define the incidence and distribution of health effects in populations exposed to electric and/or magnetic fields. However, the effectiveness of these studies has been limited by the use of indirect, imprecise, and/or inaccurate measures of exposure. Uncertainty in exposure measurements is magnified by the absence of a plausible biological effect mechanism in any EMF-cancer association and by the difficulty of formulating a dose-response relationship. No proper measure of EMF exposure has been defined.

The exposure assessment methodologies currently in use are surrogate or indirect measures of exposure, exposure models, and field measurements. Indirect EMF exposure measures which have been used are wire configuration codes, job titles, and census codes (indicators of occupation). Exposure models based on historical data have been used to project exposure values. Field measurements provide screening information for short-term exposures but may not give good indications of average long-term exposures.

Various categories of wiring configurations have been devised by researchers to substitute as measures of exposure in homes. These include, for example, very high current configurations (VHCC) and ordinary low current configurations (OLCC), both of which are dependent on the proximity of a dwelling to specific types of powerline wiring configurations.

Job titles have also been used as surrogates for exposure to EMF. Occupational epidemiologic studies have focused on telecommunications workers, electrical engineers, and other occupations considered to be exposed to EMF. However, actual exposures in these groups were largely unknown and were assessed on the basis of exposure categories. One study attempted to determine actual occupational exposures by using portable dosimeters for measuring individual exposures to EMF. Even within a single job category, considerable variability in field exposures was found.

Field measurements have shown some promise when used in comparison with wiring configurations and for linking spot measurements to 24-hour average magnetic fields. However, a single 24-hour measurement may yield imprecise results. A model based on measurement data seems to provide a better index than the measurements alone.

Exposure assessment studies are also subject to confounders. Subjects may be exposed to carcinogens in the environment as well as to EMF. A true confounder will be related to both EMF and cancer. In one EMF study, traffic density was studied as an indirect measure of exposure to vehicle emissions and benzene (both related to cancer), and a statistically significant association between cancer and traffic density was found. In another study the "wire code effect" was most pronounced among females, older children, those living in multi-family housing, disadvantaged persons, and those whose mothers smoked during pregnancy. These outcomes indicate the importance of other factors in correlation with cancer risk.

In order to assess the results of epidemiologic studies of EMF, one must consider both internal and external validity. Internal validity is concerned with the criteria, procedures, attention to confounders, and chance that go into designing and performing a study. External validity is concerned with how the results of a study can be generalized and whether the study addresses the causal nature of the association between EMF and disease.

After confirming that a study is internally valid, epidemiologists follow several guidelines to aid in the determination of external validity. These include strength, consistency, specificity, temporality, dose-response gradient, biological plausibility, coherence of evidence, and effect of intervention. The magnitude of risk ratios or strength, for example, can be used to partially assess the external validity of an epidemiologic study. Risk ratios less than 2.0 are likely to be affected by bias or confounding; risk factors greater than 5.0 are more likely to reflect a true increase in risk. A causal hypothesis may be further strengthened when experimental evidence is available. Laboratory or experimental studies completed under controlled conditions provide valuable data regarding the generality of a hypothesis that is being considered.

An essential component of epidemiologic evidence in the study of human cancer and its causes is time trends for various cancers. In the United States, such data have been compiled by the American Cancer Society back to 1930. Data for the years 1930-1987 for various cancer sites including lung, leukemia, brain, breast, and total cancers for males and females and adults and children were compiled for this report. One of the important findings in these data is the effect of the shifting age distribution of U.S. population. Total cancer mortality rates appear to have doubled over the last 50 years, but when adjusted for changing age distributions, the rate increases by only about 20% over the same time interval. An increase in the size of older age groups necessarily leads to an increase in the number of people dying of diseases associated with old age, which include cancer. In addition, the total age-adjusted cancer mortality rates change dramatically when lung cancer deaths are subtracted. Mortality rates for cancer minus lung cancer have remained nearly constant for males and have actually decreased for females over the period of study.

Of particular importance to this study are the findings for male adult leukemia and brain/central nervous system (CNS) cancers, and male and female childhood leukemia, brain/CNS, and total cancers. Mortality rates for all these cancer sites were undergoing substantial increases prior to the exponential growth period (beginning in 1945) in U.S. electric power consumption. In general, mortality rates for these cancers began to level off or decline after the period of rapid increase in electric power consumption.

In previously published reviews of EMF epidemiologic studies which are cited in this report, results from both residential and occupational settings were analyzed. Two initial studies of EMF and disease were done by Wertheimer and Leeper in 1979 and 1982. In the former study, the authors found a excess of high-current wiring configurations near former homes of children who had died of cancer, and in the latter study, the authors found an increase in adult cancer mortality associated with high-current wiring configurations. Other EMF reviews included a study of residential childhood leukemia and exposure to EMF with a summary odds ratio of 1.33, a residential exposure study of childhood cancer of the CNS with an odds ratio of 2.44, an occupational exposure study for leukemia with a risk estimate of 1.18, an occupational exposure study for myeloid leukemia with a risk estimate of 1.46, and several other occupational exposure studies. Many of the studies mentioned in the reviews cited in this report lacked precise assessments of exposure. One study for male breast cancer among telephone workers reported a standardized incidence ratio of 6.5, which has been interpreted to lend support to the proposal that EMF increases cancer risks by interfering with melatonin production. However, melatonin production may be independently affected by the shiftwork of the subjects.

Childhood cancers associated with residential EMF exposures were explored in five studies. Two of the five studies exploring associations of EMF with total childhood cancers reported significant associations with odds ratios of 2.22 and 2.10. With regard to childhood leukemia, none of the studies showed a consistent association with EMF, but two produced odds ratios of 2.35 and 2.10. The findings for childhood tumor of the CNS were also inconsistent with only one study producing a moderately elevated odds ratio of 2.86.

Adult cancers associated with residential exposures were evaluated in five studies. Only two out of the five studies produced significant results. One reported an association of EMF with total cancer (odds ratio of 1.28) and associations for lymphomas, cancer of the CNS, uterus, and breast. The other reported a significant association with lung cancer. In addition, four of the five studies reported weak associations of EMF with adult leukemia.

This report evaluates occupational EMF studies in association with all cancer sites, leukemia, tumors of the CNS, melanoma, and other cancer sites. In addition, this report evaluates several studies which examined the associations between paternal occupations having potential for EMF exposures and childhood cancers and adverse effects on reproduction. This report also evaluates 15 studies of the association of occupational exposures with all cancer sites. Because of differences in definitions, methodology, and other inconsistencies, it was impossible to determine any causal relationships. Leukemia incidence among occupationally exposed individuals has been given the most attention, and results for this site are suggestive of a causal association. Among 15 studies of leukemia and EMF, several have yielded weak, but statistically significant, results. However, problems with confounding factors and inaccurate exposure assessments limit the usefulness of the leukemia results. Cancer of the CNS has also received increased attention. Studies of this site have been beset with the same problems as the leukemia studies, and half of the studies have produced inconclusive results. Significant results were reported for associations of job categories with malignant melanoma and eye cancer, but not for testicular cancer. Finally, three of six studies of childhood cancer/paternal occupation which were evaluated in this report showed significant results. Five studies were completed on adverse reproductive effects, and in three of these studies statistically significant associations were found with spontaneous abortion, frequency of abnormal pregnancy, and congenital malformation.

Adding to the public's concern over cancer and EMF has been the misuse of cancer epidemiologic data. Because cancer incidence data are generally unavailable, time-trend studies are usually based on mortality rates. Mortality rates can be expressed in several ways, but in order to present a true picture, two factors affecting such presentations must be taken into account: data must be age-adjusted to account for shifting age distributions in the population of the U.S., and improvements in medical care which have dramatically decreased the proportion of the population dying from infectious diseases must be heeded. Consideration of these two factors produces a much different view of the present importance of cancer as a cause of death. In addition, no positive correlation is seen between age-adjusted cancer mortality trends and increases in U.S. electric power consumption, which one would expect to see if an EMF relation exists. (Lung cancer, of course, remains at the top of the list for cancer mortality.)

Utilizing cancer statistics, risk managers in Federal regulatory agencies seek to achieve protection of public health and the environment while responding to the requirements of the Office of Management and Budget, defending the technological and economic feasibility of a proposed action, and following legislative mandates. Ultimately, risk managers respond to specific problems based on assessments which are formed using accepted scientific criteria. However, several models for risk assessment have evolved. New approaches to risk assessment are being formulated which recognize the importance of a scientific approach to risk decisions.

Historically, the attention surrounding EMF grew out of public concern in the 1960's for the aesthetic and nuisance problems related to high voltage transmission lines. Reports in the late 1960's and early 1970's by Soviet scientists concerning possible health effects of EMF changed the focus of public concern. Western scientists failed to confirm the Soviet findings, except that a study in Denver in the late 1970's seemed to confirm the earlier studies. Negative findings did not ease public concerns.

In conclusion, much disagreement exists over the relationship, if any, between EMF and disease. Available epidemiologic evidence has produced limited conclusions. Findings related to leukemia remain suggestive, and associations with cancer of the CNS and other cancer sites are inconclusive.

In order to improve the quality of future EMF epidemiologic studies, the Committee offers several recommendations. The exposed population must be well defined. There should be more than one reference cohort. More work needs to be done to accurately assess the complex nature of EMF exposure. New EMF measurement technologies need to be explored. The relationship, if any, between residential wiring configurations and EMF exposure needs to be studied. The biological basis of any health effects in humans needs further study. Epidemiologic results should provide guidance for new experimental studies. Special care must be taken in future studies to control for confounders and to avoid internal inconsistencies.

4. Experimental Studies of EMF Exposures

The Committee examined the results of numerous laboratory experiments, comprising in vivo (alive) studies of EMF effects on animals (e.g., rats, baboons) and in vitro (test tube) studies at the cellular level. These studies focused on animal behavior, cancer initiation and promotion, developmental and growth effects, endocrine system and immunity and cell-cell (membrane) interactions.

While the quantity and quality of EMF research have improved dramatically in recent years, the EMF effects data base is still in a state of infancy when compared to the research literature on other potential environmental exposure risks. Although laboratory studies generally provide a greater opportunity to control extraneous variables than do epidemiologic and field studies, many opportunities still exist for sources of error to enter into even the best designed study. It is possible that the EMF literature, like most scientific literature, contains false positives and false negatives. The Committee has found that the scientific literature on EMF contains results of laboratory studies that were performed under a variety of exposure metrics (e.g., frequencies, field intensities, exposure duration, earth's static magnetic field). Thus, the inconsistencies and contradictions of study findings may be due to unknown errors and/or the numerous aforementioned laboratory conditions. This circumstance makes it difficult to sort through the literature, interpret the evidence, and draw definite conclusions with respect to EMF effects.

Nonetheless, the Committee believes that, based on its evaluation of the laboratory and epidemiologic literature, there is at this time no conclusive evidence to suggest that EMF due to electric power transmission lines poses a human health hazard. The Committee believes that this conclusion is basically corroborated in other EMF literature summaries and background reports prepared by expert scientific and research panels.

The following observations can be summarized on the basis of the studies evaluated by the Committee:

The interaction of variables which control actual exposure to EMF is poorly understood. Undoubtedly, the inconsistencies and contradictions found in the scientific literature are due, at least partly, to this fact.

Under certain circumstances, animals and humans can detect and avoid electric fields. However, no research to date has presented any conclusive evidence that these fields, detected or not, produce any deleterious and/or long lasting impacts on animal or human behavior.

One of the current models for carcinogenisis involves two steps, initiation and promotion. The initiation step involves direct or indirect permanent damage to the cell's genetic material (DNA). Ionizing radiation and certain chemicals have been identified as cancer initiators. Promotion is characterized by uncontrolled cell growth (tumor formation) after exposure to an initiator, which causes or allows the expression of genetic damage. Neither electric nor magnetic fields are energetic enough to cause damage to DNA, and it is generally accepted that power frequency fields are not cancer initiators. However, scientists have suggested that EMF may be a cancer promoter. No firm conclusions can be drawn on the promotion theory at this time. Hypotheses are only now being advanced. Additional information is clearly needed.

Most of the EMF studies reviewed by the Committee found no teratogenic effects during embryonic development or during postnatal growth. A few studies do show effects. Some show effects only under "pulsed" fields, which are not normally associated with 60-Hz alternating current transmission. Certain studies show effects using one animal strain, but no effects with another. A high incidence of effects is observed in the controls of various studies, making interpretation of the data difficult. Overall, these laboratory studies tend to lead to the conclusion that there is no proven detrimental effect on prenatal development or postnatal growth from exposure to EMF.

It has been suggested that exposure to EMF can affect animal immune systems. Whole-animal studies have not shown such an effect, but certain cellular studies indicate possible effects. Hypotheses need to be developed and tested before any definitive conclusion can be drawn.

Several studies suggest that EMF exposure causes changes in the function of animal endocrine systems. For example, reduction in night-time melatonin production and alteration of biological rhythm have been recorded in animals exposed to 60-Hz fields. Numerous physiological effects due to melatonin reduction have been hypothesized, but the potential health effects due to such reduction needs further investigation.

Many in vitro studies have shown no effect on cells exposed to EMF, while others have shown positive effects. Although the results of these studies are complex and inconclusive, a growing number of positive findings imply that, under specific conditions, EMF can produce cellular changes. For example, levels of calcium which is involved in the regulation of numerous physiological processes have been shown to be affected in several test systems. The significance of these results is unknown.

Although effects have been observed at the cellular level, with most being attributed to changes occurring at the cell membrane, the actual biophysical and/or biological mechanism is unknown. Various mechanisms have been postulated, but all are speculative. More research is needed to evaluate these mechanisms. If a mechanism is established at the cellular level, this will support the positive laboratory and epidemiologic studies.

5. Judicial Issues

Although the EMF health effects issue is still actively debated in scientific circles and the public press, it has been a factor in several types of judicial proceedings for some time. An increase in judicial proceedings on this issue is expected. As used here, "judicial" includes siting, zoning, condemnation, and tort proceedings. The PUC is concerned only with transmission line siting considerations.

An early concern about EMF health effects was expressed during Public Service Commission hearings in New York in the mid-1970's on a proposed 765-kV transmission line. Since then, many proceedings have involved presentation of evidence relative to the EMF health effects question. Over 200 proceedings involving EMF cases related to power transmission and substations have been reported. Of more local interest, nine Texas electric utilities have reported one or more proceedings where EMF or other health effects issues were raised.

Review of the information available on EMF-related judicial proceedings shows that, to date, little weight has been given to EMF health effects claims by objectors, intervenors, and plaintiffs. Due to public perceptions of potential hazards and scientific interest, however, the EMF issue is assured continued involvement in judicial proceedings. To respond to these continuing concerns, the utilities are developing strategies including keeping up with EMF-related research, complying with regulations regarding the planning and siting of facilities, surveying public awareness about EMF health effects, and developing public education and information programs.

6. Regulatory Issues

As powerline-frequency transmission grids have expanded, so have the health concerns of those citizens living, working, or going to school close to power lines. Some citizens believe that regulations are necessary to protect public health. Such regulations are being contemplated and enacted in some states.

Several approaches to regulations can be considered for controlling power line placement. Specific circumstances may dictate which approach is used. When adopting regulations, a government agency may use a standard (an acknowledged criterion for comparison) or a limit (a specified level which is restrictive). Other options are to use a guideline (an optional standard or limit) or a criterion statement (usually a document for making informed decisions about regulations). Ordinarily, regulations which are protective of health are based upon health risk assessments, an approach which takes into account all the evidence and weighs benefits versus risk to assign an acceptable level of safety.

If health-based regulations designed to protect the public or exposed workers are contemplated for transmission line siting, explicit health data are required. At present, however, no such data exist, nor is there any other rational approach for setting exposure regulations to protect public health. Before occupational regulations can be adopted, a consistent health effect must be found which is related to a measure of EMF exposure (such as frequency, intensity, or time). The necessary basic EMF data would then be combined with the so-called "healthy worker" criteria which define possible exposure time on the job and basic human physiological quantities. Similarly, biological evidence, quantification of dose, and risk assessment information must be available to set regulations for populations. Any regulations written in the absence of the mentioned data would offer no protection and could possibly hinder further investigations into real health effects.

International organizations such as the World Health Organization, the International Radiation Protection Association, and some countries (the United Kingdom and Australia) have addressed the EMF issue. These groups have found that the scientific data suggesting health effects due to long-term environmental EMF exposure are not persuasive.

In the United States, the Congress, several federal agencies, a few institutes, and some national associations have performed some preliminary work on the EMF issue. Although the federal government has no clear mandate or authority to take regulatory action concerning 60-Hz EMF and the existing evidence does not compel immediate action, some federal action has occurred. Congress has hosted hearings to collect testimony on the issue; the U.S. Environmental Protection Agency has conducted a review of EMF scientific literature; the U.S. Department of Energy has maintained a strong research program in the area of basic EMF science; the U.S. Department of Transportation is evaluating "maglev" trains; and several other agencies have maintained a more limited involvement in the area. Organizations like the National Council on Radiation Protection and Measurements and the American National Standards Institute have not pursued the issue at a rigorous level but may do so when the scientific results become less speculative. Associations like the National Association of Regulatory Utility Commissioners and the Conference of Radiation Control Program Directors have urged greater federal involvement.

At present, the only generally applied national standard for EMF is the National Electric Safety Code, which deals with reducing shock hazards from transmission lines. This code is not intended to provide protection from possible long-term health effects due to chronic exposure.

Because of the lack of federal leadership on the EMF issue, the states have responded individually. The result is varied and lacks consistency. The states' responses have fallen into four categories: (1) take no action, (2) study and report on the issue, (3) fund research, and/or (4) use regulatory authority to establish standards. At least one common thread runs through these efforts: In the absence of a firm dose-response relationship or intended results, no method for evaluating the benefit of EMF standards is available. In the body of this report, the Committee details the actions taken by seven states.

Texas powerline siting problems are similar to those in other states. In some cases siting permit applications have been contested, and the applicants have been taken to court. A health-based standard would have simplified the siting process by providing design criteria to achieve compliance. Without clear evidence upon which to develop a health-based standard, the Commission may make use of Section 23.44 of the Public Utility Regulatory Act, which addresses new construction. Section 23.44 is based on American National Standards Institute (ANSI) and National Electric Safety Code (NESC) standards. If EMF standards are issued by ANSI and/or NESC, the Commission could readily adopt them as guides. A question remains, however, about regulatory jurisdiction over city-owned utilities in siting questions. Another option for the PUC is to defer to the Texas Department of Health which has the ultimate responsibility for developing statewide health standards.

7. Policy Issues and Options

The current status of scientific evidence regarding EMF health effects is unclear. There is no definitive indication that EMF exposure can affect health, and there are no data that establish convincingly that it does not. In fact, as is often the case in situations involving very low probability cause/effect relationships, it may not ever be possible to prove an effect or the lack of an effect.

With respect to the EMF health effects issue, state legislatures find themselves in a quandary. Acceptance of false positive conclusions may result in a significant expenditure of taxpayers' money and divert attention from efforts to seek the true source of any increased risk. By contrast, not acting on false negative conclusions is likely to be interpreted by the public as irresponsible disregard for citizens' safety. Therefore, it seems reasonable to expect legislatures to actively support efforts to resolve the conflict.

Regulatory agencies normally address scientific uncertainty, such as the EMF health effects question, through procedural mechanisms similar to those used in the courts and legislatures. The details of the mechanisms vary considerably depending on the nature of the regulatory agency and its legislative charter. Political pressures to "do something" about the EMF issue may result directly or indirectly in the search for regulatory relief, especially if no action is achieved at the judicial or legislative levels.

In at least 17 states, legislative or administrative agencies have formally considered the possibility of health effects as a result of EMF exposure. Responses range from dismissal of the question due to lack of evidence (Wyoming) to codification of formal EMF limits in transmission lines (Florida). Courts and legislatures are actively considering actions in several states.

Different responses and their rationales are tied to different views of what constitutes the key problem in the EMF debate. There have been at least four different ways to define the EMF "problem", each with distinctive views of the scientific evidence, of the proper role for science to play, and of the proper perception of risk. More importantly, each definition carries a policy prescription along with it. In the absence of a conclusive body of scientific findings that would provide a firm grounding for deciding which of the four ways of constructing the problem is the most appropriate, one is left to decide largely on the basis of pre-existing beliefs and values that each of us brings to the EMF issue.

In this instance, the values of experts alone may provide too narrow a basis for legitimating one definition of the problem over others. Recognizing this limitation, the Committee recommends that, until science can provide a clearer path, state officials should engage the public in open discussions of both the evidence to date and the public values that influence its interpretation.

CONCLUSIONS AND RECOMMENDATIONS

The following are the Committee's overall conclusions and recommendations regarding standards, siting criteria, research, and public education.

1. Standards

1.1 Conclusions

The Committee has examined much of the current EMF scientific literature. Many epidemiologic studies have investigated the possibility of an association between disease and residence near installations transmitting electricity. Epidemiologic studies have most frequently investigated the possibility of an association between various types of cancer and exposure to EMF. To date, the results from these epidemiologic studies have been inconsistent and inconclusive.

The results of the laboratory studies evaluated by the Committee are also inconsistent and in some cases inconclusive. However, it is apparent that under specific exposure conditions, biological changes do occur. It appears that many variables (e.g., frequency, intensity, exposure duration, field orientations) can affect the results of these studies, which undoubtedly play an important part in the inconsistencies reported in the literature.

The Committee believes that, based on its evaluation of the existing EMF research, the evidence at this time is insufficient to conclude that exposure to EMF from electric power transmission lines poses an imminent or significant public health risk. In general, the Committee's evaluation is corroborated by other EMF literature summaries and background reports.

The Committee concludes that at present there is insufficient evidence regarding human health effects of EMF to provide the basis for a health-based standard. The Committee can find no reason to create arbitrary numbers to use as a desired level of exposure, because the use of such numbers cannot be argued or defended on the basis of scientific evidence. The primary objective of the Committee is the protection of public health, and the Committee can find no scientific argument to support standards, either through guidance or through regulatory criteria.

The Committee has reviewed various state EMF standards. However, the use of numbers for an arbitrary standard in the absence of scientific justification sets a de facto risk level which is not supported by available evidence. Use of such numbers, which is strictly political, can generate a false sense of security, diverting resources from evaluating a genuine risk associated with some other environmental factor.

The Committee concludes that regulatory activities should be divorced from the EMF issue, at this time, and that the Public Utility Commission of Texas (PUC) take action regarding the EMF health effects issue only when, or if, action can be justified on a public health basis. If such action is required, the Committee concludes that the issue be referred to the Texas Department of Health (TDH), since the PUC does not have authority over all EMF sources (e.g., appliances, home wiring). The TDH is the state agency with authority in health matters.

1.2 Recommendations

The Committee recommends that neither the PUC nor other state authorities attempt to set EMF standards through guidelines, regulations, or legislation.

Should new evidence emerge establishing a clear association of human health effects from EMF exposure, justifying promulgation of standards, the Committee recommends that the EMF issue be referred to the Texas Department of Health.

2. Siting Criteria

2.1 Conclusions

The Committee concludes that at present, the existing criteria used by the PUC for siting transmission lines appear to be adequate. The Committee concludes that a plan for engineering interventions is not warranted at this time. The Committee noted that "prudent avoidance" in siting of transmission lines has been the de facto philosophy in the PUC criteria since 1976, by avoiding population centers, historical sites and existing facilities. Matters of safety and rights-of-way criteria have influenced the selection of routes. Based on current evidence, the Committee finds this approach adequate and acceptable.

2.2 Recommendations

The Committee recommends that the PUC continue its policy of de facto "prudent avoidance" in the siting of transmission lines. We further recommend that, at this time, the PUC not expand existing routing criteria to include concerns regarding health effects of EMF exposures.

3. EMF Research

3.1 Conclusions

While the quantity and quality of EMF research have increased, the EMF effects data base, however, is still in a "state-of-infancy" when compared to the research literature on risks to other environmental exposures. Continued research will help to reduce the current level of ambiguity inherent in EMF findings, while increasing the certainty of research results and confidence in research conclusions. The Committee concludes that the research agenda developed and funded by the Electric Power Research Institute (EPRI) should continue together with enhanced federal funding. A considerable number of large and well-designed studies are currently under way. These studies offer the potential of more conclusive information than exists at present. Increasing the number of studies without a coherent research plan is not likely to contribute to resolving the current inconsistencies in available research results. A carefully coordinated and comprehensive national research agenda with adequate funding from a mix of governmental and non-governmental sources is needed.

The Committee also notes the need for a more systematic review of available research results to resolve the inconsistencies in the published studies and to identify areas of needed research. Most reviews of available evidence conducted to date have not employed rigorous review criteria and quantitative methods such as those used in meta-analysis. Such reviews would entail extensive reanalysis of data from studies specifically selected because they satisfy study design criteria. A review of this type was beyond the resources available to this Committee.

The application of limited state resources to the EMF issue cannot be justified at this time, when more direct public health benefits can be derived from other uses.

3.2 Recommendations

The Committee recommends that the PUC continue to review research findings from on-going studies of the association of EMF with human health effects as these data become available. The PUC should continue this review through the Committee on EMF Health Effects.

The Committee recommends that Texas not develop a specific EMF research program at this time.

4. Public Forum

4.1 Conclusions

Since the mid-1970's, EMF has been an issue in over 200 legal proceedings involving the electric utility industry in the U.S. Approximately 75% of these occurred during siting of electrical facilities, primarily transmission lines, and during condemnation proceedings.

The Committee recognizes that the EMF health issue is often introduced in legal proceedings (e.g., hearings). When EMF health effects concerns are addressed in this setting, the expense and delays in siting decisions are unwarranted. The quasi-judicial role of a state regulatory agency may facilitate the establishment of a better arena than the judicial arena for the expression of differing views and conflicting evidence. The Committee recognizes that, regarding transmission lines, the PUC has jurisdiction. However, transmission lines are not the only source of EMF exposure. It is anticipated that a public forum sponsored by an appropriate state agency, addressing all exposures, would provide a nonadversarial setting for the review of concerns regarding the EMF health effects issue.

4.2 Recommendations

The Committee recommends that the Texas Department of Health assume the leadership role in sponsoring any public informational meetings for the exchange of EMF information. Such meetings, if deemed necessary, can be scheduled in conjunction with the release, by the PUC, of the Committee's annual reports.

5. Education Of The Public

5.1 Conclusions

The Committee has not addressed the important need for public education regarding risk assessment, as this was beyond the scope of its work. However, the Committee recognizes the need for follow-up research and education in public risk perception and risk communication in conjunction with dissemination of risk information to the public.

The Committee also did not investigate the question of personal options such as prudent avoidance. However, with the present uncertainty regarding the association of EMF exposure with health effects, there is no clear indication regarding what specific aspects of EMF exposure should be avoided.

The public needs to be informed about the EMF health effects issue, and involved in the discussion of concerns arising from this issue. At present, the TDH and utility companies do respond to public concerns regarding potential health effects of environmental exposures by speaking to public groups and by distributing written information. Some electric utility companies also make EMF measurements for their customers.

5.2 Recommendations

The Committee recommends that electric utility companies and the TDH continue to be responsive to the public's need to have general information regarding potential EMF health effects, and continue to provide needed information through brochures, audiovisual presentations, and field measurements.

1.0 INTRODUCTION AND BACKGROUND

1.1 Introduction

The Public Utility Commission of Texas (PUC) recognized the increased concerns regarding exposure to powerline-frequency (i.e., 50 and 60-hertz) electric and magnetic fields (EMF) and their possible effects on human health. On April 18, 1988, the Commission resolved that a Committee (i.e., Electro-Magnetic Health Effects Committee) be appointed to research the literature and monitor the on-going research on the health effects of electric and magnetic fields from electrical transmission and distribution lines, and report annually their findings to the Commission. Committee members were originally appointed in December, 1988 and met for the first time in January, 1989. In May, 1989 the Committee issued an Interim Report. Additional members were added in 1989 and 1990. The following report represents the first complete review, and will be up-dated with new research findings, conclusions and recommendations on an annual basis.

The members of this Committee represent the research community, the state public health agency and the suppliers of electric services. The members hold credentials in medicine, epidemiology, biology, biochemistry, engineering, health physics, political science and biostatistics. Committee members are familiar with the current scientific EMF literature, and are actively engaged in reviewing hundreds of documents and published EMF research findings.

This Committee is similar to others that have performed literature reviews and made recommendations regarding possible health effects from these fields. However, it differs in one major respect: the Committee was established because of the foresight of the Public Utility Commission of Texas and not by legislative or judicial mandates.

The Committee has neither been placed under a deadline to produce a recommendation nor has it been funded to conduct its review or conduct new research. It serves as an independent review body to evaluate scientific evidence and to provide recommendations and advice to the Commission on the possible health effects associated with EMF exposures.

This report is divided into seven major sections: Introduction and Background, Engineering and Exposure Assessment, Epidemiology of Health Effects and Exposure to EMF, Experimental Studies, Judicial Issues, Regulatory Issues, and Policy Issues and Options.

1.2 Background

Until recently, serious inquiry about biological effects associated with electricity was limited to safety issues, primarily those identified with electrical shock. Several events in the 1960s and 1970s prompted inquiry about the biological effects of exposure to electric and magnetic fields (EMF). Reports from the Soviet Union in the early 1960s suggested neurological and cardiovascular effects in workers exposed to electric and magnetic fields. The controversy increased in 1974 when the New York Public Service Commission began hearings on a proposed 765 kilovolt (kV) transmission line, resulting in the New York Electrical Utilities funding a 5-year, $5-million EMF research program. Many articles concerning biological effects of exposure to electric and magnetic fields have appeared in the technical literature during the past two decades. Many more have been published in the popular press. These events have increased the public's concern over possible health effects when exposed to EMF.

Electric fields are produced by the voltage applied to a wire and are measured in volts per meter (V/m). Magnetic fields are produced by the current flowing through a wire and are measured in terms of gauss (G). The amount of power that a line transmits is the product of its voltage and current. Power systems are designed to hold voltages relatively constant, while currents increase and decrease depending on the power demand. Therefore, for a given voltage the electric field will remain relatively constant over time, but the magnetic field will increase or decrease depending on power demand.

There are basically three stages in generating electricity and moving the electricity from the electric stations to the end user (Figure 1-1). First, electricity is generated at an electrical generating station at about 20,000 volts (20 kilovolts). The power is then passed through a transformer which increases the voltage so that the power can be transported with minimal losses. In the second stage, electricity is transported over high voltage transmission lines (i.e., 69 to 765 kV).

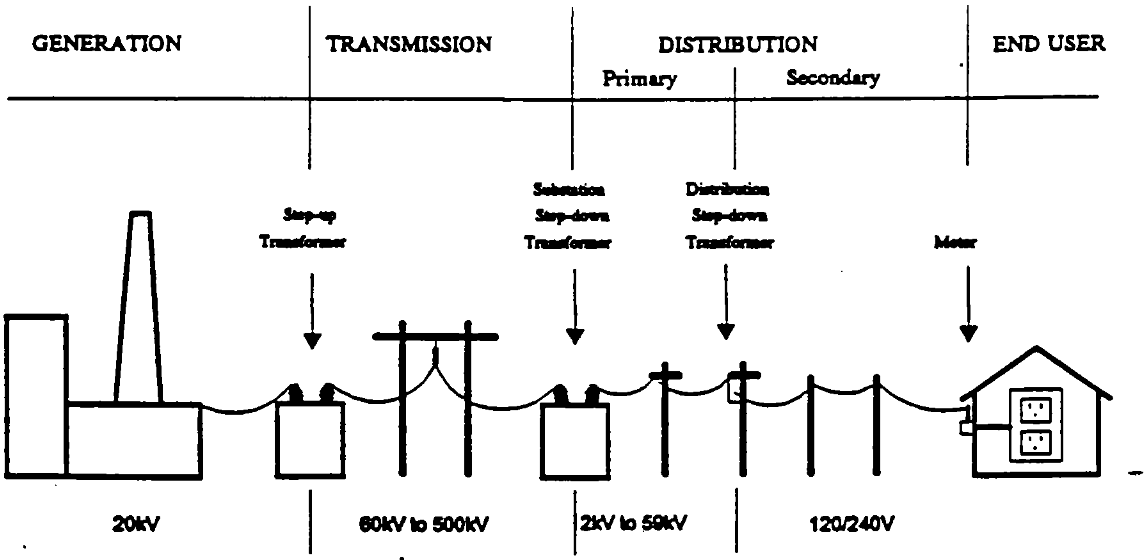

Figure 1-1. Schematic illustration of the stages in an electrical system used to transfer power from the generator via transmission and distribution lines to an end user. (Modified from Office of Technology Assessment Report-Biological Effects of Power Frequency Electric and Magnetic Fields).

Currently in the United States there are more than 300,000 miles of alternating current (AC) powerlines ranging from 115 to 765 kilovolts (kV). However, 500 kV is the highest operating voltage currently used in Texas.

Transmission lines connect to substations where the voltage is reduced and power is transferred to lower-voltage distribution lines. In the third stage, distribution lines deliver power locally to individual users. The distribution system is composed of two voltage levels. One is a "primary" circuit (2 to 59 kV) that delivers power from a substation to a distribution transformer. From there the power flows through a "secondary" circuit to an end user. The "secondary" circuit voltage is low enough (120/240 volts) to operate household electrical appliances, lights, etc.

The electricity we use in our homes, offices, etc. is alternating current (AC) in contrast to direct current (DC) which is like that produced by batteries. Alternating current does not flow in one direction, but instead alternates back and forth. The current used in North America alternates back and forth 60 times per second, which is called 60 hertz (60 Hz), compared with 50 times per second (50 Hz) in Europe and other countries.

Although the major public concern has been associated with EMF exposure from transmission lines, EMF are also present whenever electricity is used. As electricity is generated at electrical generating stations and transferred to homes via transmission lines, substations and distribution lines, EMF are produced. But these fields are also produced in homes, offices and other buildings, due not only to the proximity of the transmission and distribution lines, but due to electrical wiring in the facility and the use of electrical appliances (e.g., can openers, hair dryers, video display terminals, toasters, electric blankets). Thus, the sources of exposure to fields are numerous, exposure to fields is ubiquitous and if a true human health hazard exists, the response will need to be comprehensive, involving society as a whole.

Electric and magnetic fields are not something new. Scientists have had a good understanding of them since the nineteenth century. For example, processes in the earth's core give rise to the earth's magnetic field. Unlike the alternating fields associated with transmission lines and appliances, the earth's magnetic field does not alternate, but is static.

The EMF from powerlines and appliances are of extremely low energy and frequency. They are markedly different in frequency (i.e., Hz) from ionizing radiation (e.g., gamma rays, xrays, ultraviolet rays) in the electromagnetic energy spectrum (Figure 1-2). Not only is the energy in the 60-Hz frequency not great enough to cause ionization, there is not even enough energy to heat tissue as is the case for microwaves. The non-ionizing and athermal (i.e., non-heating) characteristics of EMF produced from 60-Hz frequencies are two of the reasons why some scientists believe that these fields could not induce biological changes. However, biological changes

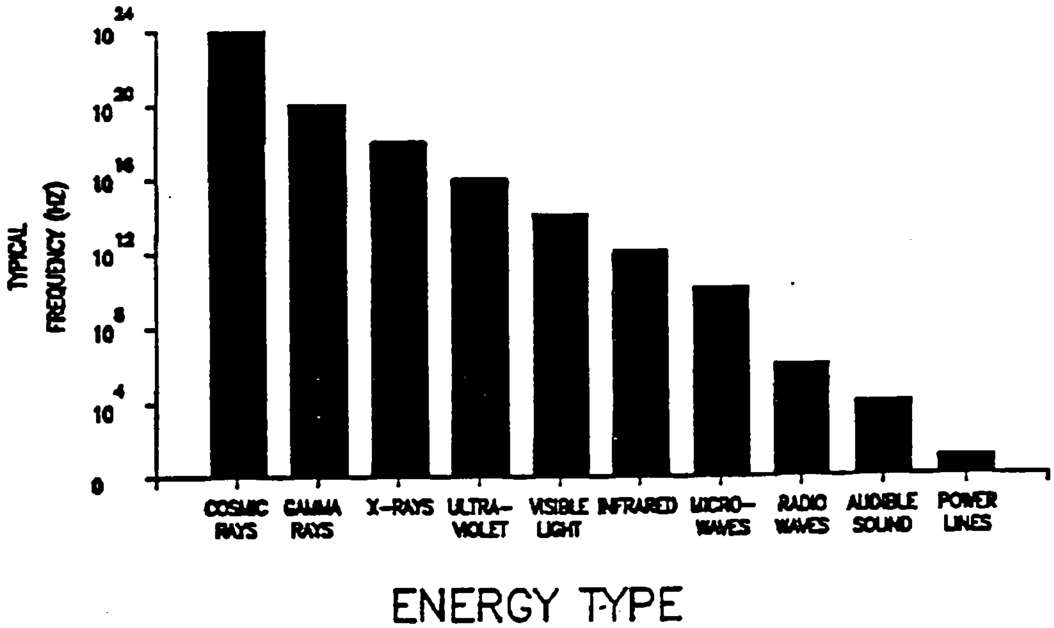

Figure 1-2 The electromagnetic spectrum

have been observed, under experimental exposure conditions, and these observations have increased the concern for possible human health effects.

Electric fields can be easily blocked by trees, buildings, earth and other objects. However, magnetic fields are not easily blocked and can pass through buildings, earth, and humans.

Some individuals have presented the contention that EMF exposure to electrical appliances is just as great a potential health hazard as exposure to EMF produced from transmission lines. Because the intensity of EMF decreases rapidly as one moves away from a source, the fields at the edge of the rights-of-way for a transmission line (since the source is 25' to 40' above the ground) may not be much greater, and in certain cases may be less than, the fields next to an electrical appliance (e.g., oven, hair dryer, electrical shaver, can opener), especially for magnetic fields. Such comparisons are of value, but field intensity is only one of the important variables to be considered in evaluating potential health effects.

Exposure duration (i.e., acute vs. chronic) must also be considered. Since most appliances are used infrequently and for short duration, their exposure may be of less importance. Also, it is realized that the public perceives involuntary exposure (e.g., transmission line) to be more of a health hazard than voluntary exposure (e.g., appliances).

During the past decade, extensive research programs evaluating the possible health effects of exposure to EMF have been performed in the U.S. The U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) have sponsored much of this research. These studies have helped answer many unknowns, but many questions remain. Notwithstanding these unknowns in the scientific data base, these uncertainties have triggered public, regulatory, and judicial involvements. This report evaluates the EMF scientific literature and addresses the regulatory and judicial involvement in the issue.

2.0 ENGINEERING AND EXPOSURE ASSESSMENT

2.1 Introduction

Studies of the possible effects of power-line frequency electric and magnetic fields on health are hampered by problems in measuring exposure. Exposure should not be confused with dose. Exposure is the simultaneous occurrence of some agent (e.g., electric or magnetic fields) in the presence of a subject (e.g., human), whereas dose is the amount of agent actually interacting with the subject. Dose inherently involves a thorough understanding of the cause and effect relationship between the agent and biological effect. Currently, science is only beginning to understand this relationship between electric and magnetic fields and their interaction with biological systems. In this section the acronym EMF will be used for electric and magnetic fields.

The essence of exposure assessment is determining, through direct measurement or estimation, the amount of a causal agent occurring in the subject's environment. The assay of this agent is often called the "metric of exposure"--the quantity that explicitly is related to dose and the one we want to measure. Ideally, science must first identify the mechanism by which the agent affects the subject before we know what to look for. For example, if a subject drinks a glass of chocolate milk and then breaks out in a rash, what caused the rash? Was it the milk, the chocolate, some by-product of the reaction between the milk and chocolate, the color of the mixture, or the material from which the glass was made? Most exposure assessments have assumed that the average magnetic or electric field strength found in the subject's environment is the "metric of exposure." Yet, several studies, both in vitro (cellular) and in vivo (animal), have suggested other aspects of the electric and magnetic fields, besides average field strength, may be the measure sought.

Like with the host of properties associated with the glass of chocolate milk, any one of the properties manifested in the EMF environment could be the metric of exposure. For example, associated with every field are aspects of wave shape, frequency, harmonic content, and transients (spikes), and, if transients are present, their host of properties. Furthermore, the exposure metric could be the variability of the field or perhaps the number of times the subject passes in and out of the field. The exposure metric could be the occurrence of fields in certain windows of frequency and/or amplitude, or even more complex, some type of interaction between the strength and orientation of an external field and the earth's magnetic field. Animal and cellular studies have not clearly identified any single metric of exposure. Exposure assessments have been relegated to measuring only the convenient and simple properties of an environment due to the obscurity of the metric and the scarcity of sophisticated instrumentation necessary to measure aspects more complex than time average field strengths.

Many exposure assessments to date have relied on average exposure during a sampling period. Inherent in the averaging process is a loss of information; the more subtle aspects of EMF, such as windows, transient exposure, etc., are obscured when instantaneous field values are averaged. Also averaging fails to portray any temporal variations.

Exposure assessment is important to epidemiologists, biologists, and regulators. To correlate a disease with a suspected agent, epidemiologists must be able to measure the difference in exposure among the subjects for the metric of interest and for a host of possible confounders present in a real environment. To investigate a suspected interaction, biologists must be able to design experiments that accurately mimic exposure in the real environment. If their extrapolations of laboratory experiments to the real environment are to be believable, they must be able to simulate accurately and control the exposure of their subjects to the suspected agent. And finally if science does identify a public health hazard, regulators must be able to identify explicitly which aspects of EMF are threatening public health and at what level those aspects should be limited.

2.2 Summary

The Committee has reviewed the major elements of exposure assessment through reviewing the literature, examining computer models and communication with manufacturers and users of EMF measuring equipment. We find that for making survey measurements of EMF associated with powerlines, commercial instrumentation is readily available and acceptable standards, specifying how these measurements should be made, have been published. However, for measuring exposure, only a few choices of commercially available instruments exist, and the instrumentation to make thorough and intensive engineering measurements must be custom assembled. Also, there are no standards to specify how exposure and engineering measurements should be made.

When it is impossible or not feasible to actually measure exposure, EMF exposure can be estimated by using computer models, spot measurements, and surrogates. Several computer programs exist to accurately estimate field levels for the simplistic geometries usually found around transmission lines. The Electric Power Research Institute (EPRI) is currently developing a program to calculate magnetic fields found in the more complex residential geometries composed of distribution circuits, house wiring, and ground return paths. EPRI has also developed a program to estimate exposure based on time-weighted averages of field strength. Under controlled conditions, spot measurements may be combined with the subjects' activity patterns to estimate exposure. Surrogates must be used with great care since they often suggest other factors besides powerline EMF, which may be associated with cancer.

Preliminary studies show that electric fields in the home are not greatly affected by outside powerlines, but these line may be important contributors to interior magnetic fields. EMF in the work place is similar to that in the home. High current devices appear to be more prevalent in the work place than high voltage devices, so higher magnetic fields are more likely than electric fields. Little data exists on EMF in other areas.

2.3 Electric and Magnetic Field Fundamentals

2.3.1 Introduction

This section lays a foundation of the basic concepts about electric and magnetic fields fundamental to understanding exposure assessment. The reader already possessing a basic understanding of powerline fields may wish to skip this section and refer to it or the glossary as needed.

2.3.2 Basic Electrical Concepts

The source of both electric and magnetic fields is electric charge. Charge can be either positive or negative. Like charges repel and opposite charges attract. This electric force acting between charges is about a billion-billion-billion-billion times (10^{36}) stronger than the force of gravity between the two charges.

A conductor is any material that allows electrons to move freely and to redistribute charge. At some level of voltage, most materials become conductors. Metals are the best conductors. When electrons in a material are not free to move, the material is called an insulator. This property of opposing the movement of electrons is called resistivity. In a wire, resistivity is expressed as resistance and is measured in Ohms. An ideal conductor has zero resistance and an ideal insulator has infinite resistance.

Current is the movement of charge through a conductor and is measured in Amperes (A). A circuit is created when a continuous path for the current is formed. With direct current (DC), like that produced by a battery, the current flows in one direction at a constant level; whereas with alternating current (AC) both the level and direction of the flow change periodically with time. Frequency is the number of these complete cycles that the alternating current undergoes in one second and is expressed in cycles-per-second or Hertz (Hz). Electrical power systems in North America operate at 60 Hz, while 50 Hz is predominate elsewhere, including all of Europe. For 60-Hz alternating current, 60 complete cycles occur every second with the current's direction reversing during each cycle.

Conceptually similar to water being pumped through a pipe, electrical current is "pushed" through a conductor by a difference in electric "pressure" or potential between the ends of the conductor. This difference in potential is measured in volts and is called voltage. With alternating current, both the voltage and current vary sinusoidally, as Figure 2-1 shows.

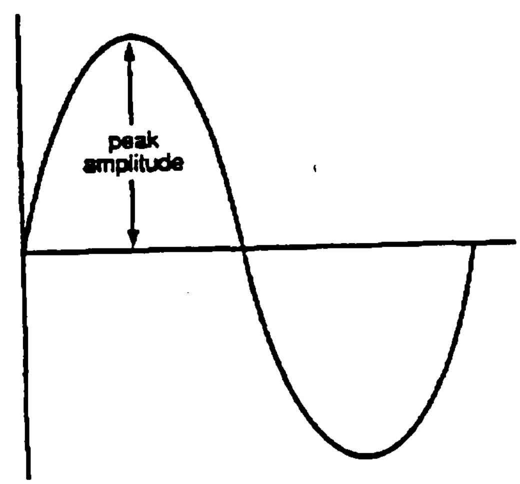

Figure 2-1. Alternating sinusoidal wave shape for current or voltage. The quantity flows one direction during the first half of the cycle and reverse direction during the second. (EPRI, 1989)

2.3.3 Field Concepts

A set of values of a physical quantity at different points in space can be represented as a field. An example of a simple field is the temperature across the State of Texas at noon on January 1, 1990. Each geographic point in the state has associated with it a measurable value of temperature. By associating a temperature reading with every reporting point in the state, we could construct a temperature field.

The above example is a scalar field, where the property being measured is a value easily read on a single scale. More pertinent to the electric or magnetic fields is the idea of a vector field, where each point not only has a value associated with it, but the value is oriented in a specific direction. One example of a vector field is the trajectory of each fragment of a hand grenade during an explosion. A snapshot would show that each piece of shrapnel is travelling at a specific speed in a certain direction. We can describe the explosion in terms of this vector field. Another example of a vector field is the pattern formed by water spraying from the end of a fire hose. A vector field describing the flow will consist of the speed and direction of each molecule of water at every point in the flow.

2.3.4 The Electromagnetic Spectrum

As shown in Figure 2-2, the electromagnetic spectrum encompasses the frequency range of all electromagnetic energy. Near the bottom of the spectrum are extremely low frequency (ELF) waves like powerline fields and near the top are very energetic cosmic rays. In the middle of the spectrum, in a small frequency band, is visible light; different frequencies of light produce different colors. Below visible light are frequencies that produce infrared, microwave, and radio waves, while above visible light are ultraviolet, x, gamma, and cosmic rays. The product of frequency and wavelength of electromagnetic radiation is always a constant–the speed of light. Therefore, the higher the frequency the shorter the wave length. A 60-Hz power frequency has a corresponding wavelength of 5,000 kilometers (about 3,000 miles). In comparison, the wavelength of a television transmission is about 3 meters.

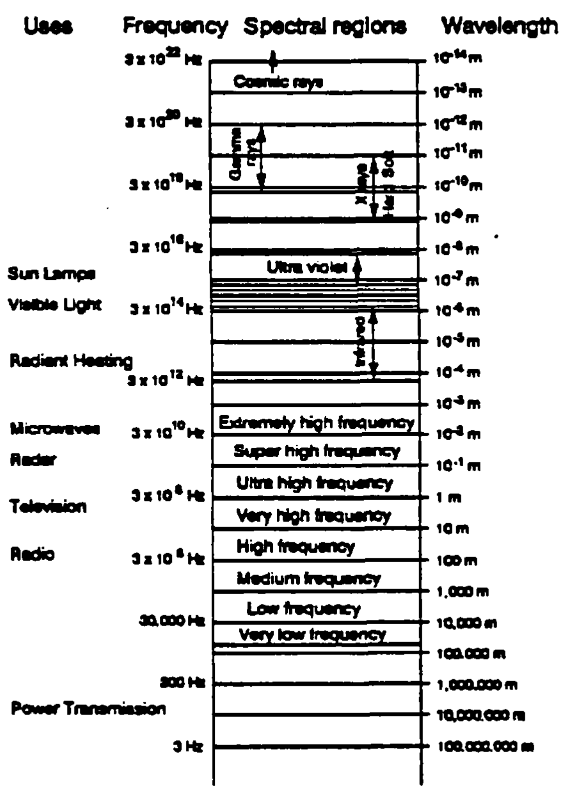

Figure 2-2. The electromagnetic spectrum shown by frequency and wavelength. At a frequency of 60 Hz and a wavelength of 5,000 km, powerlines are at the bottom of the figure. Frequencies less than 300 Hz are designated as extremely low frequency (ELF). (EPRI,1989)

The way the electric and magnetic fields from a source of electromagnetic energy appear to an observer depends on the distance to the source in comparison to the wavelength of that source. When the distance from the source is large compared to its wavelength, the electric and magnetic fields are linked together as electromagnetic radiation. The area where this linking occurs is called the "far" or "radiation" zone. At anything greater than atomic distances, visible light will always appear as a radiation.

When the distance from the source is small with respect to wavelength, the electric and magnetic fields appear as separate quantities. Earth based observers are always in the so called "near" or "static" zone of power frequency fields because of their long wavelength. Therefore, power frequency fields behave as separate, independent, non-radiating electric and magnetic fields. So when studying power frequency fields, we consider the electric and magnetic fields as separate quantities and not as electromagnetic radiation.

2.3.5 Electric and Magnetic Fields

Electric and magnetic fields are vector fields. Within the field, the electrical force produced by the field on a unit charge can have a different magnitude and direction at each point in space and time. These fields are defined by the forces exerted on electrical charges.

Electrical charges cause electric fields, which can be described in terms of electric field strength (E) with units of volts per meter (V/m). The electric field is defined by the force it exerts on a static unit of charge. The electric field is a function of the voltage of the source–the higher the voltage the stronger the field. Transmission line electric fields are typically measured in thousands of volts (kilovolts) per meter (kV/m).

Moving electrical charges cause magnetic fields. Just as the electric field is defined by the force exerted on a stationary unit of charge, the magnetic field is defined by the force exerted on a moving unit of charge. The magnetic field is usually measured in terms of its magnetic flux density (B), although some instruments may be calibrated in magnetic field strength (H). The magnetic field strength and flux density are related to each other by a permeability constant (μ) i.e., $B=\mu H$. The most common units of magnetic flux density are the gauss (G) and tesla (T) and for magnetic field strength it is the ampere/meter (A/m). Table 2.1 shows the equivalence between units. Powerline magnetic fields are usually described in terms of thousandths of a gauss (milligauss or mG) or millionths of a tesla (microtesla or μT).

Table 2.1 - Equivalence Between Magnetic Field Units

Units	G	mG	T	μT	A/m
G	1	1000	0.0001	100	80
mG	0.001	1	10^{-7}	0.1	0.08
T	10^4	10^7	1	10^6	800,000
μT	0.01	10	10^{-6}	1	0.8
A/m	0.0125	12.5	1.25×10^{-6}	1.25	1

The electric field at a point is a function of the voltage of the source and the distance to the source. The electric field strength increases as the voltage is raised or the distance to the source is reduced. Because utilities design their systems to maintain powerline voltage levels within a fairly narrow range over time, the electric field at specific point from a particular powerline will vary little with time and can almost be considered constant.

The magnetic field is independent of the voltage, but depends on current in the conductor and the distance to the conductor. The magnetic field increases with more current and increases the closer you get to the source. Unlike the electric field, the magnetic field from a powerline exhibits a great temporal variability since it is a function of the circuit loading, which varies by time of day and season of the year.

The magnetic field drops off with increasing distance from the source. The electrical and physical characteristics of the source dictate how rapidly this decrease occurs. Generally, magnetic field levels will decrease according to one of three relationships with distance: inversely with distance, inversely with the square of distance, or inversely with the cube of distance. Figure 2-3 illustrates these three relationships for a source of the same strength. Doubling the distance will decrease the field to one-half under the inverse relationship, to one-quarter under the inverse squared, and to one-eighth under the inverse cubed. The conditions under which these relationships occur will be discussed later.

Earth's Electric Field. The earth possesses an essentially static electric field, which is vertically-directed with a strength about 130 V/m near the surface. It is caused by the separation of charge between the earth and the ionosphere. Together they form a capacitor with the earth being the negatively charged plate and the atmosphere being the positively

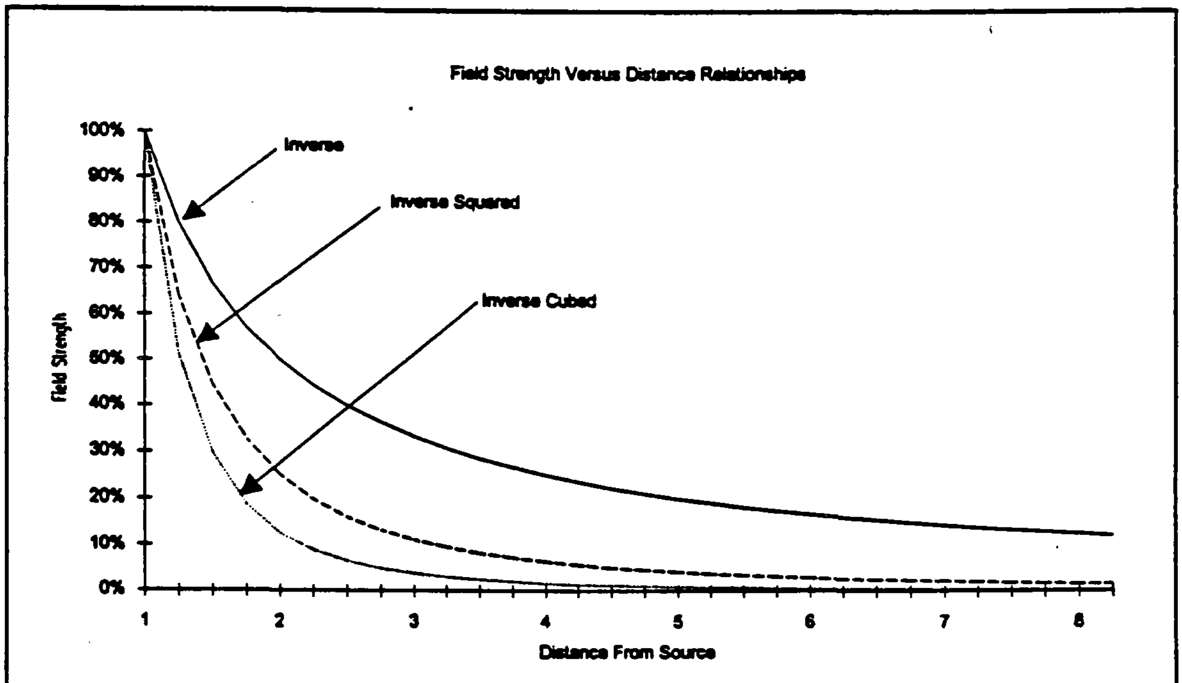

Figure 2-3. Field strength varies with distance from the source according to inverse, inverse-squared or inverse-cubed relationships.

charged plate. Lightning maintains the potential difference by transferring the excess charges. On average, about 2000 thunderstorms are occurring at any time, and there are about 100 lightning flashes per second worldwide. The field follows a diurnal cycle as shown in Figure 2-4. Fields of 10 kV/m or higher can occur during thunderstorms. (EPRI, 1989)

Earth's Magnetic Field. The earth also possesses an essentially static magnetic field. Current flowing through the earth's molten interior is believed to be the source of the geomagnetic field. Its magnetic flux density averages about 500 mG at middle latitudes, but varies between the equator and the poles. The vertical component of the geomagnetic field is greatest at the magnetic poles, reaching about 670 mG and falls to zero at the magnetic equator. Conversely, the horizontal component's maximum of about 330 mG occurs at the equator and is zero at the magnetic poles. (EPRI, 1989)

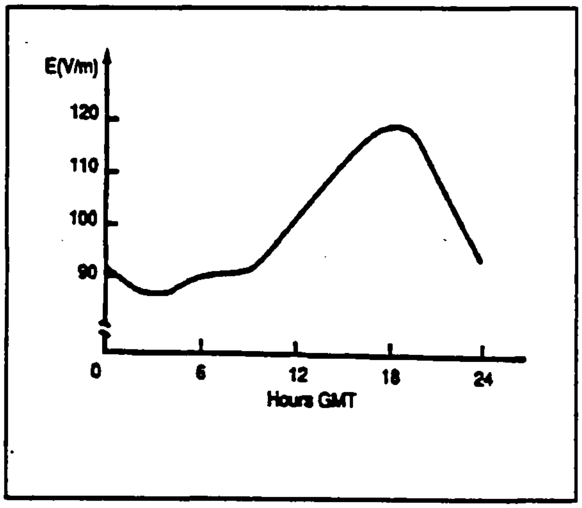

Figure 2-4. Average diurnal variation of the atmospheric potential gradient. The peak occurs near 7 p.m. Greenwich Mean Time (GMT) and is associated with peak thunderstorm activity around the globe (EPRI, 1989).

Man-made Power Frequency Fields

Overhead Transmission Lines. The most common means of transporting electric power is by overhead alternating-current transmission lines. Transmission lines are often grouped by their design operating voltages. Two groups are high voltage (less than 345 kV) and extra high voltage (345 kV and above). A typical transmission line has three phase conductors per circuit. Multiple, or "bundled," conductors for each phase are used at higher voltages to control corona-related effects (such as audible noise) or to increase power handling capability on heavily loaded lines. Figure 2-5 shows a typical transmission line. In each phase conductor, the sinusoidal voltage or current wave is out of phase with the other two phase conductors by one-third of the wavelength.

The transmission line is said to be balanced if the vector sum of the phase voltages and phase currents add up to zero. Ideally no currents will be flowing in the shield wires or the ground. Because of differences in the electrical characteristics of each phase and the differing amounts of single phase load attached to each phase, transmission lines are seldom precisely balanced. Even under balanced conditions, some current will be induced into the shield wires, unless they are isolated into short segments.

Transmission lines are identified by their nominal

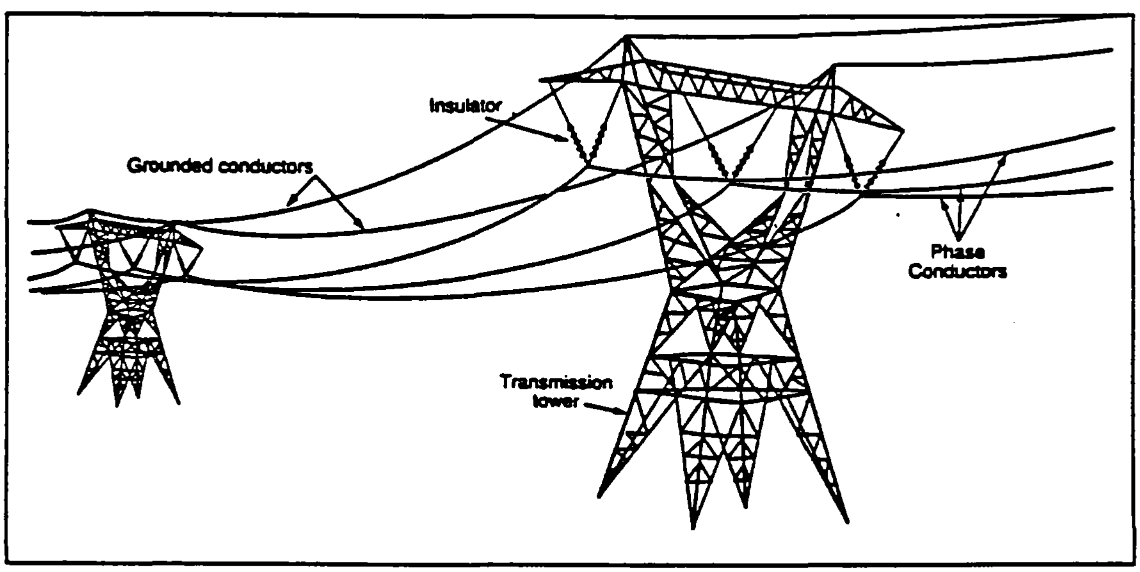

Figure 2-5. A typical three-phase single-circuit AC transmission line. (EPRI,1989)

phase-to-phase voltage. Typical nominal voltages in Texas are 69, 115, 138, 230, 345, and 500 kV. In practice, actual operating voltage will be within a few percentage points of the nominal voltage.

Electric fields near transmission lines are usually calculated or measured at a height of 1 m above the surface. The strength of the electric field from a transmission line is dependent on three factors: the operating voltage of the line, the height of the conductors above the ground and the distance from the line to the point of measurement. Figure 2-6 shows the electric field profiles for a 500-kV, 345-kV, 230-kV, and 138-kV single-circuit transmission lines. Because the field profile is symmetrical about the center of the transmission line for symmetrical arrangements of the phase conductors, often only one-half of the profile is shown. The calculations assume an open, flat surface in the area about the transmission line. Conducting objects such as vegetation, buildings or fences will "perturb," or distort the electric field.

The electric field that permeates space surrounding a transmission line can be described as a rotating vector field. The electric field at each point in space may have a different magnitude and direction and varies cyclically at the powerline frequency. The loci of the field vector describes an ellipse, with the maximum electric field occurring along the semi-major axis and the minimum electric field occurring along the semi-minor axis. Figure 2-7 shows the field ellipse.

Electric current in the transmission line phase conductors produces a magnetic field. Figure 2-8 shows calculated magnetic flux densities profiles at 1 meter above the ground for different transmission lines. The peak magnetic field beneath a 500-kV line carrying 2,150 megawatts (MW) is about 450 mG. For a single-circuit 345-kV transmission line carrying 1,050 MW is about 330 mG. The peak magnetic field for a 230-kV line carrying 350 MW is about 170 mG and the peak magnetic field for a 138-kV line carrying 112 MW is about 95 mG.

Unlike the electric field, the presence of most objects does not perturb the magnetic field thus making shielding very difficult.

For balanced conditions, the transmission line's magnetic field will decrease with the square of the distance from the line. Generally transmission line phase currents will be better balanced than distribution line phase currents. If an unbalanced condition occurs, the resulting magnetic field would be proportional to the degree of unbalance in the phase currents (i.e., the net current) and would decrease as distance between the line and point of interest increases.

The design of the transmission line will influence the strength of the power frequency fields under and next to the transmission line. The parameter of transmission line design having the most effect on the strength of

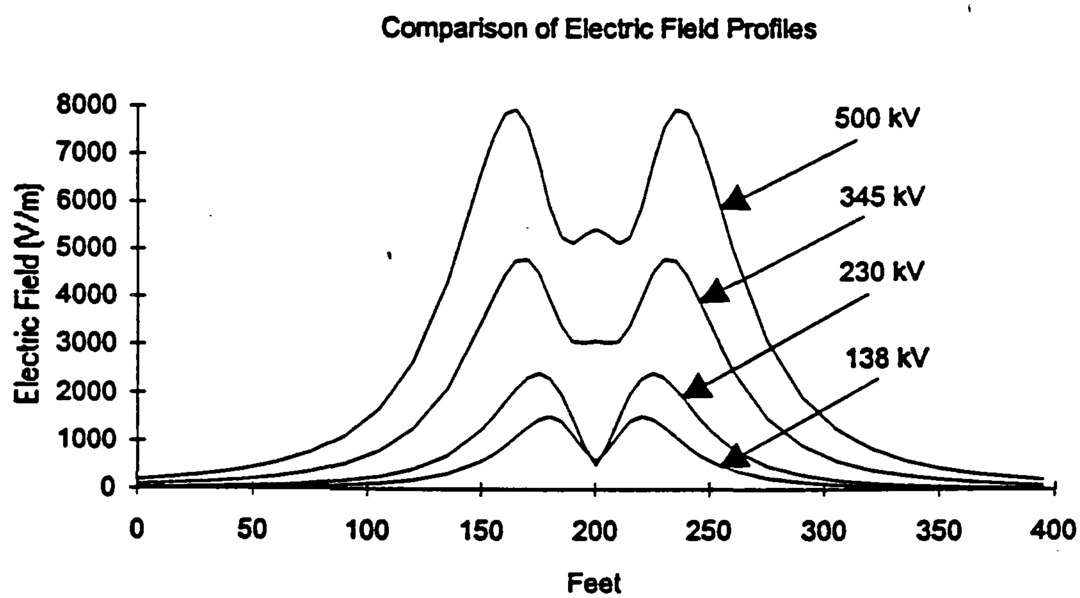

Figure 2-6. The maximum electric field lateral profile for 500-kV, 345-kV, 230-kV, and 138-kV transmission lines. The profiles are symmetrical about center of the line (located at 200 ft.). Conductors are at minimum clearance conditions and the field measured at 1m above the ground.

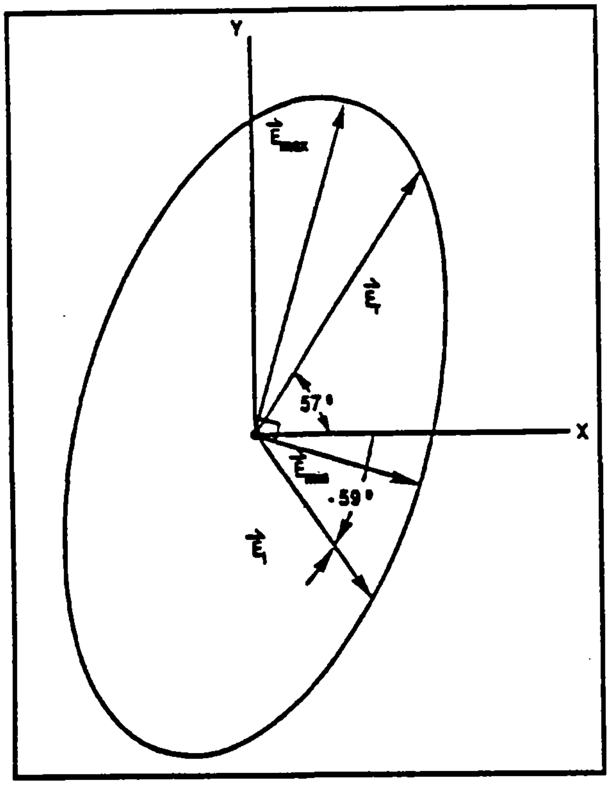

Figure 2-7. The electric field ellipse at a point in space. The maximum field occurs along the semi-major axis and the minimum along the semi-minor axis. The field vector rotates at the power frequency. (EPRI, 1982)

fields is the height of the conductors above ground. Figures 2-9 and 2-10 show the electric and magnetic field profiles for a single circuit 345-kV transmission line with conductor heights of 33', 43', 53', and 63'. As the figures show increasing the height of the conductors lowers the field strength under the line.

But, the distortion of the electric field by the earth produces a curious effect: raising the conductors slightly increases the electric field's strength at points greater than a certain distance from the line. This distance is called the critical distance. Figure 2-11, which shows the resultant electric field profiles for the two extremes (33' and 63'), more clearly shows this effect. With increasing conductor height, the electric field strength decreases at those points located less than the critical distance, the electric field stays the same at the critical distance, and it increases at distances greater than the critical distance.

The critical distance depends on the distance between phase conductors and the diameter of the phase bundles. The significance of the critical distance is that in cases where it is desirable to reduce the electric field at some point on the ground, conductor height must be increased for points within the critical distance (i.e., usually locations within the right-of-way) but decreased for points greater than the critical distance (i.e., usually locations outside the right-of-way).

Since the magnetic field is unaffected by the presence of the ground, this critical distance phenomena does not affect the magnetic field profiles. Magnetic field intensities, for all points on the ground, will always be reduced with increased conductor height.

Another parameter of transmission line design affecting only the electric field strength is the size of the phase conductors. Figures 2-12 and 2-13 shows the effect on the magnetic and electric fields respectively of doubling and halving the 18 inch bundle spacing. Decreasing the diameter of the phase conductors or, for bundled phases, decreasing the bundle spacing decreases the electric field strength, but has no effect on the magnetic field strength. Drastic changes are required to affect significantly the electric field at ground level, and the opportunities for manipulating phase diameter are limited by mechanical, electrical, and cost constraints.

The distance between phases can affect the electric and magnetic field levels. Figures 2-14 and 2-15 show the effect on the electric and magnetic field profiles, respectively, for the same transmission line with different phase spacings of 37.5', 27.5', and 17.5'. The canceling effect of one phase upon the others suggests that more compact lines will have lower fields at ground level. The amount of compaction is limited by the corona performance, tower construction and spacing, and National Electric Safety Code's clearance considerations. The orientation or configuration of the phases also can have a significant impact on the ground level fields. Figures 2-16 and 2-17 show the electric and magnetic field profiles for three possible phase configurations: vertical, horizontal (flat), and an equilateral (delta). All three configurations have the same phase spacing (27.5') and minimum conductor height (33'). The vertical and flat configurations have the highest maximum ground-level electric field under the line while the delta has the lowest. The electric field outside the right-of-way is lowest for the vertical configuration and highest for the flat. The flat configuration has the highest maximum ground-level magnetic field and the broadest profile, whereas the delta and vertical present lower maxima and more compact profiles. But, vertical configured lines require the tallest towers and therefore are the most expensive.

For transmission lines composed of more than one circuit, the phase sequencing can have a dramatic effect on the ground level fields. Also using a lower voltage distribution circuit beneath a transmission circuit can <u>sometimes</u> raise or lower ground level fields.

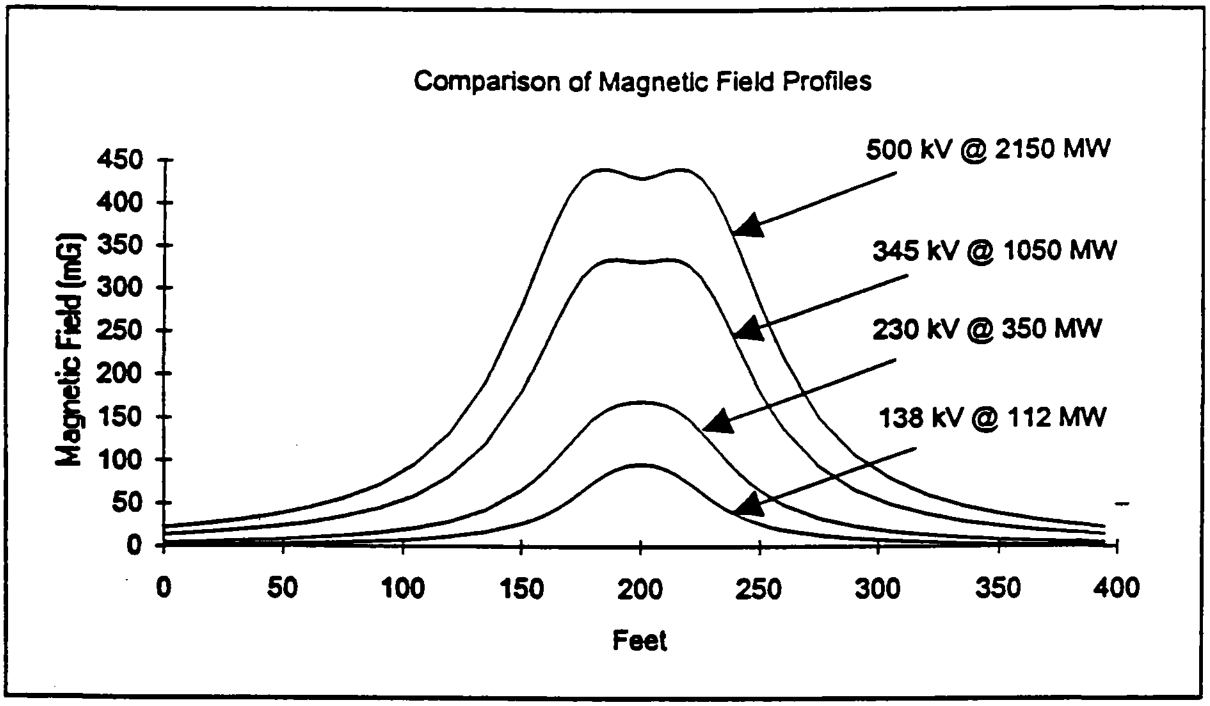

Figure 2-8. The maximum magnetic field lateral profile for 500-kV, 345-kV, 230-kV, and 138-kV transmission lines. Lines are at maximum operating load of 2150, 1050, 350, and 112 Megawatts, respectively. Conductors are at minimum clearance conditions and field measured at 1m above ground.

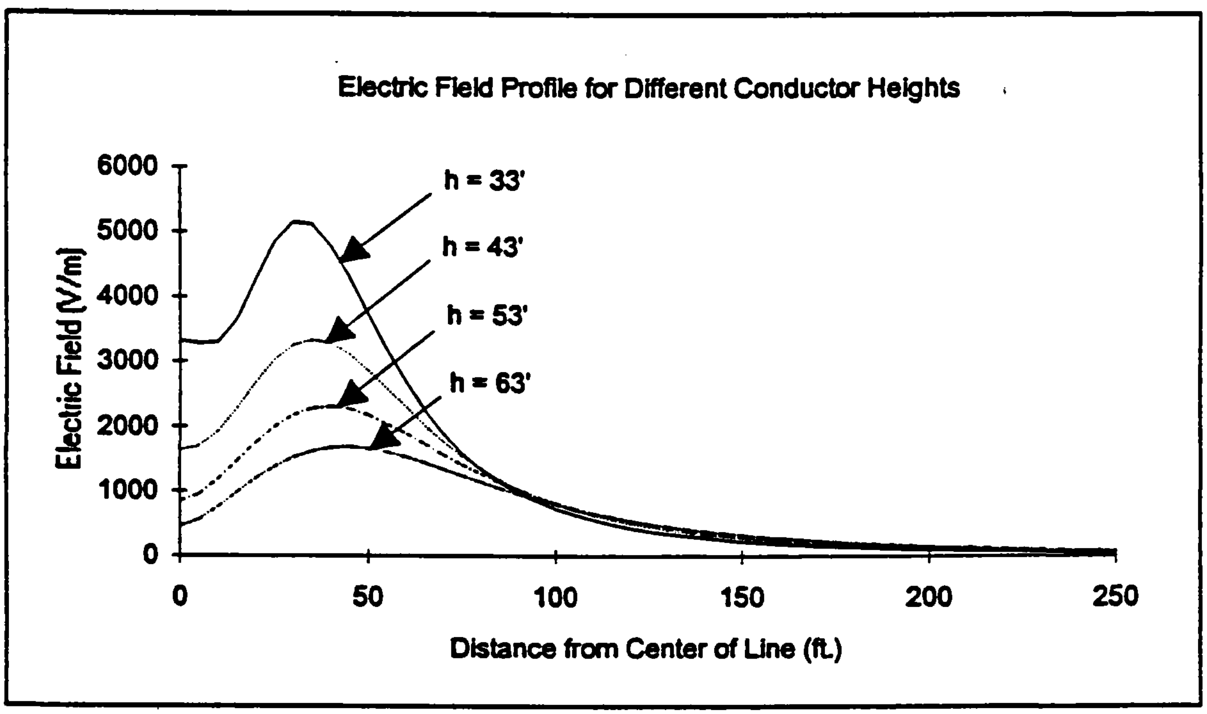

Figure 2-9. Electric field profiles at 1m above ground for single-circuit 345-kV transmission lines with conductors 63, 53, 43, and 33 feet above the ground. The profiles are symmetrical about center of line and only one side is shown.

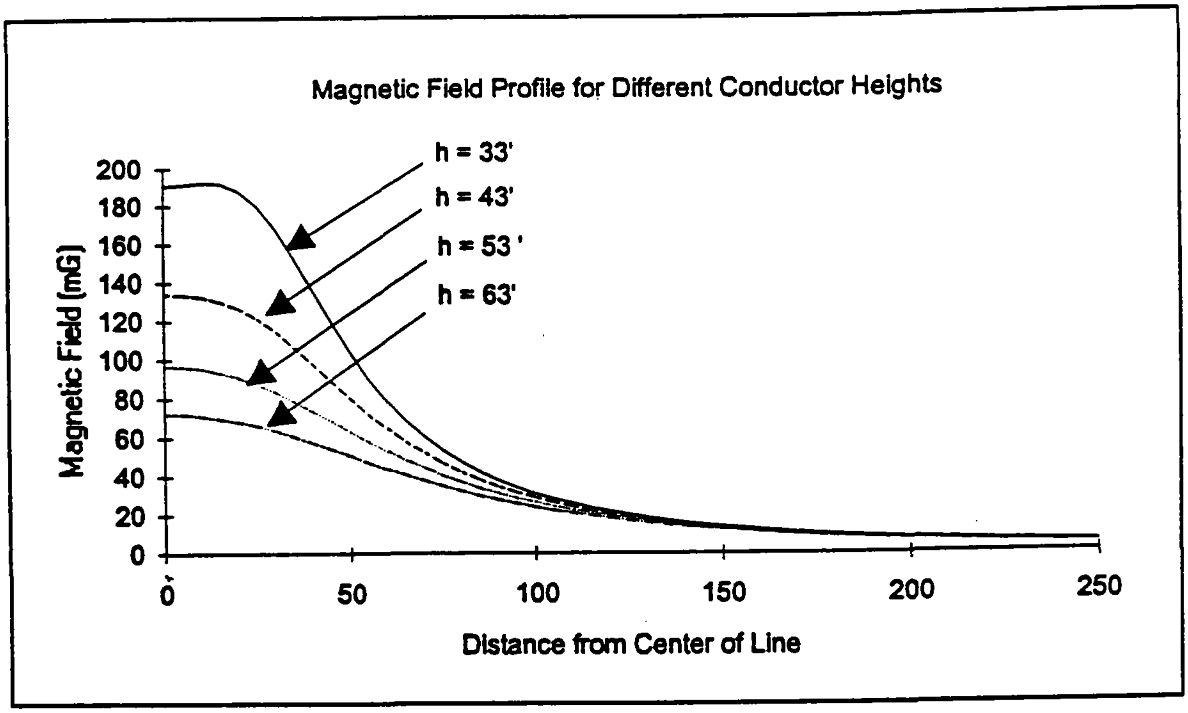

Figure 2-10. Magnetic field profiles at 1m above ground for single-circuit 345-kV transmission lines with conductors 63, 53, 43, and 33 feet above the ground. The profiles are symmetrical about center of line and only one side is shown.

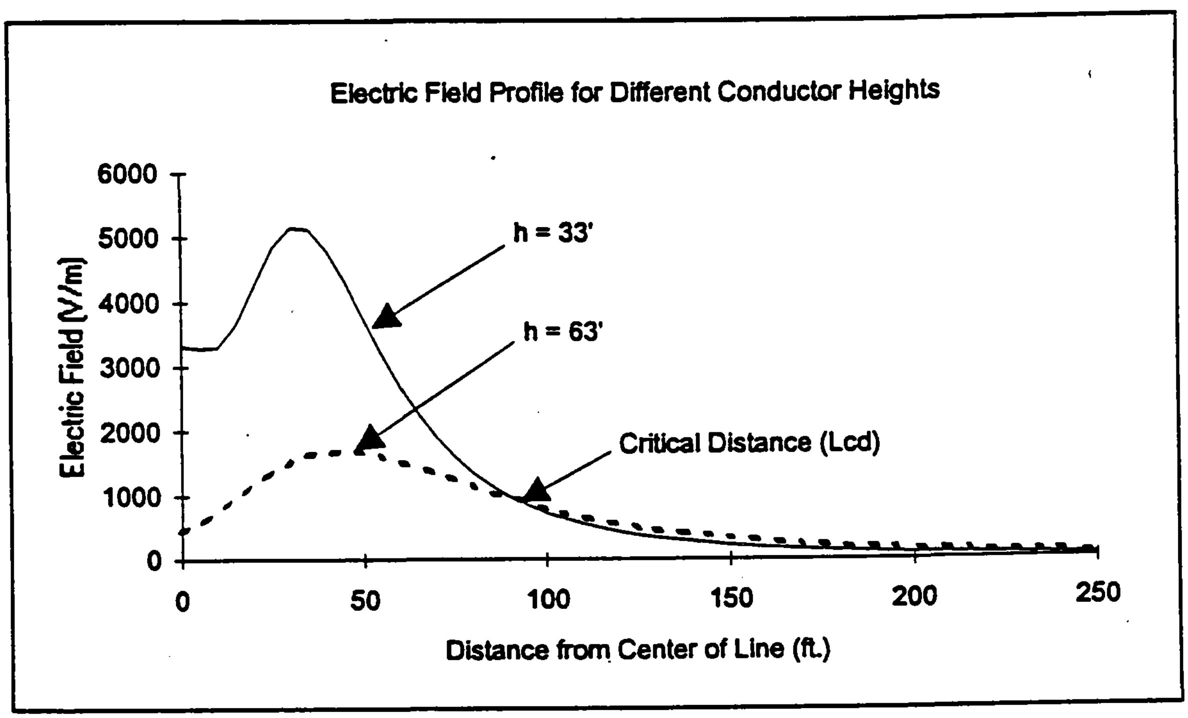

Figure 2-11. Critical distance (L_{cd}) for electric field from a 345-kV transmission line. The intersection of the field profiles occurs at L_{cd}. Increasing conductor height lowers E-field inside Lcd but raises E-field outside of L_{cd}.

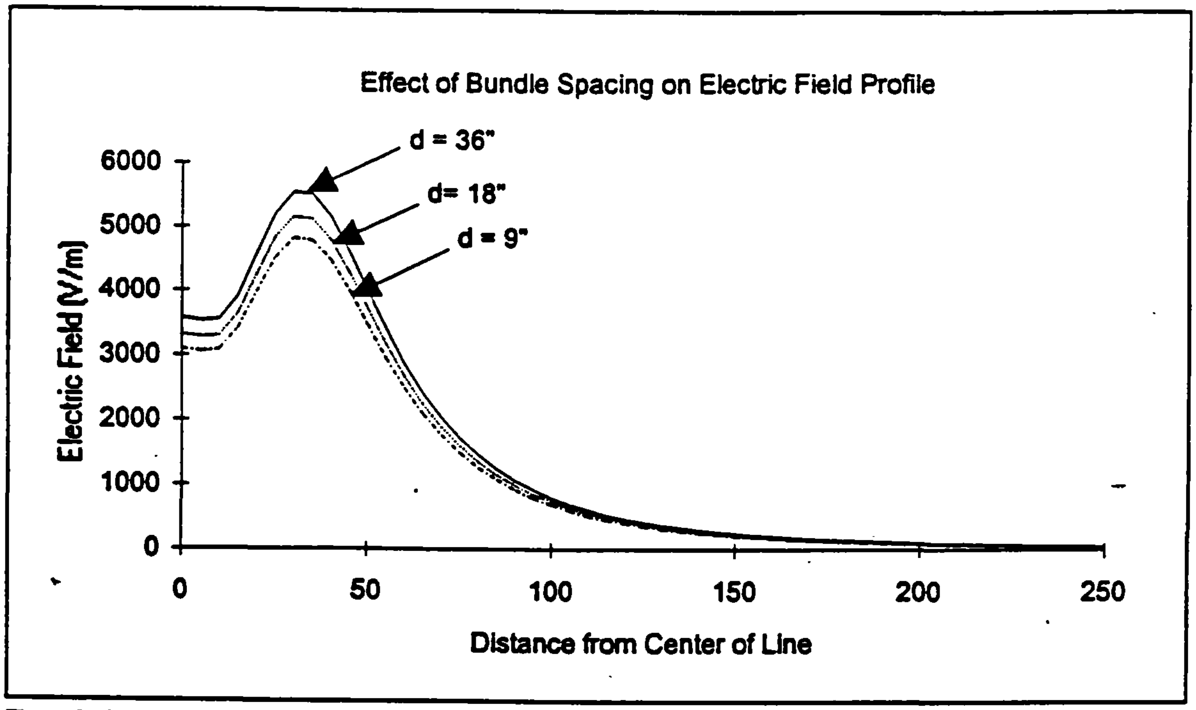

Figure 2-12. Electric field profiles for phase conductor bundle spacings of 9, 18, and 36 inches for a single-circuit 345-kV transmission line. Lines with smaller conductors (i.e., closer bundle spacing) have lower electric fields.

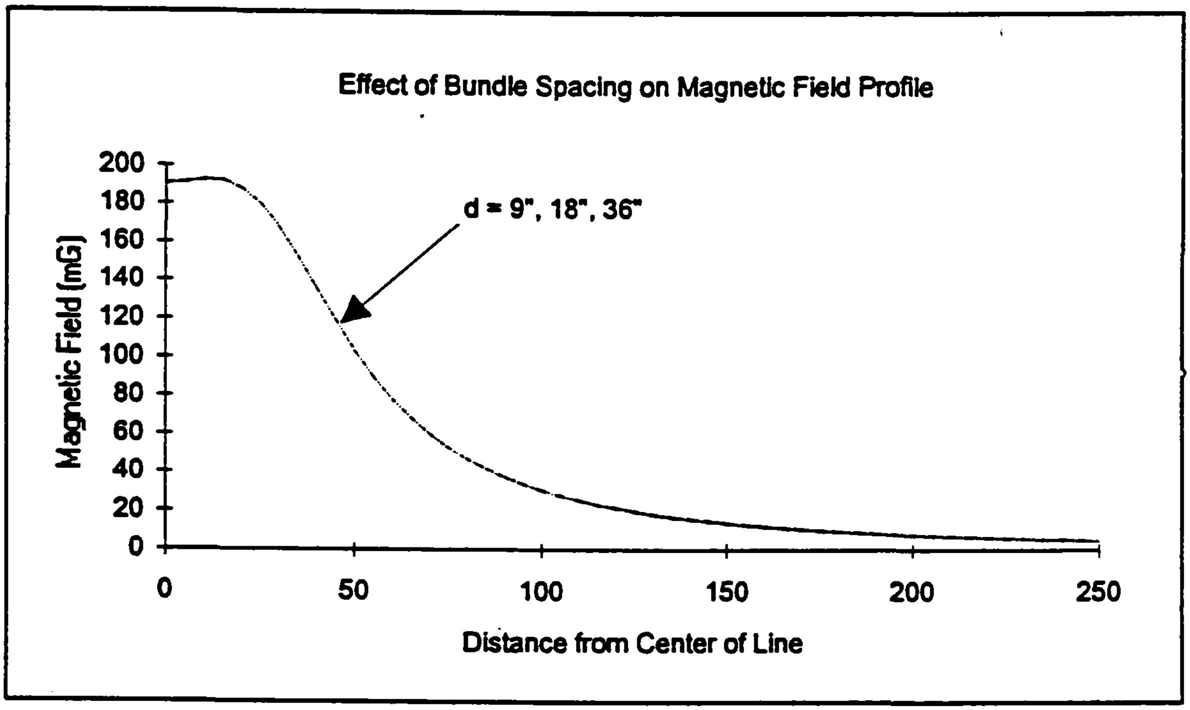

Figure 2-13. Magnetic field profiles for phase conductor bundle spacings of 9, 18, and 36 inches for a single-circuit 345-kV transmission line. Conductors size (i.e., bundle spacing) has no effect on magnetic field strength.

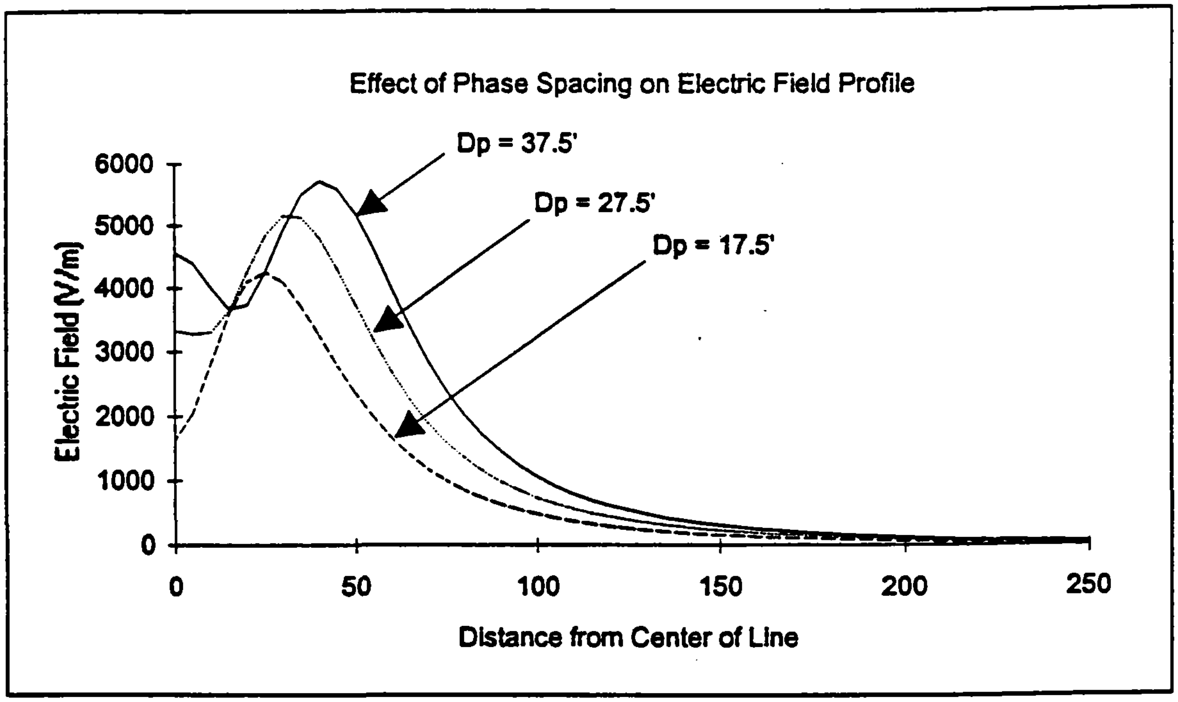

Figure 2-14. Electric field profiles for phase conductor spacings of 17.5, 27.5, and 37.5 feet for a single-circuit 345-kV transmission line. Compact transmission lines (narrower phase spacings) have lower electric fields.

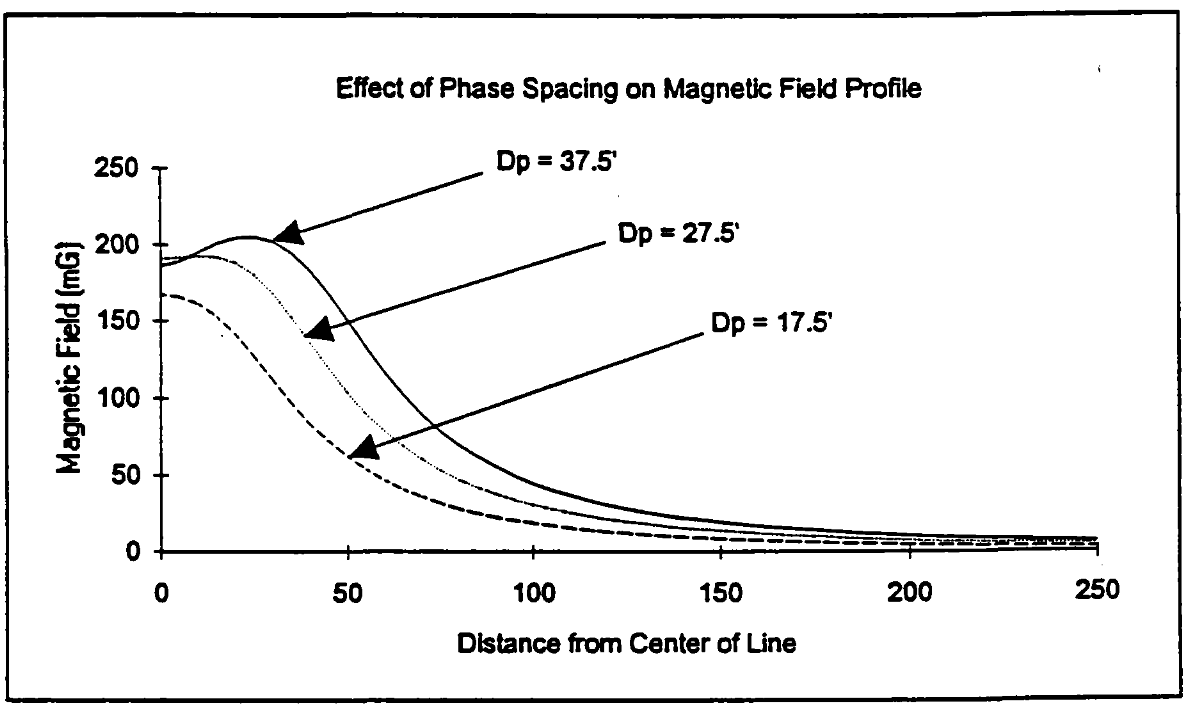

Figure 2-15. Magnetic field profiles for phase conductor spacings of 17.5, 27.5, and 37.5 feet for a single-circuit 345-kV transmission line. Compact transmission lines (narrower-phase spacings) have lower magnetic fields.

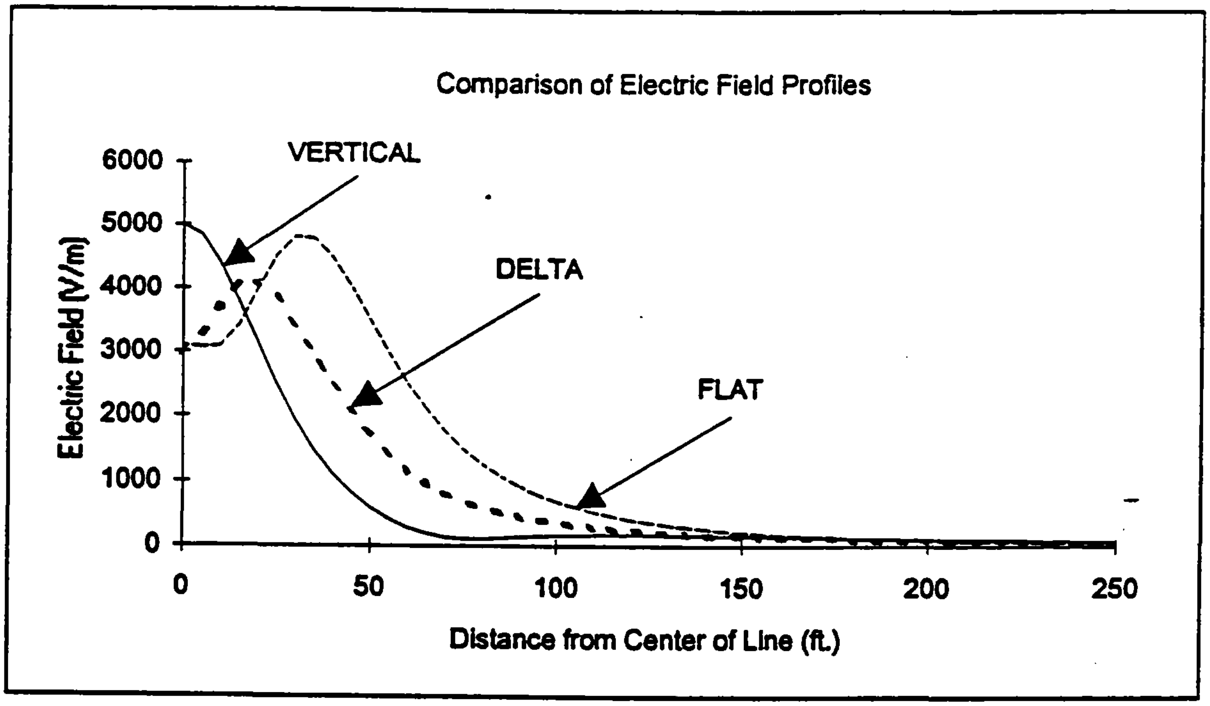

Figure 2-16. Electric field profiles for single-circuit 345-kV transmission lines with flat (horizontal), delta (equilateral) and vertical phase geometries. The phase spacing and minimum conductor height is the same for each configuration.

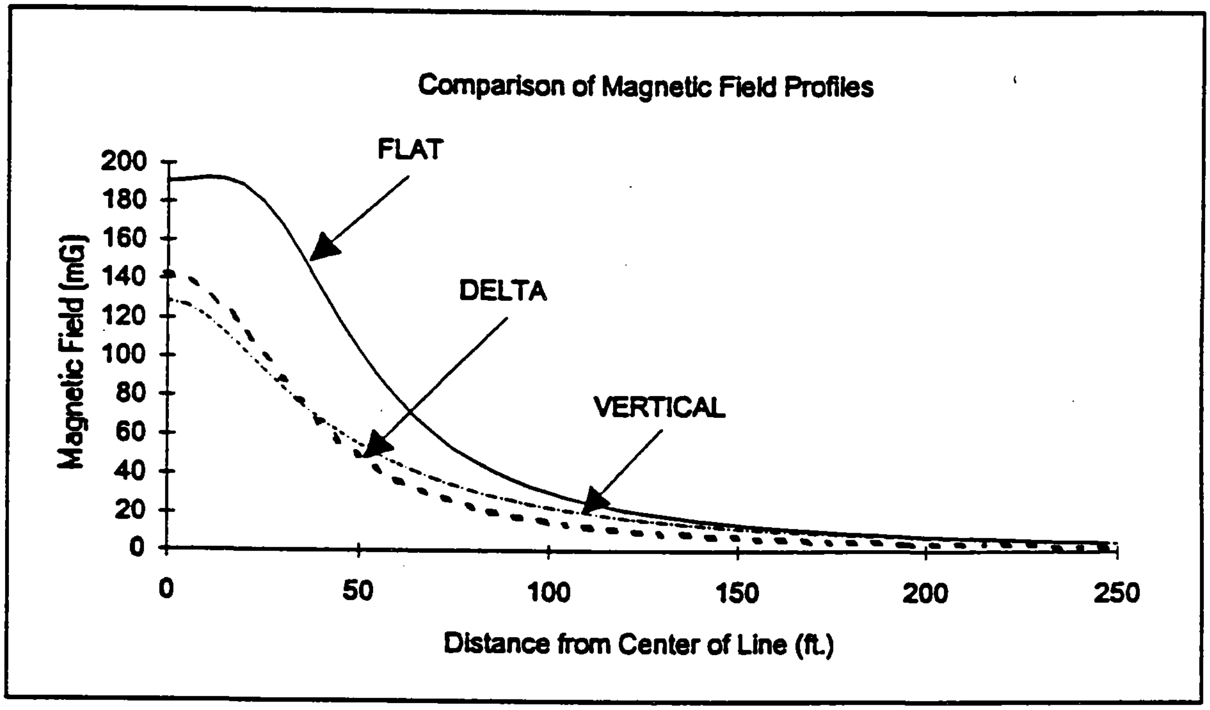

Figure 2-17. Magnetic field profiles for single-circuit 345-kV transmission lines with flat (horizontal), delta (equilateral) and vertical phase geometries. The phase spacing and minimum conductor height is the same for each configuration.

Fields Near Underground Conductors. Placing conductors underground rather than suspending them overhead from towers or poles changes the characteristics of the fields. Underground conductors rely upon rubber and plastic materials for insulation instead of air; therefore, the phase conductors can be located much closer together than is possible with overhead lines. Sometimes all three phase conductors are combined into a single cable. With the conductors closer together, the fields tend to be lower due to the canceling effect from the phase differences among the conductors. The electric field is further reduced or eliminated by the earth, or in the case of a cable, a grounded shield which sometimes encircles the phase conductors. Although the fields can be lower, people can be in much closer proximity to the underground conductors than overhead, so exposure levels may be similar to those of overhead transmission lines. Thus putting conductors underground may not necessarily guarantee that exposures would be reduced.

Transmitting power through underground cables is tremendously more expensive than using overhead transmission lines. Not only do high voltage underground cables themselves cost more per foot and are more expensive to install than overhead transmission lines, but due to the higher capacitive reactance found in cables, more circuits will be required to carry the same amount of power.

Fields in the Home Environment. Any use of electricity will produce electric and magnetic fields. Electric field levels measured at the center of different rooms, typical of housing in United States, are shown in Table 2.2, while Table 2.3 lists levels measured 30 cm (about 1 foot) away from various home appliances. The data in the tables are from limited measurements and should be considered anecdotal. They do suggest the general range of levels that may be encountered in the home, although wide variability should be expected. Preliminary measurements, (Bracken, 1988), indicate that the electric fields found in residences result from internal sources (house wiring, appliance, etc.) rather than external sources such as transmission and distribution lines.

Table 2.2 - 60-Hz electric field levels at the center of various rooms in a typical U.S. home. (Source: WHO, 1984)

Location	V/m
Laundry Room	0.8
Dining Room	0.9
Bathroom	1.2-1.5
Kitchen	2.6
Bedroom	2.4-7.8
Living Room	3.3
Hallway	13.0

Table 2.3 - Typical 60-Hz electric field levels at 30 cm from 115-V home appliances. (Source: WHO, 1984)

Appliance	V/m
Electric Blanket	250
Broiler	130
Stereo	90
Refrigerator	60
Electric Iron	60
Hand Mixer	50
Toaster	40
Hair Dryer	40
Color TV	30
Coffee Pot	30
Vacuum Cleaner	16
Incandescent bulb	2

The magnetic field produced by most appliances is from a loop of wire or many-turn coil. Necessarily, because of the compact size of most appliances, the diameter of this loop or coil is small and achieves high magnetic fields with either high currents or multiple turns. At distances larger than the diameter of the coil the field approximates a three dimensional dipole field (Monitor Industries, undated) and decreases with the cube of the distance (see Figure 2-3), therefore falling off very quickly.

Table 2.4 shows the magnetic flux densities at distances of 3 cm, 30 cm and 1 m from several appliances. At 30 cm, levels range from 0.03 μT to 30 μT (0.3-300 mG). Notice how rapidly the magnetic field decreases with increasing distance. Unlike electric field levels in the home, magnetic flux densities close to some household appliances are higher than encountered under transmission lines (EPRI, 1989). However; when comparing the time-duration exposure to appliance fields, two points must be considered:

Table 2.4 - 60-Hz magnetic flux densities near various appliances. (Source: WHO, 1987)

Appliance	Magnetic Flux Density, μT		
	3cm	30cm	1m
Can openers	1000-2000	3.5-30	0.07-1
Hair dryers	6-2000	0.01-7	<0.01-0.3
Electric shavers	15-1500	0.08-9	<0.01-0.3
Drills	400-800	2-3.5	0.08-2
Mixers	60-700	0.6-10	0.02-0.25
Portable heaters	10-180	0.15-5	0.01-0.25
Blenders	25-130	0.6-2	0.03-0.12
Television	2.5-50	0.04-2	0.01-.15
Irons	8-30	0.08-0.15	0.01-0.025
Coffee makers	1.8-25	0.08-0.15	<0.01
Refrigerators	0.5-1.7	0.01-0.25	<0.01

- *Appliance fields, generally, exist only a small fraction of the time--most appliances are off more than they are on.*

- *Because the fields of most appliances fall off rapidly with distance, the areas in which the fields are elevated due to operation of the appliances are small compared to the total living area.*

Residential background magnetic fields, away from appliances, range from 0.05 to 1 μT (0.5-10 mG) (EPRI,1989). Figure 2-18 shows the major sources of magnetic fields, which are distribution lines, residential grounding systems, unusual wiring configurations within the residence, and nearby transmission lines. The following will discuss each of these sources.

The power distribution lines that gird the alleys and streets of residential neighborhoods are a source of magnetic fields in the home environment. These lines consist of both primary and secondary conductors (wires). Three separate sources of magnetic fields can be identified for distribution lines: balanced currents in primary wires, balanced currents in secondary wires, and net current that is the vector sum of all individual wire currents.

The primary carries power from a step-down transformer at the substation to the pole-top transformers on the distribution line. The primary may include a neutral wire, which may or may not be connected to the secondary neutral wire. The secondary carries power from the pole top transformer to the customers' service drops. The secondary usually consists of two energized wires at the nominal residential voltage of 120 V (240 V between the two wires) and the neutral, which is at ground-potential (zero volts). The secondary serves several residences, while service to each home is supplied via a service drop, which is generally a three-wire line connected to the secondary conductors.

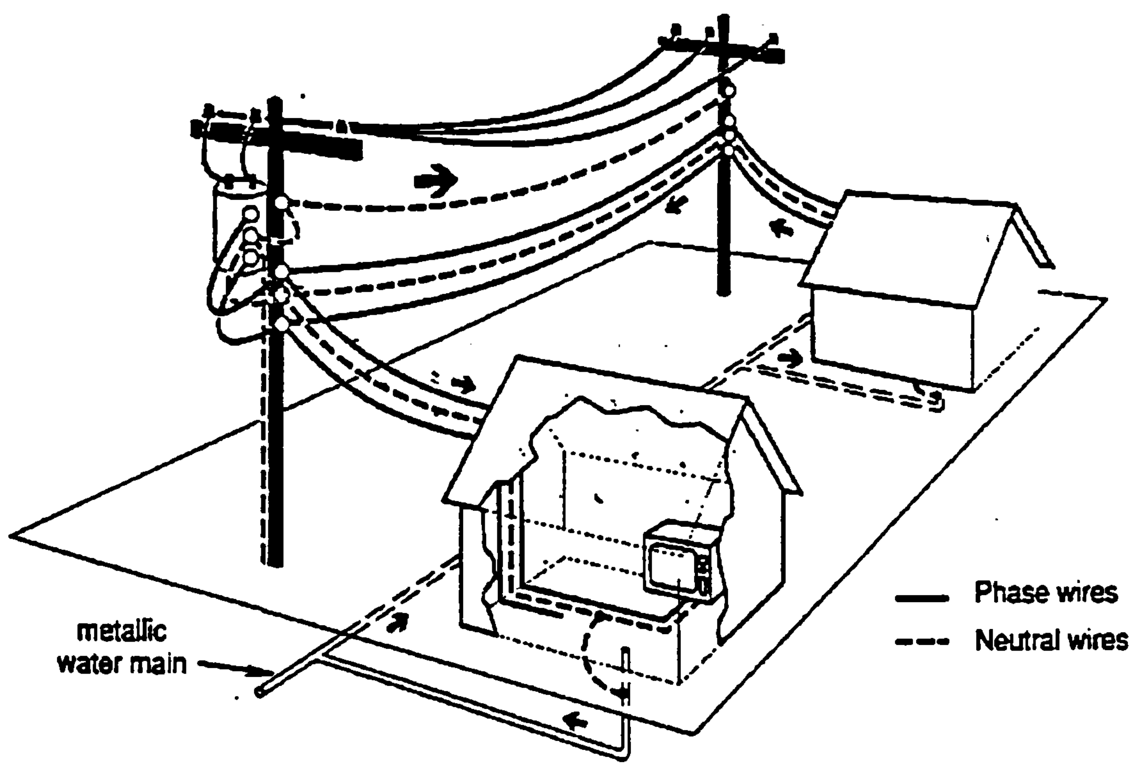

Figure 2-18. **Residential magnetic field sources include appliances, grounding systems and overhead distribution lines (primary, secondary, and net current). Other possible sources are unusual wiring, underground cables and nearby transmission lines.(EPRI, 1989)**

Safety precautions and engineering practice dictate the number, location, and type of grounds in the distribution system, but these multiple ground connections provide multiple return paths for the load current. The primary's neutral is grounded at each distribution transformer and at regular intervals along the line. If a portion of the load current returns through any of these ground paths instead of through the neutral conductor, an unbalanced condition will occur and a net current will exist, producing a magnetic field in the residence.

As mentioned earlier, the fields from balanced currents decrease proportional to the square of distance, whereas the fields from unbalanced currents (i.e., net current is not zero), decrease proportional to distance. At locations far from the line, the net current becomes a major contributor to the magnetic field. Therefore predicting the magnetic field level at such locations based only on balanced conditions often underestimates the actual level if a net current is present. The magnetic field caused by a net current in the distribution system will be more uniform throughout a residence than that caused by balanced currents.

The grounding system at the residence can be a very significant source of magnetic fields in the home environment. It consists of the connections between the service drop's neutral wire and the electrical ground at the residence. A common safety practice is to ground the neutral wire at the service entrance by connecting it to a metallic water pipe. This allows neutral current from household appliances to return through both the service drop neutral and the ground connection to the water line (Figure 2-18). The current returning on the water pipe (the ground current) flows to the water main, and then to neighboring water pipes and service drop's neutrals. While done for safety reasons, grounding the neutral wire at the service entrance can cause large current loops that are a source of magnetic fields.

The amount of the house current flowing back to the distribution system through water pipes or other ground return paths may be small. However, if some of the current does return by a way other than the neutral wire, it most likely will be through the water pipe. Ontario Hydro Research (Mader, 1989) has shown that they can predict residential magnetic fields by combining a measurement of the outside ambient magnetic field with the magnetic field calculated to be produced by ground paths currents. They calculate the ground path magnetic fields by measuring the current in the water pipe. Other possible ground return paths are through cable television lines, telephone lines, ground rods, connections to steel reinforcing rods in concrete floors and foundations, and equipment connected to ground.

Ground currents produce a very non-uniform magnetic field within the living space of a residence because of the widely differing distances and convoluted routings of the grounding system's current paths. The field also varies greatly in time since the ground current changes every time a 120-V appliance operates.

House wiring is generally not a significant source of magnetic fields. When the supply and return currents are equal, the opposite fields cancel and produce very little field at distances of more than a few inches from the wiring. In other situations, which may not violate any electric codes, more than one supply or return path is present. This might happen when controlling one socket of a duplex outlet from a remote light switch, wiring adjacent outlets from different sources but using only one neutral return for both, and controlling one light fixture from two switches.

Two methods of wiring may be commonly found in houses: Romex cable and "knob and tube." Modern practice is to use Romex cable, which combines supply, return and ground wires closely together in one cable. Older houses may contain "knob and tube" wiring, which uses discrete supply and return wires often separated by several inches and supported in the attics and walls by a series of porcelain standoffs (knobs) and insulating tubes. Experience has shown that houses with knob and tube wiring generally have higher fields.

However, by far the most common situation found in house wiring that results in unbalanced currents is connecting the neutral to ground at a location in the residence besides the service entrance. In houses with metallic plumbing, the neutral is usually connected to the plumbing by a ground strap. Some current may flow through the ground strap back to the transformer serving the house, resulting in an unbalanced condition.

Electrical appliances (garbage disposals, ice makers, whirlpool baths, refrigerators, etc.) connected to the plumbing also may provide additional ground return paths for the neutral current. These can produce multiple current loops and be a source of magnetic fields within the home.

Table 2.5 - Residential magnetic field source characteristics. (Source: EPRI, 1989)

Source	Spatial Distribution in living space	Temporal distribution	Harmonic Content
Transmission Lines	Practically uniform	Relatively uniform	Practically zero
Distribution Primary	Non-uniform	Diurnal cycle	Low 3rd harmonic (1-5%)
Distribution Secondary	Non-uniform	Very non-uniform	High harmonic content
Net Current	Slightly non-uniform	Non-uniform	High 3rd harmonic (20-150%)
Grounding System	Very non-uniform	Very non-uniform	High up to 11-17th harmonics
Unusual Wiring	Very non-uniform	Very non-uniform	May be high
Appliances	Extremely non-uniform	Extremely non-uniform	Depends on appliance

EPRI (EPRI, 1989) has summarized (Table 2.5) the residential magnetic field characteristics for different sources. The table includes appliances as field sources and observations on the harmonic content of the fields.

2.3.6 Field Measurement Fundamentals

Although the type and purpose of a measurement dictates the type of equipment used, all instruments rely on a few fundamental principles to detect and measure EMF. Electric fields can be measured by three types of field meters as Figure 2-19 shows: the free body meter, the ground reference meter and the electro-optic meter. The free body meter measures electric field strength by metering the current or time varying charge induced between the halves of a dipole probe (see Figure 2-20). For many instruments the case itself is the probe. The free body meter is self contained, allows measurements above a ground plane, and does not require a known ground reference. The ground reference type meter measures the electric field strength by metering the current flowing between a probe placed in the field and a known ground reference. Its use is restricted to measurements on flat grounded surfaces. The electro-optical meter uses the Pockels effect to measure electric field strength. The Pockels effect is the change in refractive properties of certain crystals in the presence of an applied electric field and is proportional to the first power of the electric field strength. Although compact, the electro-optical meter lacks sensitivity in fields of less than 5 kV/m and is expensive. The free body and ground reference meters have been available commercially for about the last fifteen years, whereas the electro-optical meter only recently.

Magnetic field meters operate by detecting the voltage induced into a probe by the magnetic field. The probe element is a shielded wire coil. When the coil encounters a time-varying magnetic field, a voltage will be induced in the coil based on Faraday's Law of Induction (see Figure 2-21). The device can be made more sensitive by increasing the number of turns in the coil. The induced voltage is proportional to magnetic flux density perpendicular to the plane of the coil. The probe may be composed of a single element or three orthogonal elements that simultaneously measure the magnetic fields in all three geometric planes.

Hall-effect Gauss meters, which measure magnetic flux density from DC to several hundred hertz, are also available, but because they suffer from low sensitivity and from saturation effects due to the earth's magnetic field, authorities do not recommend their use (Misakian, 1988).

2.3.7 Cyclotron Resonance

To explain some inconsistent and ambiguous results of bioeffects experiments, some scientists have postulated a complex interaction between the earth's DC magnetic field and an external AC magnetic field (i.e., from a powerline). At specific combinations of intensity and orientation of the two magnetic fields, it is suggested that certain charged molecules (ions) of biological significance exhibit a resonance phenomena at frequencies near the powerline frequency. This phenomena is known as cyclotron resonance.

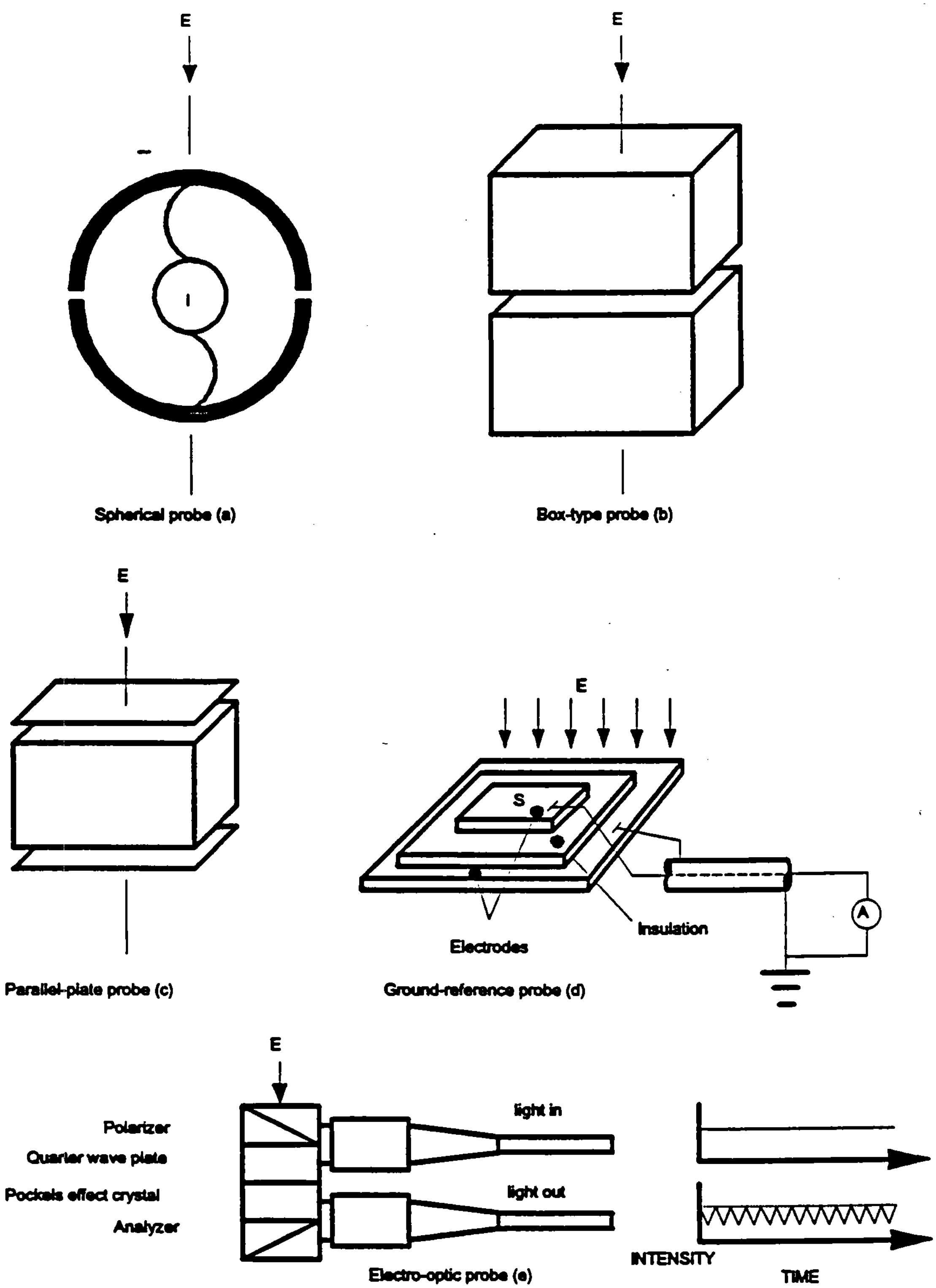

Figure 2-19. Illustrations of three types of electric field meters:

1. **free body: (a),(b),(c)**
2. **ground reference: (d)**
3. **electro-optical: (e)**

(IEC, 1987)

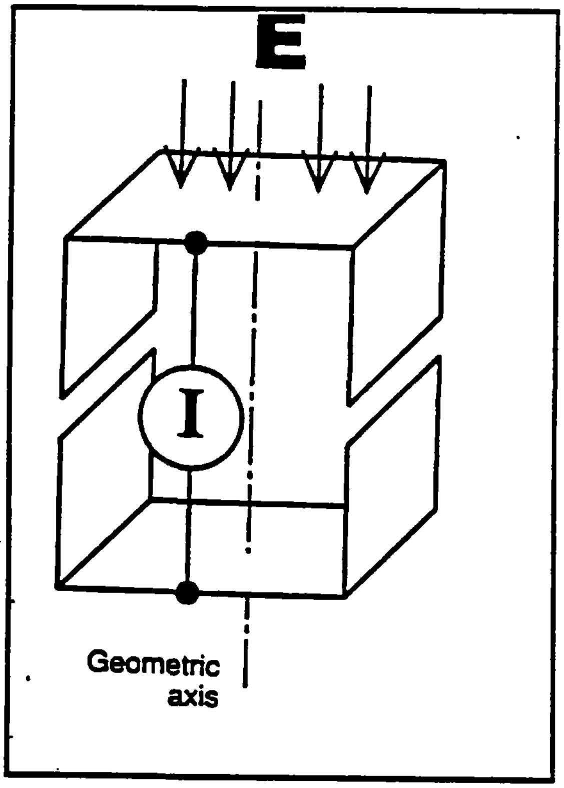

Figure 2-20. Diagram of a free body electric field meter. The device measures the current induced between its two isolated conducting halves. The induced current is proportional to the strength of the electric field. (EPRI, 1989)

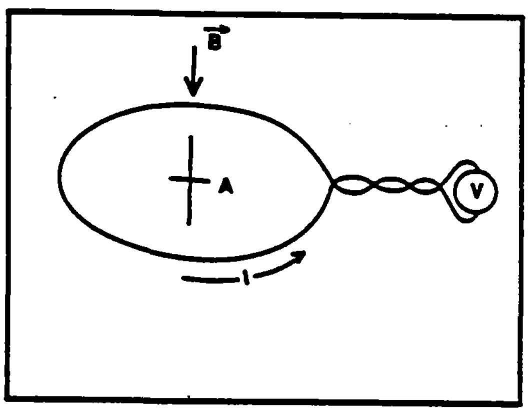

Figure 2-21. Diagram of a magnetic field meter. The voltage (V) induced in the coil will be proportional to the flux density (B) of the external magnetic field. (EPRI, 1991)

2.3.8 Biological Scaling of EMF

The establishment of precise exposure of EMF in laboratory studies on animals and tissue samples is complicated. Since EMF interaction in experimental animals can be very different from humans, it is often necessary to scale the field to duplicate the suspected conditions to mimic human exposure levels. For example, investigators might use a 65-V/m electric field on rats to simulate the same exposure of a 10-V/m field on humans, whereas they might use a 35-V/m field if the study was being done with pigs. The electric field level used in a study will depend on the size, shape and posture of the exposed subject, the particular electric parameter (electric field, induced current, or induced current density) being investigated, and the degree to which the exposed subject is grounded.

The electric field is perturbed by conducting objects in the field. Conducting objects can act to increase locally the electric field intensity. The amount of this concentration depends on the shape and size of the objects and the orientation of that object to the electric field. The field intensity above the head of a standing grounded person, may be as much as 15 to 20 times the unperturbed field (EPRI, 1988), whereas the field above the backs of pigs or rats is increased seven or four times, respectively. Concentration effects vary based on the specific part of the body and the subject's posture, but in general, the concentration of the electric field will be greatest about those surfaces with smaller radii of curvature.

The amount of current induced in an exposed subject depends on the strength of the surface electric field on the subject's body, the conductivity of the subject's tissue in which the current flows and how well the subject is grounded. To accurately simulate biological effects caused by current, allowances for the differences between the conductive cross-section to the induced current of the human and subject's bodies must be made. The level of the electric field can be adjusted to get the same current density, which is the amount of current flowing through a given unit of area. Internal current density varies among different animals in a way similar to the variation of surface electric field strength. Thus the strength of the applied electric field will depend on the type animal and also the desired current density.

The magnetic field is unperturbed by presence of biological materials; still in exposure studies, the strength of the magnetic field must be adjusted to compensate for the differences in the perimeters of the human's and exposed subjects' bodies. Faraday's law, which relates the induced electric field to the external magnetic field, can be used to calculate the appropriate magnetic field levels for various body radii.

2.4 Exposure Assessment Fundamentals

2.4.1 Introduction

This section develops a working definition of exposure assessment and was adapted from materials prepared by Robert M. Patterson, Temple University for: Seminar on New EMF Epidemiologic Results And Their Implications, October 16-19, 1990. Its objective is to create an understanding of the basic goals of exposure assessment rather than to list strict criteria or performance guidelines. From these goals, detailed guidelines and criteria could be derived as needed. It also discusses the general tools and strategies of exposure assessment, and describes the particular instruments used with EMF. Data from EMF exposure studies are used to explain what is known about the sources and nature of exposure to these agents.

2.4.2 Exposure v. Dose

Exposure (of a person to an agent) is the joint occurrence in space and time of the person and the agent. It is different from dose, which is the amount of the agent interacting with the person. As expressed by the Council on Environmental Quality (CEQ, 1989), "dose is the concentration or quantity or risk agent reaching tissues, organs or cells within the exposed organisms where damage may occur." Applying this distinction, one could be exposed momentarily to a vapor that is toxic when inhaled and, by not breathing, have no dose. One could be exposed to a systemic, poisonous chemical spilled on the skin, but unless it is absorbed through the skin there is no dose and no effect.

A human exposure assessment gives a qualitative and quantitative picture of the exposure of people to agents. In general, exposure assessments try to define "(1) substances that target organisms, species, or environments; (2) the intensity of exposure; (3) in what way; (4) for how long; and (5) under what conditions" (CEQ 1989).

2.4.3 Reasons for Exposure Assessments

The reason for making exposure assessments can be placed in two broad categories, described as routine and novel.

Routine assessments are common in environmental regulatory compliance activities and in the day-to-day practice of industrial hygiene. They are conducted when the effects of an agent are known. The techniques of the assessment are often prescribed.

Assessments in the novel category occur when little is known about either the agent or its effects, or both. They can provide new information to further our understanding of the agent. For example, an exposure assessment might seek to define where the agent occurs, in what amounts, and under what conditions, or it might try to define who is exposed and the detail of their exposure. In the latter case, it could be an integral part of a health effects study that is looking for a cause and effect relationship. There may be little guidance as to how or even what to measure. Most extant assessments of EMF exposure are in this category.

An assessment for regulatory compliance is relatively straightforward because the agent and the techniques for measuring it are given. When trying to link environmental exposures to an effect, however, there is normally a well-defined effect but little notion of the cause. The effect might be an increase in a certain disease in a population. The causative agent, however, can be very difficult to determine because of the variety of exposures of those with the disease. Even with a strongly suspect agent, adequate exposure assessment becomes critical in identifying a cause and effect relationship. The better the exposure data, the more surely a true link can be uncovered.

The causative agent may be identified by using epidemiologic studies. Causality cannot be established until certain supportive characteristics of association between an agent and a disease is demonstrated. The characteristics include strength, consistency, specificity, temporal relationship, biological plausibility, and coherence of evidence. However, because of time, cost, inherent difficulty, or other constraints, exposure assessment is often the study element done with least accuracy. In fact, as discussed later, the parameter that should be measured is sometimes not even known.

According to a report by the Office of Science and Technology (1985), "exposure assessment is often the most resource-demanding portion of the (risk) evaluations..." The Task Force on Environmental Cancer and Heart and Lung Disease (1981) has stated, "Many authorities agree that the weakest link in our understanding of the environmental health studies is our knowledge of human exposure."

2.4.4 Elements of an Exposure Assessment

With a definition of exposure and an appreciation of the importance of exposure assessment, the elements of an exposure assessment can be simply stated: *Measures of exposure should mimic the receptor's experience of interest.* From this statement, volumes could be filled with cookbook instructions covering nearly every conceivable situation. However, that is not necessary or even desirable. An exposure assessment can be designed with two keys: the first is knowing what to mimic; the second is knowing how to mimic it. This is explored using a common example.

Suppose that an exposure assessment is to be made of indoor, ambient temperature (like EMF, a physical agent). Guidelines are found describing rules for setting out a monitor to measure air temperature in a dwelling, and they state that the monitor shall:

- operate continuously
- be located at a height of 1.5 meters above the floor,
- be placed on an inside wall, away from drafts and direct sunlight and provide an electrical signal reflecting its measurement.

Based on these guidelines, a monitor is positioned and operated to assess (and react to) air temperature.

Of course, this monitor is a thermostat for operating a home heating and cooling system. Consider how it might be deployed given the objective of mimicking the experience of interest. That experience is our comfort, which relates to the temperature in the room. The mimicking is done by measuring temperature with a thermostat, which then drives the furnace or air conditioner accordingly. The thermostat is not placed on the ceiling because no one occupies that space. It is not placed on an outside wall because it is relatively cold (or hot) there. Similarly, no one ordinarily sits in drafts. The thermostat should be located to mimic one's experience of air temperature and thermal comfort in the home. Sometimes, one thermostat is not adequate because of variability in the home environment, and two thermostats are used. That is just a response to spatial variability of temperature; additional locations are added to be sure that the experience of interest is continually mimicked. The point is that the same advice expressed by the guidelines can be obtained by thinking about what is to be mimicked by measurements.

With that broad idea of the objective of an exposure assessment, consider the latter part of the above statement, i.e., the "experience of interest." This is sometimes expressed (or obfuscated) as the "exposure metric." The exposure metric tells what characteristic of exposure is being measured. It might be the time-averaged value, the peak value, the time that the value exceeds some stated level, or something else. The time-averaged concentration, the peak concentration, and the amount of time that the concentration exceeds a given level are all different exposure metrics. Depending on the agent, the values in each case may be expressed in units, such as parts per million, milligrams per cubic meter, or milligauss. Consider the experience of interest in terms of another familiar example, exposure to carbon monoxide.

An exposure assessment for carbon monoxide might be made with a personal monitor, a device that one can wear and that measures ambient concentrations. One choice could be that it measures the average of all concentrations over some long time period, such as days. However, the body responds to carbon monoxide on a shorter time scale, so perhaps it would be appropriate to measure over a shorter period. Carbon monoxide exposure can be measured essentially continuously, but the body may not respond rapidly enough to warrant continuous measurement. Besides, a peak level that occurs during exhalation would not really matter. Some intermediate time scale would then be best, and it need be no shorter than the time it takes to complete a breath. Thus, a rational basis for an assessment of human exposure to carbon monoxide might be: the experience of interests is the average concentration over the time it takes to complete one breath. (A monitor that sampled only the air inhaled would be even better but difficult and expensive to produce.) Because the action of carbon monoxide in the body is known, and because an indicator of exposure persists, this example can be carried further.

The ambient level relates to the experience of interest for exposure, but the real experience of interest for assessing the effects of carbon monoxide exposure is the level at which it has combined to form carboxyhemoglobin in the blood. From the earlier definitions, that would really be an assessment of dose, not exposure. Hence, a better assessment would be based on dose, because that is where the biological effects are produced. Notice, however, that the mechanism must be understood first. Knowing nothing about carboxyhemoglobin, one would assess exposure to carbon monoxide.

The best assessment is conducted by the bodies of those exposed. Blood carboxyhemoglobin level mimics the experience of interest better than monitoring could ever do because it reflects not only the level of exposure but also the body's response. It acts as an "internal monitor." The emergence of biological monitoring in the practice of industrial hygiene is based on uncovering similar responses to other agents. An internal monitor for EMF would greatly increase confidence in epidemiologic studies of hypothesized health effects from EMF.

Carbon monoxide is an easy example for exposure or dose, because the mechanism for its effects is known. EMF is more difficult because of the "illusory nature of reported effects". As with most environmental agents, EMF exposure can be recorded as time-averaged measurements. With conflicting laboratory results, with reports of effects in windows of power, frequency and temperature, and with conflicting results from epidemiologic studies, an exact idea of what should be measured does not exist. After considering ambiguous results, some researchers have speculated that the experience of interest is not the field frequency or intensity per se, but rather may be movement in and out of a field of some undetermined parameters. Given the range of possibilities that this notion uncovers, the parameters probably are indeterminable as well as undetermined. This seems to arise from a faith that a cause-and-effect relationship certainly exists, and we can uncover it if we just measure the right way.

2.4.5 Exposure Assessment Tools

Exposure assessments can use one or a combination of three basic tools: surrogates, models, and monitoring (CEQ, 1989). Surrogates are "stand-ins" for the actual agent, and they are assumed to have attributes that relate to the agent under study. For example, wire codes are surrogates for actual exposure to background residential magnetic fields. Models are used to estimate or predict exposure from basic, available information and, for EMF, physical principles. Monitoring would be expected to come closet to replicating exposures.

Exposure Surrogates. Instead of monitoring exposure directly, a substitute or surrogate is often used. An exposure surrogate is defined as a factor that is used to represent exposure to an agent when a direct measure of exposure is not available. Number of cigarettes smoked per day is a surrogate for exposure to cigarette smoke. A stationary monitor collects surrogate data for the exposure of a mobile population. (In the extreme, one might argue that virtually all exposure assessment uses surrogates.) Surrogates find wide and often creative application in health effects studies. Their use in EMF studies is illustrative and is outlined here.

Probably the most familiar surrogate for EMF exposure of the general population is the wiring configuration of the electric power distribution network. It was used by Wertheimer and Leeper (1979) in their original study of childhood cancer and has since been used repeatedly by them and others (e.g., Fulton et al., 1980; Wertheimer and Leeper, 1982; Savitz et al. 1988; Severson et al., 1988). The basic idea is that magnetic field intensity is directly related to current and proximity to the source. Because thicker wires can carry more current than do thinner wires, and because field intensity decreases away from a source, it is presumed that higher magnetic fields occur closer to thicker lines. Wertheimer and Leeper (1979) divided their study population into groups having presumably different magnetic field exposures according to factors that included wire thickness, voltage rating, and proximity of nearby lines.

Others have employed source strength and distance in different ways. Some studies have used distance from sources such as transformers and substations as well as from overhead lines (Strumza, 1970; McDowall, 1986; Coleman et al., 1985). Some studies of workers have used the strength of the source, for example the voltage of equipment at the work place (Knave et al., 1979; Nordstrom et al., 1983).

For studies of workers, however, the most commonly used exposure surrogate has been occupational classification, such as electrician, electronics worker, electrical engineer or welder. Virtually all published occupational studies to date have used this surrogate (e.g., Milham, 1982, 1985a, 1985b; Wright et al., 1982; McDowall, 1983; Coleman et al., 1983; Calle and Savitz, 1985; Pearce et al., 1985; Tornqvist et al., 1986; Spitz and Johnson, 1985; Olin et al., 1985; Stern et al., 1986). It is not known whether workers in their so-called "electrical occupations" are in fact exposed to elevated EMF levels. They are, of course, exposed to other agents, such as welding or soldering fumes and solvent vapors, which might be confounding exposures. An exposure assessment based merely on surrogates is at best speculative.

Exposure Models. The distinction between surrogates and models can be difficult to draw. Somewhat as exposure assessment blends into dose assessment, surrogates blend into models. The wiring configuration code might be thought of as a crude model for EMF exposure because it has some physical foundation: thicker wires carry more current, which produces higher field levels. Computer-generated models for estimating electric and magnetic field exposure levels have been developed by the Electric Power Research Institute (EPRI) and other groups, including the Bonneville Power Administration.

EPRI has developed the "EXPOsure CALCulation" model, EXPOCALC, for transmission line electric and magnetic fields. It is working on another, called RESICALC, for distribution lines and residential sources. EXPOCALC calculates field levels near transmission lines and incorporates a time-activity model (discussed below) for estimating exposure. Model inputs include the environmental setting and the physical and electrical parameters of the line; outputs include contour maps of field intensity and exposure histograms. RESICALC is similar in concept, but it will focus on the home and include the effects of distribution lines, household wiring, and unbalanced return currents through water pipes.

Kaune (1987) has built a model of magnetic field levels based on a sample of Seattle residences, using statistical relationships between wiring configurations and measured field levels. The most important input to this "empirical regression model" is the number of service drops near the residence. Distance from distribution lines correlates only weakly with measured fields. It is important to note that a statistical model based on data collected in one locale may not be valid elsewhere.

Exposure Monitors. EMF monitoring instruments have advanced very rapidly in recent years, due largely to work by EPRI. Their technical bases of operation was described in the section 2.3.6.

Monitors may be classified as survey or personal, depending on their design and intended use. Survey monitors require an operator and are suitable for stationary measurements. Personal monitors do not require an operator and can be worn on the body, continuously measuring fields to which one is exposed.

Many companies manufacture monitors and section 2.5.3 describes in detail several instruments that are commercially available. They differ in how they record measurements. Some, useful mainly for surveys, indicate only the instantaneous field intensity, perhaps on a dial, with no way of recording or averaging. Some average all field levels over time. They yield an exposure metric of time-averaged levels, expressed with units of kV/m or mG, which could be used to distinguish among average exposures of workers. If the length of time of exposure is noted, the total, integrated exposure could be expressed by multiplying the average by that length of time, with units of (kV/m) hr or mG hr. The more sophisticated instruments of this type collect data separately for different field level ranges; for example, <2 kV/m, 2-4 kV/m, 4-7 kV/m, and so on. Rather than averaging all exposures, they average in each of the ranges.

The Average Magnetic Field Exposure Meter, or AMEX, is illustrative of a simple, time-integrating, personal monitor for magnetic field exposure. Developed by EPRI, the AMEX measures exposure by storing the charge related to the current induced by the magnetic field in each of three, mutually perpendicular coils. The total charge is proportional to the product of the field intensity and the exposure time. i.e. integrated exposure.

Other devices can give continuous readings of the field intensity. When connected to a recording device, such as a chart or tape recorder, they can collect data over time or space for later analysis. The most sophisticated instruments now include a built-in computer to control data recording and recovery. An example of the state-of-the-art is the EMDEX, also developed by EPRI. The EMDEX uses three orthogonal coils to measure the magnetic field, and it is capable of sampling at rates from about once each second to about once every five and one-half minutes, giving a range of collection frequency that might be matched to environmental conditions.

2.4.6 Exposure Assessment Strategies

Using the objective of mimicking the experience of interest, some broad exposure assessment strategies can be developed. First, though, it is recognized that not all EMF exposure is continuous. So, lacking an exposure metric, the ideal exposure assessment would yield continuous data on the exposure of the population being studied. The simplest way to do this would be by equipping everyone with a personal, continuously recording monitor. But what happens when someone engages in an activity during which the monitor cannot be worn? What if the size of the study population is greater than the available number of monitors or the resources to use them? Now something less than the continuous, population-wide ideal must suffice. How this is done is what exposure assessment strategies are about: coming as near the ideal as possible under the technical constraints of available monitoring methods and the resource constraints of time, money, and subjects.

Exposure was defined earlier as requiring a person and an agent to be at the same place and time. A continuous personal exposure monitor essentially accompanies a person everywhere and continuously measures the amount of agent. The same measured data could be generated by knowing the concentrations of the agent at all times and places, and then superimposing these on the person's movements. Instead of using a monitor that moves with the person, stationary monitors that record everywhere continuously would be used (at least everywhere that the person goes). Variations and blends of these two approaches—personal continuous monitoring (or possibly modeling or use of surrogates), or continuous monitoring of locations combined with knowledge or assumptions about a person's activity (again, with possible use of modeling or surrogates)—encompass exposure assessment strategies for EMF. Historical assessments must rely on the latter approach. The exact details are the result of the study constraints and the investigator's imagination.

Instead of continuous data, average or instantaneous data are usually gathered. Instantaneous data, also called grab samples, reflect the conditions at one location and time, for example, spot measurements in the center of a room. Average data are referred to as integrated samples and can be averaged in space or time, or both. Many grab samples can be compiled into an integrated sample, if conditions are assumed to be constant or smoothly varying between samples. When data are collected in the center of a room and used to represent the conditions throughout the room or residence, spatial averaging has been assumed. Implicit time averaging is assumed when measurements taken only periodically are used to represent continuous exposure. (True spatial averaging of some chemical pollutants in air can be done with sophisticated sensing techniques; an equivalent capability does not exist for EMF.)

Another approach employs survey techniques, similar to an opinion poll: Individuals are singled out as being representative of the larger population, and their exposure is monitored. The results are extrapolated to the larger population.

Still another approach uses time-activity patterns (patterns of how and where people spend their time) with measurement data from different "microenvironments," or separately identifiable locations. Microenvironments are defined so that exposure characteristics can be assumed similar within specific microenvironments, such as homes, but dissimilar between microenvironments, such as between homes, substations, and offices. Monitoring studies characterize levels of the agent for each microenvironment; activity patterns can be developed by sociological research. The time-activity patterns tell where people are and how long they spend there, while the microenvironment data supply the exposures. When combined, they yield an assessment of time-averaged exposure.

Each new exposure assessment offers the opportunity for a unique strategy. The major danger in this, however, is that the ability to compare the results of different studies can be compromised by differences in how exposure is assessed. That is why it is important for new studies to include the techniques of previous ones and for protocols to evolve to a common point. However, since we do not know which, if any aspect of EMF is bioactive, or could be the agent, using standard measurement techniques might preclude identification of the true agent, if such exists.

2.4.7 Confounders

A confounder is an agent that is associated with both the presumed, causative agent and the effect being studied. Confounders are important considerations in exposure assessments because of their possible role as the true causative factor. Many potential confounding factors have been identified that are relevant to epidemiologic studies of EMF. When occupational classification is the exposure surrogate, the association may be confounded by exposures to other agents such as solvents. In community studies that rely on wiring configuration codes for exposure assessment, results may be confounded by other urban environmental factors that have the same routing and usage density features as electric distribution lines. These factors could include air pollution from local street traffic, gas lines, potable water and sewer lines, or telephone lines. Not all of these might be plausible confounders. On the other hand, benzene is a known carcinogenic component of automobile exhaust and may be a confounding factor. Well-designed studies include exposure assessments of plausible confounders for all study subjects.

2.4.8 Conclusion

Exposure assessments are performed to document levels of agents having known effects or to elucidate suspected ones. While vital to health effects studies, good exposure assessments are often lacking, in large part due to their inherent difficulty. We can design an ideal exposure assessment by following the simple notion that our measurements should mimic the receptor's experience of interest. For EMF studies the important experience of interest is unclear, although the practice has been to measure time-averaged levels, as is done with other environmental agents.

Tools for marking exposure include surrogates, models, and monitors. Surrogates, which are substitutes for a measure of exposure to the real agent, have often been used in exposure assessments. EMF exposure monitors have become rapidly more sophisticated in recent years and are finding wide use in a number of epidemiologic studies.

Starting with the ideal assessment, strategies can be designed that accommodate technical and resource limitations. However, exposure data are sufficiently variable that careful exposure assessments will be needed to identify any health effects on EMF.

2.5 Measurements

This section will examine the types of measurements performed in assessing fields and exposure, review any recognized standards for measuring fields from powerlines, and survey commercially available instruments used to make measurements.

The objective of a study will largely prescribe the EMF measurement. The extent, accuracy, and duration of the data collection will dictate the type of instrumentation used. The measurements may be covered by an existing standard that further specifies the type equipment and procedure used.

2.5.1 Measurement Categories

Three specific categories of measurements (Dietrich, 1988) are often made: survey measurements to find the field strength at specific locations at a specific time, exposure measurements to estimate the exposure of a subject over time, and engineering measurements to more completely characterize the nature of the fields in an environment.

Survey Measurements. Survey measurements find the strength of EMF at a specific point-in-space and instant-in-time. Often measurements will be done serially at several points on a path perpendicular to the transmission line to find the line's lateral field profile. Maximum and minimum field strength may be determined by rotating the measuring probe about the field ellipse. The instant-in-time nature of these measurements precludes detecting long term variations of the field quantities. The serial nature of these measurements allows temporal variations occurring during the measurements to confound determination of an accurate field profile.

The equipment most often used for survey measurements is the self-contained free body meter. The meter may have probes to measure electric fields or magnetic fields. The meter provides either an analog meter movement or a digital display to show the root-mean-square (RMS) value of the measured quantity. Survey meters have no recording capability, although some may offer outputs for stand alone recorders. They are point-in-space and instant-in-time devices. Selective electronic filtering permits only the measurement of 60-Hz powerline frequency fields. But, some meters allow overriding the selective filtering, enabling measurement of harmonics or other frequencies beyond the fundamental frequency.

Exposure Measurements. Exposure measurements introduce the time parameter into the field measurement regime to find the extent of exposure to power frequency fields that a subject experiences. Such measurements are of primary importance to human and animal exposure studies. The most accurate way to measure exposure for human subjects is to outfit the person with a recording exposure monitor. An alternative method is to take survey measurements of all areas that the subject is likely to frequent during a normal daily routine and to record the time spent in each area. Although limited in applicability for human subjects, this method is suitable for caged animal studies. The equipment designed to make exposure measurements is specialized based on the application. Some devices that are to be worn emphasize light weight and compact size while retaining measurement capability.

Engineering Measurements. Engineering measurements go beyond the single point-in-space and instant-in-time approach used by survey measurements and the periodic sampling or time weighted averaging used in exposure measurements. If, as discussed in the introduction of the exposure assessment (section 2.1), the true metric of exposure turns out to be more complicated than average field level, these more extensive measurements will be necessary to find the presence and amount of the particular property.

Engineering measurements attempt to more completely characterize the EMF environment at a location over a long duration. Engineering measurements may include field strength, field polarization, field orientation, temporal variations, spatial variations, harmonic content, wave shape, transient content, and source identification. Engineering measurements would be required to assess the subject's exposure to fields of specific windows of frequency and amplitude, or the occurrence of complex interactions between field strength and orientation of the powerline's fields and the geomagnetic field.

The equipment employed for making engineering measurements is specifically designed and customized to the problem under study. A typical system would consist of multiple sensors (each specially fabricated) designed and calibrated to interface with a multichannel data acquisition system.

2.5.2 Measurement Standards

The Institute of Electrical and Electronic Engineers (IEEE) first published a standard in 1979 for making measurements of powerline electric and magnetic fields entitled "IEEE Recommended Practices for Measurement of Electrical and Magnetic Fields from AC Powerlines." More recently, IEEE revised this standard (ANSI/IEEE, 1987) and the American National Standard Institute (ANSI) has approved it. The standard establishes a uniform procedure for conducting survey measurements of powerlines and calibrating instruments, or more specifically as stated in the standard:

"The purpose of this standard is to establish uniform procedures for the measurement of power frequency electric and magnetic fields from alternating current (ac) overhead powerlines and for the calibration of the meters used in these measurements. A uniform procedure is a prerequisite to comparisons of electric and magnetic fields of various overhead powerlines. These procedures apply to measurement of electric and magnetic field levels close to the ground. They also can be tentatively applied to electric field measurements near an energized conductor or structure with the limitations outlined in . . . this standard."

For measuring electric fields, the standard specifies the use of a free body meter, and for measuring magnetic fields, a shielded coil probe connected via a shielded cable to a shielded detector. Acceptable calibration equipment and procedures for both instruments are prescribed by the standard.

As Figure 2-22 shows, the electric field measurement procedure is to make several measurements along a line perpendicular to the powerline (lateral profile) and along a line parallel to the powerline (longitudinal profile). First, measurements of the lateral profile should be made at mid-span where the conductors are closest to the ground. Measurements should be made from the center of the line to at least 30 m (100 ft.) beyond the outside conductor. At least five equally spaced measurements should be made under the phase conductor. Complete profile measurements should commence in the region of interest beyond the outside conductor and progress successively to the opposite side of the right-of-way.

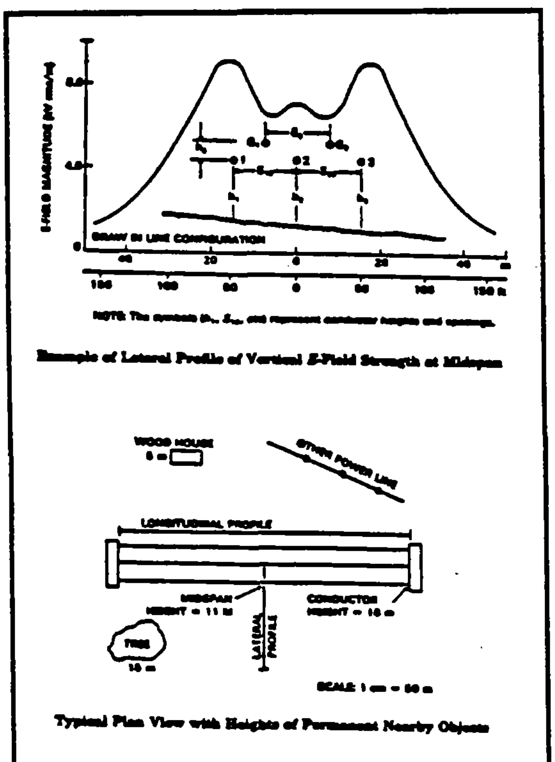

Figure 2-22. Lateral profile and plan view of IEEE standardized procedure for conducting survey measurements of the electric and magnetic fields from powerlines. (ANSI/IEEE, 1987)

Next, the longitudinal profile of the electric field should be made, beginning at mid-span at the point (as determined from the lateral profile) of the greatest field strength. Measurements at five nearly equal consecutive increments along a path parallel to the line should be made in both directions from the mid-span point for a total distance equal to one span.

Magnetic field measurements are made using the same procedure as for the electric field's lateral and longitudinal profiles. The standard specifies that all measurements (both electric and magnetic fields) be made with the sensor at the height of 1 m above the ground.

The standard specifies that the combined errors due to all sources (calibration, temperature effects, interference, operator proximity, etc.) should not exceed 10% for both electric and magnetic field measurements.

Recently the International Electrotechnical Committee has also published a standard (IEC, 1987) for measuring power frequency electric fields. The IEC standard is similar to the IEEE standard, with the exception that IEC recognizes the electro-optical electric field meter, which is not widely used in the United States.

While these two standards address survey type measurements, no published standards exist that specify procedures for making exposure and engineering type measurements.

2.5.3 Commercial Instrumentation

A review of manufacturers' literature shows that several magnetic field meters and a few electric field meters are commercially available. Although the Committee's review of commercially available instrumentation is not exhaustive, it does indicate what is on the market and the capability of the equipment. Microwave News (Microwave News, 1989) published an extensive summary list of commercial instruments and that summary is shown in Table 2.6. Most of these instruments are for making survey-measurements, while only a couple are available for making exposure-measurements, and none are available for making engineering-measurements. Please refer to the fundamental section for a description of the measurement principles used in these instruments.

Survey Instruments. Survey instruments measure power frequency fields at a single point-in-space and instant-in-time. Several instruments are commercially available.

Although no longer being manufactured, one of the most widely used and versatile survey instruments is the "Deno" Power Frequency Field Meter (Electric Field Measurements Co., 1985). It is a multi-function instrument–a free-body electric field meter with accessory probes and inputs for measuring other field quantities. Besides electric and magnetic fields, the instrument can measure space potential, and the open-circuit voltage and short-circuit currents induced in objects by the fields. The unit's measurement range is from 1 to 100,000 V/m for electric fields and 0.125 to 12,500 mG for the magnetic flux density. The instrument reads magnetic field strength in A/m, which must be multiplied by the conversion factor of 12.5 to obtain magnetic flux density in milligauss.

The meter features a large analog dial, probes for magnetic field and space potential, and an eight foot insulated handle used to isolate the meter from the effects of the operator's body during electric field measurements. Output jacks on the meter allow the use of an oscilloscope for further analysis of these fields.

When using the meter on its more sensitive magnetic field ranges, the operator must take care to hold the probe motionless while taking readings. Any movement of the probe will cause a saturation of the instrument by the earth's magnetic field. Electric Field Measurement Company (EFMC) of West Stockbridge, MA. formerly sold the meter for about $1200.

EFMC has replaced the "Deno" meter with a low cost electric and magnetic field meter (Electric Field Measurement Co., 1989) consisting of a 3.5 inch general purpose digital multimeter and special electric and magnetic field probes. The probes convert the field values to a voltage signal allowing the actual field quantities to be read directly on the multimeter's liquid crystal display. The probes produce 1 mV of output for 1 mG of magnetic flux density or 1 V/m of electric field strength. The Model M116PLUS can measure electric fields as small as 0.1 V/m and magnetic fields as weak as 0.1 mG. The unit's upper range is over 30 kV/m and a few hundred gauss for the electric and magnetic fields respectively. The M116PLUS costs about $250.

Monitor Industries of Boulder, CO. sells a single-function magnetic field meter (Model 42A) (Monitor Industries, undated) that uses a 6-inch diameter pick-up coil to sense AC magnetic fields. Offering stable low-level measurements, the Model 42A provides true RMS reading with a flat response over a frequency of 40 to 1000 Hz. The design avoids the problem of movement of the probe in the geomagnetic field saturating the instrument. Another interesting feature is an internal speaker allowing a qualitative indication of the frequency content of the magnetic field being measured. This is handy when attempting to identify the various magnetic field sources that might simultaneously be present. The 42A has an optional linear mode in which the meter's sensitivity is proportional to the frequency of the magnetic field–fields of higher frequency give larger readings. The price of the instrument with the optional linear mode is about $325.

Holaday Industries of Eden Prairie, MN produces an extremely low frequency (ELF) field strength meter (Holaday Industries, 1989) that measures both electric and magnetic fields. The sensitivity range of their model HI-3600-02 is 1 V/m to 200 kV/m for electric fields and 1 mA/m to 200 A/m for magnetic fields. It features true RMS detection, automatic ranging, maximum reading hold, and waveform signal output. An interesting option is a fiber optic coupled remote sensor for measuring electric fields without perturbing the field.

Table 2.6 - Gaussmeters and Dosimeters: (Source: Microwave News, 1990)

Company, Address, Contact	Meter Name	Price	Bandwidth (other bands)	Min-Max/ No. of Scales	Accuracy	Size/Weight (in./lbs.)	Options/Comments
F.W. Bell, Inc. 6120 Hanging Moss Rd. Orlando FL 32807 (407) 678-6900 Contact: Steve Dalal	Model 4048 Model 9200 Model 9500 Model 9903	$650 $1,500 $2,800 $5,800	0-12kHz 10Hz-10kHz 20Hz-10kHz 20Hz-50kHz	0.1 G-20 kG/3 10 mG-20 kG/4 1 mG-300 kG/6 1 mG-3 MG/7	2.5% 2.5% 1.0% 1.0%	4x7x1.8/1 8.8x4.5x11/8 14x7.5x14/19 18x7.5x16/36	All models are Hall Effect devices. All can measure DC Fields. All except 4048 can output to an oscilloscope.
Combinova AB, c/o Ergonomics, Inc. P.O. Box 964 Southhampton, PA 18966 (215) 357-5124; FAX (215) 364-7582 Contact: Frances George	MFM 10	$6,700	5Hz-10 kHz	0.1 mG-10 G/4	2.0%	15.2x4.6x10/6.6	Data can be stored and transferred to computer.
Electric Field Measurements Box 326 W. Stockbridge, MA 01266 (413) 637-1929; FAX (413) 637-2826 Contact: Dr. Don Deno	Model 116 Model 116+ EMDEX-C	$75 $250 $2,000	60-Hz 60-Hz 40-400 Hz	0.1 mG-200 G/4 0.1 mG-200 G/4 0.1 mG-25 G/4	3.0% 3.0% 3.0%	1.5x1.5x2/0.4 4.75x2.5x9/2 1.8x4.8x6.5/1.3	116 sensor plugs into std. digital multimeter. 116+ includes multimeter. EMDEX stores data. Waveform capture device.
Electric Power Research Institute (EPRI) PO Box 10412 Palo Alto, CA 94303 (415) 855-2581; FAX (415) 855-1069 Contact: Dr. Stan Sussman	3D-AMAX		40-800 Hz	0.35-150 mG/ (not applicable)	5.0%	1x2x4/0.3	Fits in shirt pocket. Requires separate readout unit.
Electromagnetic Design, Inc. 9100 Bloomington Freeway Bloomington, MN 5543, (612) 888-7473 Contact: Rodger Hastings	ACGM-1 ACGM-2	$450 $990	20-150 Hz 20-150 Hz	0.1 mG-9 G/2 0.1 mG-9 G/2	1.0% 1.0%	2x4x7/1 2x4x7/1	Auto Ranging. LCD readout
Holaday Industries, Inc. 14825 Martin Dr. Eden Prairie, MN 55344 (612) 934-4920; FAX (612) 934-3604 Contact: Burton Gran	HI-3600-02	$1,195	50/60-Hz	0.1 mG- 20 G/5	5.0%	1.8x3.5x17/2.8 (with 8" diameter sensor)	Remote readouts. Signal outputs for dB/dt measurements. VDT/VLF version available.
Integrity Electronics and Research, Inc. 558 Beechnmridge St. Buffalo, NY 14222 (716) 886-7283 Contact: Tom Valone	IER-109	$595	55-65 Hz	1 μG-2G/4	2.0%	3x4x7/0.9	LCD display, E-field Module and 3-access (sic) probe available. IER-119 available for 50Hz.
MacIntyre Electronics Design Associates, Inc. 11260 Roger Bacon Dr. Reston, VA 22090 (703) 471-1445 Contact: Barbra Vayda	uMAG	$495	0-100 Hz	10 μG-2 G/3	0.5%	4x7.5x2/0.9	Model with earth field neutralization available for $649.00.
Monitor Industries 6112 Four mile Canyon Boulder, CO 80302 (303) 442-3773 Contact: Ed Leeper	Model 42B	$350	40 Hz-1 kHz	0.01 mG-2.5 G/12	7-10%	2.1x3.1x7.8/1.8	Audio speaker. Model 42B-1 with linear frequency response available for $425.00.
Positron Industries, Inc. 5101 Buchanan St., St. Montreal, Quebec, H4P-2R9, Canada (514) 345-2200; FAX (514) 731-8662 Contact: Silvo Frank	Dosimeter 378,101	$1,650	60-Hz (5-20 MHz)	60 μG-4 G/ automatic	5.0%	6x3x1/0.5	Output to computer. Stores 18 days of data. Model 378102 available for 50 Hz.
Safe Computing Company 368 Hillside Ave. Needham, MA 02194 (617) 444-7778, (800) 222-3003 Contact: George Leckner	Safe Meter Professional Meter	$145 $175	20 Hz-30 kHz (5-70 kHz) 5 Hz-1 kHz (1-40 kHz)	1 μG-230 mG/7 0.1 mG-200mG/1	5.0% 3.0%	6x3x4/0.7 5.5x3.3x1.5/0.8	Safe meter readings must be converted to mG with hand held table. Both meters rent for $29.95 per week.
Schaefer Applied Technology 200 Milton St., Unit 8R Needham, MA. 02026 (617) 320-9900, (800) 366-5500 Contact: John Schaefer	Model EM1	$90 (Rents for $40.00/wk)	10 Hz-1 kHz	0.45-10+ mG/1	5.0%	5.5x3.1x1.5/0.8	Specifies level in 1 of 10 ranges between 0.45 and 10mG, or greater than 10mG. Model EM10 has a large remote display.

Company, Address, Contact	Meter Name	Price	Bandwidth (other bands)	Min-Max/ No. of Scales	Accuracy	Size/Weight (in./lbs.)	Options/Comments
Shoden Corp. 2-23 Ojima 1-chome, koto-ku, Tokoyo, Japan (03) 637-7711; FAX (03) 637-7724 Contact: Manny Fujiwara	MFM-12A	$1,700	60Hz (25 Hz- 10 kHz)	0.1 mG- 20 G/3	5.0%	6x4x2/3	50 Hz meter available. Outputs to oscilloscope and recorder are standard.
Sydkraft AB Carl Gustafs Vag 4, S-217 01 Malmo, Sweden (40) 25 58 96; FAX (40) 97 47 74 Contact: Bo Wiberg	MFDM 3D MFDM	$1,895 $9,500	50/60-Hz 50/60-Hz	10 μG- 20 G/5 10 μG- 2 G/ automatic	5.0% 2.0%	16x12x5/2 24x17x8/245	150/180 Hz included. The program can be made to suit different requirements.
Walker Scientific, Inc. Rockdale St. Worcester, MA 01606 (508) 852-3674, (800) 962-4638, FAX (508) 963-4638 Contact: Joe Nowlan	ELF-50 Field Monitor MF-5D Fluxmeter	$180 $1,665	50/60-Hz 0-100 kHz	1 mG-51.2 G/2 0.1 mG-200 kG/3	1.0% 1.0%	6x3.3x1.5/0.5 2.8x8.5x9.3/5	ELF-50 digital displays available for $225.00. For MF-5D, probes designed for specific applications are available.

Sydkraft of Sweden markets separate electric and magnetic field meters (Sydkraft, 1988). The magnetic flux density meter operates over a range of 0.001 to 2,000 μT and is accurate within 5% over the entire range. The manufacturer has provided both an analog and a digital display for displaying values in μT of magnetic flux density. Their electric meter is a free-body meter and covers the range of 0 to 40 kV/m. Electric field strength is displayed directly on a digital display.

Integrity Electronics and Research of Buffalo, NY sells a Model IER-109 magnetic field meter (Integrity Electronics and Research, 1989) that measures magnetic flux density over a range of 2 to 2000 mG. The narrow band response of this unit prevents it from measuring any contribution from harmonics are any frequency removed from 60 Hz. The unit has a sensitivity of 0.001 mG and is accurate within 2%. Other features include audio and visual alarms, a 200-mV chart recorder output for dosimetry, and an optional 3-axis magnetic field probe. The IER-109 sells for about $600 and many accessories are available.

Exposure Instruments. For making exposure measurements three instrument are commercially available: EPRI's EMDEX, Positron's Electromagnetic Dosimeter, and Combinova's MFM10. Although the primary purpose of these instruments is to measure field levels over time, they can also be used for making survey measurements.

EMDEX (Electric and Magnetic Dose Exposure) is a hardware and software exposure assessment package developed by EPRI (EPRI, 1988). The hardware is a compact self-contained electric and magnetic field meter coupled to a microcomputer for periodic recording of the field readings. The software, which runs on an IBM Personal Computer (PC) or compatible, retrieves the field data stored in the instrument's microcomputer and then analyzes and displays the readings.

The EMDEX instrument is compact and portable--it measures about 6.0 x 4.5 x 2.0 inches and weighs 16 ounces. It can simultaneously measure and record the average electric field on the user, the three orthogonal components of magnetic flux density, and the rotational motion of the meter in the geomagnetic field. The electric field meter's measurement range is from 0 to 50 kV/m and the magnetic flux density range is 0 to 25,000 mG. The accuracy over all but the highest tier of the range is 5%. EMDEX has sampling intervals from one per second to one every 5.45 minutes. Standard sample intervals and their resulting data collection durations are shown in Table 2.7.

Table 2.7 - EMDEX Sampling Intervals (Source: EPRI, 1988)

Sample Interval (Time Between Samples)	Approximate Data Collection Time Limit
1 second	10.6 Hrs. (0.4 days)
2.5 seconds	26.5 Hrs. (1.1 days)
5 seconds	53.0 Hrs. (2.2 days)
10 seconds	106.0 Hrs. (4.4 days)
15 seconds	159.0 Hrs. (6.5 days)
30 seconds	318.1 Hrs. (13.2 days)
60 seconds	636.1 Hrs. (26.5 days)

The software allows the user to download the data from the EMDEX instrument to an IBM PC . Once resident in the PC, other programs process and analyze the data, allowing it to be displayed in graphical or tabular form. An example of the graphical display is shown in Figure 2-23.

Although the EMDEX was designed for exposure measurements it is very useful for making survey measurements. Electric Field Measurement Company offers an enhancement package for the EMDEX that includes a bicycle wheel distance measuring device. The EMDEX can be programmed to read field values at an increment of distance as measured by the bicycle wheel. Profiles and contours of powerlines, substations, and even residences can be rapidly made using this feature. The enhancement package will include software to generate field profiles of powerlines and buildings.

The EMDEX is available from and available from Electric Field Measurements (under license from EPRI) for $2000. The enhancement package is $800.

Although not as capable as the EMDEX nor commercially available, EPRI has also developed the Average Magnetic Field Exposure (AMEX) meter. The AMEX is similar in idea to a radiation film-badge dosimeter. It measures integrated magnetic field exposure with a single axis probe worn on the wrist. Measurements from the single axis probe did not capture the subject's true exposure. Consequentially, EPRI is developing (EPRI, 1989) a new version of the AMEX that will have a 3-axis magnetic probe and should solve this problem. A new more compact, improved model of the EMDEX meter called EMDEXII is also under development.

The Electromagnetic Dosimeter is a 5-channel recording dosimeter (Positron Industries, 1990) manufactured by Positron Industries under a license from Hydro Quebec/IREQ. The unit simultaneously measures and records electric field, magnetic field in three axes, and electromagnetic radio frequency (RF) disturbances. The Positron Dosimeter is considerably lighter and smaller than the EMDEX instrument, it is about the size of a Sony Walkman.

The instrument measures and records electric and magnetic fields at power frequencies. The values of the field measurement is stored within 16 separate bin registers. Each bin represents a specific frequency range; therefore, the intensity of the field is indicated by the number of bins filled. The 16 bins are divided

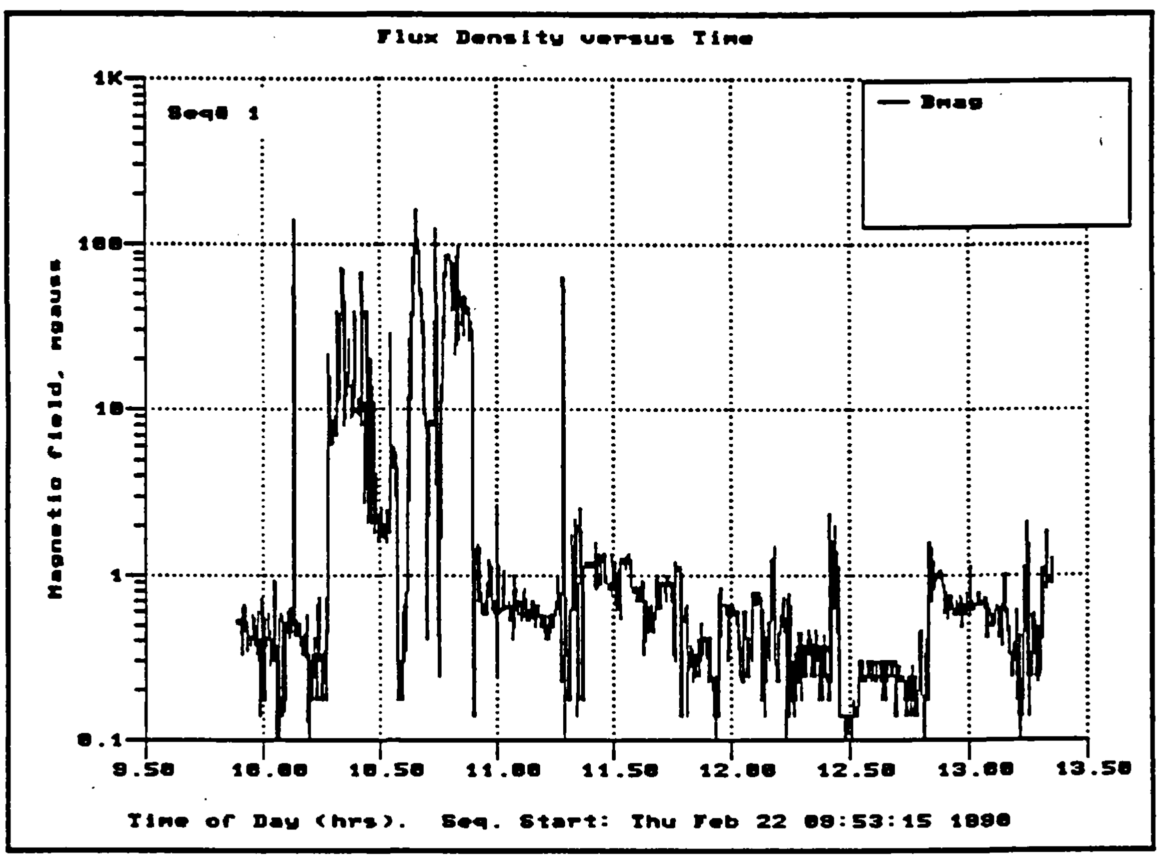

Figure 2-23. Sample output of magnetic field exposure history from Electric and Magnetic Field Exposure (EMDEX) Meter. Data from the meter is download to a personal computer for analysis and graphical display.

in a non-linear manner over the full sensitivity range of the unit. Instantaneous readings of the electric, magnetic, and RF impulse bin levels are displayed on a liquid crystal display (LCD).

The instrument can measure electric fields ranging from 0.61 to 20,000 V/m and magnetic fields ranging from 0.12 to 2000 mG. The magnetic field is measured, recorded, and stored separately for each axis (X,Y,Z). Electric and magnetic fields can be sampled at 1, 5, or 60 second intervals providing continuous recording periods of 8, 24, and 168 hours (7 days), respectively. The fifth channel effectively counts the number of high intensity RF pulses (greater than 200 V/m) occurring in a frequency range of 5 to 20 MHz.

Data from the instrument is download over a standard RS-232 port to an IBM compatible desktop personal computer. Software is provided to display graphs of chronological records of the fields at two different time resolutions, total delivered dosages, average values, as well as histograms of the data.

The Electromagnetic Dosimeter is available for either 50 or 60-Hz frequencies from Positron Industries, INC. of Montreal, Canada. It cost about $1650.

Combinova AB, a Swedish company, manufactures a recording magnetic field meter (Ergonomics, INC., 1989). Their instrument, denoted as MFM 10, is larger (15 x 10 x 4.5 inches) and heavier (6.5 lbs.) than the EMDEX and it only measures magnetic fields. The measurement range is 0 to 10 G with a 2% accuracy. The MFM 10 can store more than 4,000 readings and like the EMDEX download the readings to a PC for analysis. Available from Ergonomics, INC. of Southampton, PA, the MFM 10 costs about $6,800.

Engineering Instruments. The Committee's search did not identify any commercially available systems for performing the very detailed and exhaustive measurements needed to characterize completely the EMF environment. Although the components of necessarily sophisticated systems are available (i.e., field probes, multichannel data loggers, and powerful personal computers or engineering workstations), the Committee made no effort to study the integration of these elements into useful systems. Although most of the components do exist in "off-the-shelf" form, the Committee notes one key ingredient is missing: the software to analyze and make sense out of the vast amount of data required to be collected.

2.5.4 Conclusions

The Committee concludes the following regarding measurement of electric and magnetic fields:

- Field measurements fall into 1 of 3 categories: survey, exposure, or engineering.
- The instrumentation, procedures, and standards (if any) used to make field measurements will depend on the purpose and type of study being performed.
- Standards for making survey measurements of the fields from AC powerlines have been published by ANSI/IEEE and IEC. No standards exist for making exposure or engineering measurements.
- Survey instruments are readily available from several manufacturers for measuring both electric and magnetic fields. Exposure instruments are available, but only from a few manufacturers. Packaged engineering systems are not commercially available.

2.6 EMF Exposure Estimates

Often for a variety of reasons, assessing exposure requires estimating instead of making actual field measurements. This section will describe three methods of estimating exposure: computer models that calculate exposure, the extension of spot measurements to characterize exposure, and substitute properties, called surrogates, which are assumed to be indicative of EMF exposures.

Several situations occur when estimating may be preferable to measurement: when attempting to assess exposure for conditions when measurements are not possible, which is during extraordinary operating conditions not easily created; when attempting to quantify historical exposures, which is necessary in occupational and residential epidemiologic studies; or when the time and expense of making measurements is prohibitive and large amounts of data are required. Three of the most common means of estimating exposures are computer modeling, extrapolations of spot measurements, and the use of surrogates.

2.6.1 Computer Models

Several computer programs are available that calculate the electric and magnetic fields produced by powerlines. An informal survey of Texas utility companies, shows three programs are used predominantly: BPA's CORONA, EPRI's EXPOCALC, and APPA's TRANSPAC.

BPA's *Corona.* The Bonneville Power Administration's Corona and Field Effects Program (CORONA) was first developed as a main-frame computer FORTRAN code for predicting audible noise, radio and television interference and ozone production from AC transmission lines. The program was later extended to calculate corona loss, electric field, space potential, magnetic field, and conductor surface gradients for either AC or DC powerlines. It calculates nominal field values for DC lines, but does not calculate ion-enhanced field effects. The program can calculate the effects from a combination of up to 50 phase or pole conductors and overhead ground wires, but it is unable to analyze hybrid systems consisting of both AC and DC conductors.

With the arrival of more powerful PC's, users ported CORONA from mainframes to IBM PC or compatible systems. Data input to the program can be from either the keyboard or disk files. Input data are a physical description of the line--the number of phase and ground conductors, the number and size of the subconductors making up bundled conductors, and the physical arrangement with respect to some reference datum of the phase and ground conductors. Other data inputs are the line-to-neutral voltage of each phase conductor, the phase currents, and a host of environmental parameters, and sensor height and location data.

The user has the option of generating one or all of the following reports: audible noise, radio interference, television interference, ozone concentrations, corona loss, electric field, and magnetic field. Each report is a tabular listing of the output data. The program does not feature any graphical output capability; however it does offer the option of creating a file of calculated results in data interchange format (DIF). The DIF file can easily be loaded into any one of several popular spreadsheet packages, such as Lotus 123 or MicroSoft's Excel, for generating graphical plots of the powerline's lateral profile.

Appendix A contains CORONA's electric and magnetic field output reports for a typical 345-kV transmission line.

BPA has placed CORONA in the "public domain" and permits it to be freely copied and distributed. The only stipulation is that BPA be credited as the source of the program. It is free to anyone for the asking and in wide use across the country.

APPA's *TRANSPAC.* David R. Brown, INC. has developed, for American Public Power Association (APPA), an extensive set of computer programs (Brown, 1989) for the design and analysis of electric power transmission lines. The programs are divided into three categories: environmental effects, mechanical performance, and electrical performance. The programs run on the IBM PC or compatible with at least 512 K of memory and two floppy disk drives.

The environmental effects group contains four programs to calculate electric fields, magnetic fields, audible noise, and radio noise. The mechanical performance group features two programs to calculate conductor temperature rise and current carrying capacity, and conductor sag and blowout (i.e., physical displacement of the line due to wind loading). The electrical performance group contains six programs that calculate line electrical impedance and admittance parameters, line capability, line shield and insulator losses, switching surge performance, lightning performance, and tower footing resistance. These programs are independent of each other and can be run in any order, but they all use the same input data sets.

Input data to TRANSPAC are very similar to the input to the BPA's CORONA, although more straightforward. TRANSPAC accepts phase-to-phase voltages and allows the phase relationships between phases to be specified explicitly by a phase angle in degrees instead of using complex values for each phase's phase-to-neutral voltage. TRANSPAC is slightly limited because it allows only half the total number of phase and shield conductors as CORONA--25 versus 50. In most applications, problems seldom involve configurations of more than four or five separate circuits on a transmission right-of-way.

The electric field program's output report lists the average maximum subconductor surface gradient for each phase and shield group. It generates a tabular listing and graph of the magnitude of the maximum electric field strength that occurs at each increment along the lateral profile. Whereas CORONA lists the magnitude and angle for the maximum and the vertical and horizontal components of electric field strength, TRANSPAC lists only the magnitude of the maximum with no detail about its orientation. Both CORONA and TRANSPAC are limited to a maximum of 100 data points.

TRANSPAC's magnetic field calculation accounts for the effect of currents in the shield wires and ground return currents. Neither CORONA or EXPOCALC offer this capability. The user must supply earth resistivity and permeability to use this feature. Inclusion of the shield wires and ground return paths affect the contribution to the magnetic field results slightly as shown by comparison of the output in

Appendix A. Because of this ability TRANSPAC may be the program of choice when:

- Calculating magnetic fields at locations a great distance from the line, where contributions from ground return path can be significant; or

- Proving in regulatory and judicial proceeding that all effects (including shield wire and ground return currents) have been accounted for in the calculation of magnetic field levels.

The magnetic field report is similar in format to the electric field report. It lists the calculated currents in each shield wire and then features a tabular listing and graph of the magnitude of the maximum magnetic flux density in milligauss. Again CORONA provides more information by giving both the magnitude and angle of the maximum magnetic flux density and its vertical and horizontal components. TRANSPAC offers the choice of including or ignoring the effects of the currents in the shield wires and earth return currents.

TRANSPAC allows the reports to be sent to the printer or to a disk file. Unlike CORONA's DIF file option, TRANSPAC does not offer an easy method of transferring output data to other programs. It is possible to use a text editor to extract the data from the output file for "importing" into a spreadsheet program.

TRANSPAC is available to members through APPA for a nominal distribution fee of $150 and available to anyone else through David R. Brown, INC. for $2,995. Appendix A contains a sample run of a typical 345-kV transmission line.

EPRI's *EXPOCALC.* EPRI has sponsored the development of a computer model that assess personal exposure to the electric and magnetic fields of transmission lines. EXPOCALC (Enertech, 1988) combines field calculations similar to those performed by CORONA and TRANSPAC with activity modeling to estimate the time a person engaged in a particular activity spends in various levels of fields from nearby transmission lines. The program is designed for use on a microcomputer by persons with limited computer knowledge.

The approach EXPOCALC uses is first to characterize the physical geography of the study area. Second, the subject's activity pattern is mapped to the physical geography to calculate time spent in each location. Third, electric and magnetic contours for the electric sources are calculated for the area of the physical geography. Fourth, the model calculates the equivalent field for the specific activity by applying an activity factor to the calculated unperturbed field. The activity factor describes a known physical reference condition (e.g., current induced into a body standing erect, with arms at side) to the condition occurring in the activity (e.g., percent of reference current for a body sitting on a tractor with arms raised). Fifth, the model calculates the index of exposure by summing the product of the time spent at each location and the value of the field at that location for all activities.

EXPOCALC features function menus, built in data editor, and graphical output directly to the screen or printer. The user has the options of creating a new case by entering data from the keyboard, or loading and modifying an existing case, or running an existing case by loading an existing data file.

EXPOCALC's input has the physical description of a study area surrounding the transmission line, the electrical description and physical orientation of the phase bundles and shield wires, and the phase-to-phase voltage and current for each phase. EXPOCALC assumes a three phase transmission line with each phase separated by 120 electrical degrees. EXPOCALC offers the unique capability to account for the shielding of the electric field by buildings, fences, vegetation and other objects. EXPOCALC also accounts for the sag in the transmission conductor between supports in calculating the electric and magnetic field contours.

Users can select to run an electric field analysis, magnetic field analysis, or both. They have the option of viewing the results graphically, through contour maps or histograms, or generating the results in a tabular format. They can direct the tabular results to the screen, printer, or a data file. Although EXPOCALC generates horizontal contour plots, it is unable to generate lateral profiles.

Like TRANSPAC, EXPOCALC calculates the magnitude of the maximum electric strength and magnetic flux density. It omits giving the angle of the magnitude. The program also does not support any data exchange formats, so transferring data to other programs requires editing the output files into a form other programs can accept. A copy of the input and output reports for the typical 345-kV transmission line are included in Appendix A.

EXPOCALC is available to EPRI members for a nominal distribution fee and available to anyone else under license from EPRI through Enertech Consultants for $1200.

Comparison of Results. The electric and magnetic fields for the same 345-kV transmission line were calculated by CORONA, TRANSPAC, and EXPOCALC and the results compared. The lateral profile was plotted by importing the results into MicroSoft's EXCEL spreadsheet. The profiles start at the center of the transmission line and extend out 500 feet. As the plots for both the electric and magnetic fields show (see Figures 2-24 and 2-25), all three programs give almost identical results--the three curves overlay each.

Other Programs. EPRI is developing another program called RESICALC (Sussman, 1988) that will calculate residential magnetic fields. RESICALC allows development of complex residential models that contain multiple line and point sources each having different electric phasing and temporal magnitudes. Sources of magnetic fields considered are distribution primary and secondary conductors, water pipes, household wiring, and other sources.

2.6.2. Spot Measurements

Another method (Silva, 1988a) of assessing exposure is to use a single point-in-space, instant-in-time value obtained from a survey measurement to represent the field at a location. The chief shortcoming of this procedure is that it ignores temporal variation of the fields. This may be acceptable for electric field exposure estimates, since the electric field from transmission and distribution lines are almost constant. However, magnetic fields vary constantly and such an approach prevents characterizing the magnetic field's spatial and temporal variability. The spot measurement approach can be improved by sampling the magnetic field over a period. But, that period (usually 24 hours) may not be long enough to capture weekly and seasonal variations. Also the method portrays the entire area's fields based on the field in only one location.

2.6.3. Surrogates

A common method to assess exposure to EMF is to choose a substitute physical quantity that may reliably indicate exposures. Use of a surrogate is often desirable because of economic and time constraints. Surrogates that have been used to estimate electric and magnetic field exposure are various wiring codes,

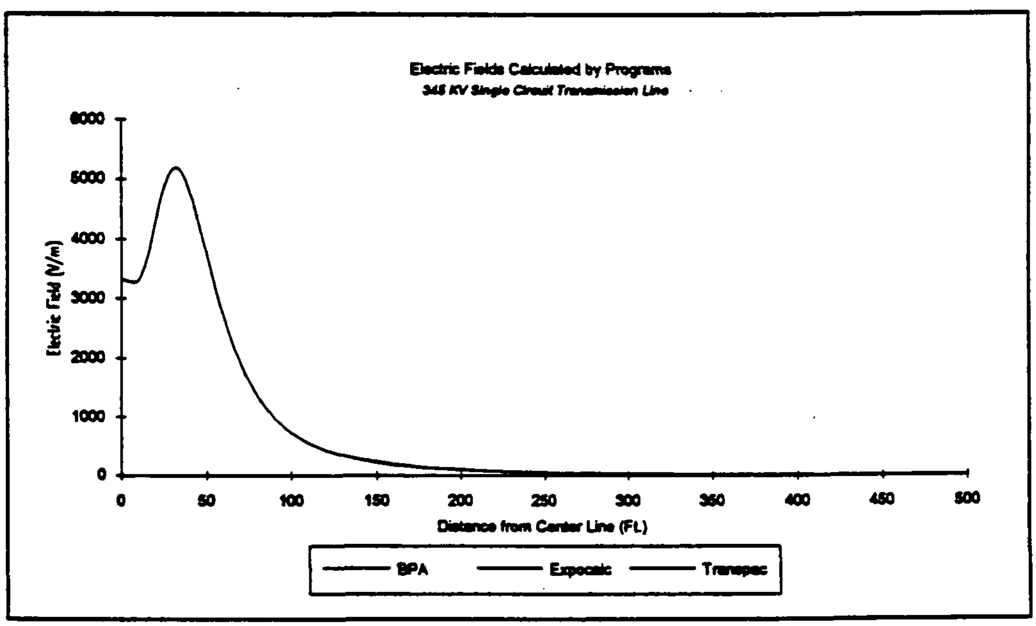

Figure 2-24. Comparison of electric field profile calculated by BPA's CORONA, EPRI's EXPOCALC and APPA's TRANSPAC. The three program yield almost identical values and the three curves overlay one another.

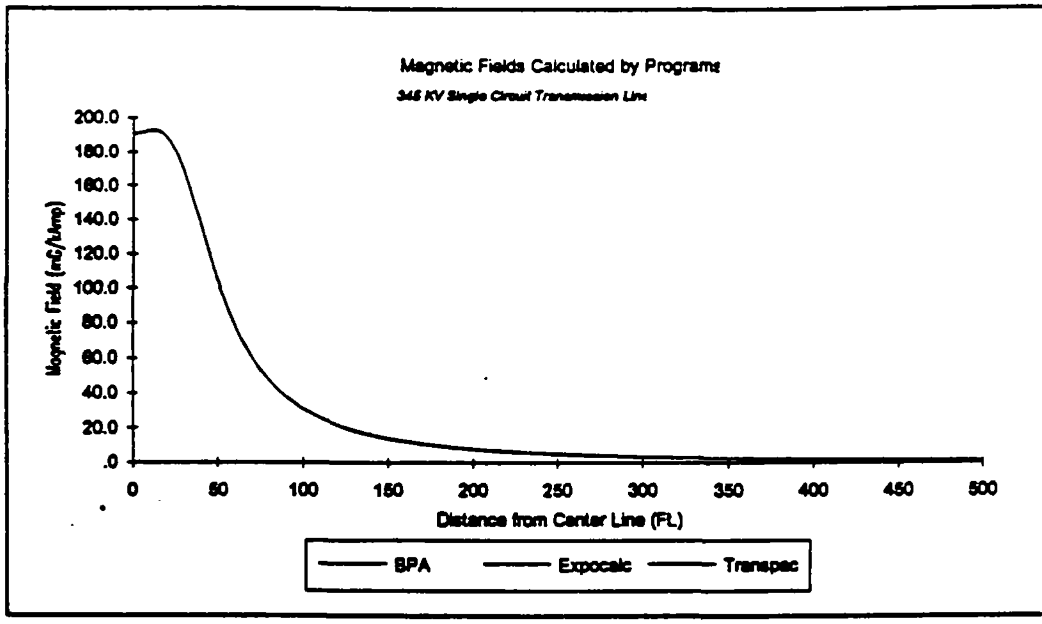

Figure 2-25. Comparison of magnetic field profile calculated by BPA's CORONA, EPRI's EXPOCALC and APPA's TRANSPAC. The three program yield almost identical values and the three curves overlay one another.

distance to powerlines, number of service drops, strength of the source, and occupational classification.

One wire code system developed by Wertheimer and Leeper (Wertheimer, 1979) attempts to characterize the historical exposure of a location to magnetic fields based on the amount of current the external wiring can carry and the proximity of the wiring to the location. Locations are divided into one of several categories such as:

VHCC - Very High Current Configuration

OHCC - Ordinary High Current Configuration

OLCC - Ordinary Low Current Configuration

VLCC - Very Low Current Configuration

The important factor in application of a surrogate is proper understanding of the accuracy of the indicator and whether the surrogate represents only the suspected quantity. For instance, Bracken (Bracken, 1988) noted that Wertheimer-Leeper code only accounted for about 20% of the variation found in one magnetic field measurement study. Keam (Keam, 1988) concluded, after reanalyzing the data from the various Denver epidemiological studies, that the Wertheimer-Leeper code is not a good surrogate for magnetic fields.

Also, critics (Wachtel, 1988) claim that wiring codes can confound the relationship between magnetic fields and cancer since they may be indicative of other factors (confounders) likely to be associated with causing cancer. Wachtel maintains that wiring codes may be surrogates for the age and type of housing construction, the density of housing, and the amount of vehicular traffic in an area.

Confounders associated with the age and type of housing construction may be: presence of toxic building material (e.g., formaldehyde, asbestos), seepage of radon gas, and proximity to toxic waste sites or contaminated water sources. The confounders associated with traffic and housing density may be air pollution and noise levels, and lack of recreational space. In fact, Savitz has recently analyzed the Denver locations (Savitz, 1989) for correlations between childhood cancer and traffic density and found risk ratios very similar to those associated with magnetic field exposure.

2.6.4 Conclusions

- Several computer programs are available to accurately calculate electric and magnetic fields.
- CORONA, TRANSPAC, and EXPOCALC are three programs in use by Texas utility companies. All three programs yielded almost identical results for the sample problem.
- Under controlled conditions, spot measurements may be combined with the

subject's activity patterns to estimate exposure.

- Surrogates must be used with great care since they can often be indicative of other factors besides power frequency EMF, which also may be associated with cancer.

2.7 Preliminary Field Measurements

Data have been collected that characterize field levels in residences and work places. Source characterizations have included measurements near appliances, as well as sources specific to certain occupations. The data collection procedures have ranged from spot, area measurements at one location, to continuous area monitoring of a location, to personal monitoring. The findings of many of these studies, were detailed in materials prepared by Robert M. Patterson, Temple University, for; Seminar on New EMF Epidemiologic Results and Their Implications, October 16-19, 1990, are summarized below.

2.7.1 Residential Exposure

Measurements of electric fields in 10 rural residences in Wisconsin and Michigan showed electric field intensities ranging from 2 to 65 V/m, with a mean value of 16 V/m and a median of 14 V/m. Magnetic field measurements at the same locations yielded a range of 0.07 to 1.6 mG, with a mean of 0.8 mG and a median intensity of 0.4 mG (IITRI, 1984).

The EPA measured 25 homes in Las Vegas and found an average of 5.8 V/m for the electric field and 2.5 mG for the magnetic field. The ranges were 2 to 12.7 V/m and 0.6 and 7.8 mG (Tell, 1983).

In New Jersey, Caola et al. (1983) measured the electric fields at homes that were 1610 m, 95 m, and 1682 m from a 500-kV transmission line and found a range of 1 to 20 V/m. Measurements in a Pittsburgh apartment revealed a non-uniform distribution of electric field levels throughout (Florig, 1986).

Barnes (1985) reported electric field levels measured in thirty-six homes in Denver under two conditions. Under "low power" conditions, with lights and appliances off, the mean value was 7.5 V/m. "High power" conditions, with lights and appliances on, produced a mean of 10.4 V/m.

As part of an epidemiologic study, magnetic field measurements were conducted in 483 Denver residences under low and high power conditions (Savitz, 1987). The mean low power value was 0.76 mG with a standard deviation of 0.79 mG, while the mean and standard deviation for high power were 1.05 and 1.3 mG. Wachtel (1986) pointed out that the difference is not statistically significant.

An epidemiologic study in Seattle incorporated electric and magnetic field measurements to assess residential exposures of cancer cases and controls (Kaune et al., 1987). Data were collected for 24 hours in 43 homes. The electric fields measured near a wall in the family rooms averaged 33 V/m, a value greater than the short-term measurements taken in the center of the room. The difference was attributed to differences in proximity to electrical wiring. The researchers found no relationship between electric and magnetic fields, between electric fields and wiring configurations, and between 24-hour and spot electric field measurements. They concluded that localized measurements are not useful for characterizing electric field exposures.

A somewhat different picture emerged from the magnetic field data in the Kaune study. The mean value in the family room was 1.0 mG, with a standard deviation of 1.2 mG and a median of 0.6 mG. Simultaneous measurements in the bedroom gave 1.0, 1.4, and 0.5 mG for the mean, standard deviation, and median, respectively. There was a diurnal variation that coincided with electric utility loads, peaking in the morning and evening, with low levels in the very early morning. For an individual residence, there was no correlation with power consumption. There was a significant correlation between twenty-four-hour and short-term levels. The researchers concluded that the predominant sources are external to the home and that ground return currents could be an important source.

Both the Denver and Seattle studies tested the Wertheimer-Leeper wire code against their measured data. Savitz (1987) found that the wire codes gave the correct average ranking of magnetic field levels among homes. Kaune et al. (1987) found some correlation between measured levels and wire codes, but the wire codes explained only 20% of the variance. As discussed earlier, he constructed a regression model of field levels. The most important predictor was the number of service drops near (within 43 m) of the residence. The presence and proximity of transmission lines were also important, as was the number of primary phase conductors. There was no significant correlation with distance to primary and secondary distribution lines.

Silva et al. (1988) measured magnetic fields in 91 buildings in six states and found the vertical component of the field to be dominant. Values measured at head level had a mean of 1.2 mG and a standard deviation of 2.5 mG. The maximum was 63 mG; the data appeared to follow a log normal distribution. In houses, they found that field levels depended on the method used for grounding. Of 31 homes with a local ground rod, the mean vertical magnetic field was 0.65 mG. It was 1.9 mG for homes grounded to the water system.

In other studies, a median level of 0.15 was found for 44 homes in the United Kingdom (Myers et al., 1985). Tomenius (1986) recorded an average of 0.7 mG at the front door of 2098 dwellings in Sweden. Measurements at 181 locations in 18 residences in Los Angeles had a geometric mean of 0.6 mG and a geometric standard deviation of 2.8 (Bowman et al., 1988). The ninety-fifth percentile was 3.4 mG. According to Stuchly (1986), levels of 80 to 120 mG have been reported in Germany in rooms where thermal storage electric heating is in use.

Figure 2-26 summarizes many of these data on a common plot (Bracken, 1988). Geometric means and standard deviations are shown when available. When these were missing, the data were assumed to be log-normally distributed and a transformation was made. Missing standard deviations were assumed to be 1.37 mG. The figure shows consistency among data in the United States and Sweden, with lower values recorded in the United Kingdom.

Electric fields near appliances average 30 to 60 V/m at one foot, but they fall off rapidly at greater distances. Levels can reach 960 V/m at the chest under an electric blanket (Florig, 1986). Preston-Martin et al. (1988) reported magnetic fields of about 24 mG under electric blankets. They estimated that electric blanket use increases "overall exposure" to electric fields by less than 50%, and to magnetic fields by less than 100%. Measurements of magnetic field exposure due to appliance use averaged 21 mG with a standard deviation of 76 mG for measurements taken at the belt (Silva et al., 1988). The high magnetic fields near

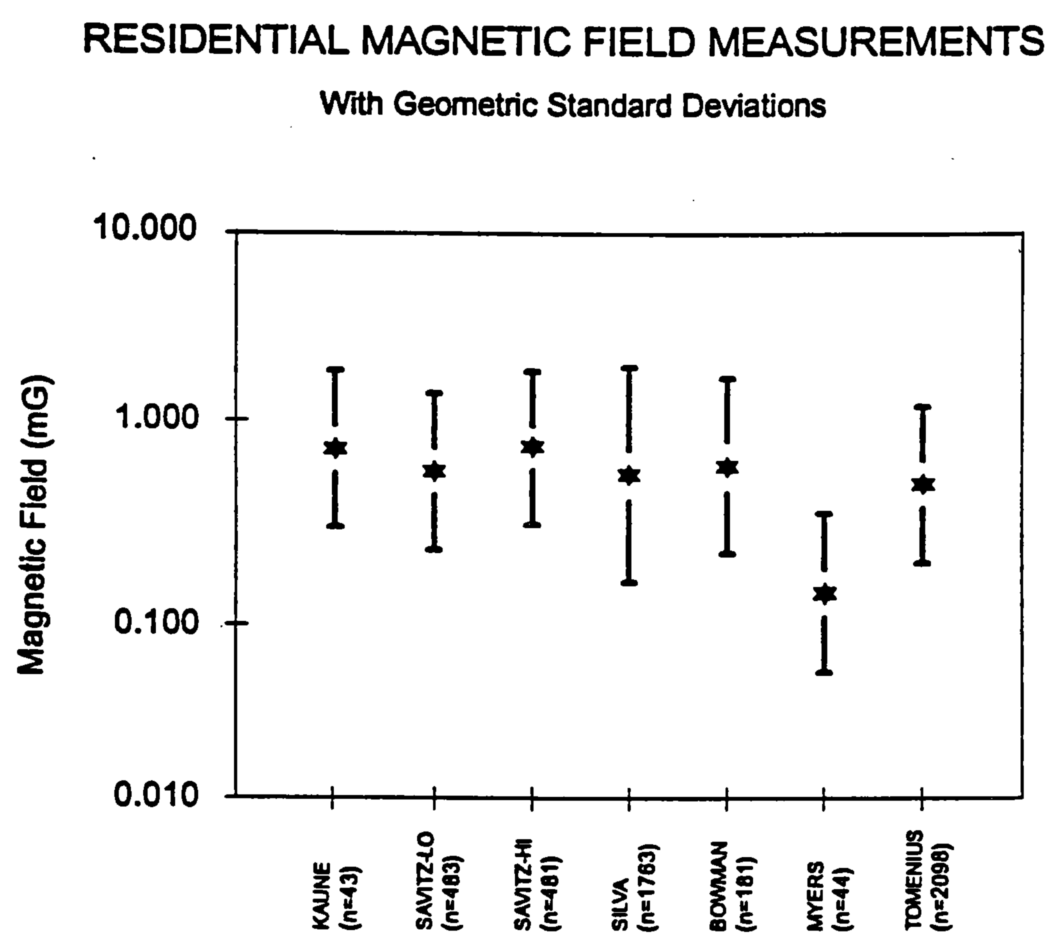

Figure 2-26.

appliances indicate that their contribution must be explicitly considered in any careful assessment of total exposure.

2.7.2 Occupational Exposure

Electric field measurements in fourteen commercial and retail locations in rural Wisconsin yielded a mean of 4.8 V/m and a standard deviation of 4.3 V/m, about one-third the values found in residences. The magnetic fields averaged 1.1 mG; the standard deviation was 2 mG (IITRI, 1984).

Bowman et al. (1988) sampled 114 work sites. "Electrical worker" environments had a geometric mean fields of 4.6 V/m and 5 mG. Secretaries had values of 2 to 5 V/m, 3.1 mG if they used a Video Display Terminal (VDT), and 1.1 mG if they did not. For powerline workers, the overhead line environment yielded geometric means of 160 V/m and 42 mG. A value of 57 mG was determined for underground lines. Other findings included 298 V/m and 39 mG at a distribution substation. Radio and television repair shops yielded 45 V/m, while AC welding produced 41 mG.

Swedish workers in a 400-kV substation spent most of their time in fields below 5 kV/m, with brief exposures above 15 kV/m (Knave et al., 1979). A study of Canadian linemen and substation workers used measurements and task activity patterns to estimate daily exposures (Stopps and Janischewskyj, 1979). Estimates ranged from 50 to 60 (kV/m)-hr for 500-kV linemen to 13 (kV/m)-hr for 115 to 230-kV lineman, and 12 (kV/m)-hr for substation workers. Using a personal exposure meter, which was worn on the arm, Male et al. (1984) measured exposures of electrical workers in the United Kingdom. The device had a threshold of 6.6 (kV/m)-hr. Among 166 transmission workers (equipment rated 132, 275, or 400 kV) and 121 distribution workers (equipment rated at 132 kV or below), only 26 transmission workers and two distribution workers had cumulative, 10-day exposures above the threshold. Among the 26 transmission workers with measurable exposures, the median daily exposure value was 1.5 (kV/m)-hr per day, and the maximum value was 24.3 (kV/m)-hr per day.

Farmers whose land is crossed by high-voltage transmission lines represent another exposed population with higher-than-normal peak exposures. Using a combination of measured and modeled concentration data, it was determined that the annual exposure of this group might range from 10 to 120 kV/m hr, with differences being attributed to the voltage of the lines (EPRI, 1985). Peak exposures ranged above 8 kV/m.

Bracken (1985) reported the use of personal electric field exposure monitors to measure cumulative exposures of utility employees. Highest exposures, 1.7 kV/m hr, occurred for linemen. Exposures generally rose with the voltage of the equipment, and daily maxima ranged from 5.1 to 7.6 kV/m hr.

Personal exposure data have been collected for work, non-work, and sleep periods in a study of 36 Canadians–20 utility workers and 16 office workers (Deadman, 1988). The time-weighted average of one week's data yielded a geometric mean-electric-field exposure of 3.1 mG. It was 1.9 mG for the office workers. Both groups had a level of 1.5 mG while sleeping. While at work, the utility workers' exposures averaged 48.3 V/m and 16.6 mG. Office workers were exposed to a geometric mean level of 4.9 V/m and 1.6 mG.

2.7.3 Exposure Summary

Bracken (1988) has summarized the characteristics of EMF exposure as follows:

- *Internal sources of electric field seem to predominate in residences. Electric fields in residences are highly variable, source dependent, and not easily predicated.*
- *Residential electric fields are in the range of 1 to 100 V/m, with area fields typically in the range of 5 to 20 V/m.*
- *Electric fields in public areas and occupational settings are comparable with residential exposures except when well-defined high-voltage sources are present.*
- *Transmission lines and other power transmission facilities represent sources of high electric field levels in outdoor areas, but levels are strongly dependent on shielding by objects.*
- *Residential magnetic fields are strongly influenced by external sources such as ground currents, transmission lines and nearby distribution lines. Appliances represent a source of highly variable fields, but predictive modeling of field levels may be possible.*
- *Domestic magnetic field levels are typically in the range of 0.5 to 1.0 mG but average levels can be much higher.*

• *Proximity to power transmission facilities is directly related to magnetic field levels in public areas and occupational settings. Higher fields are present for occupations that are associated with high-current facilities or equipment.*

Figure 2-27 depicts electric and magnetic field levels typical of various sources and environments.

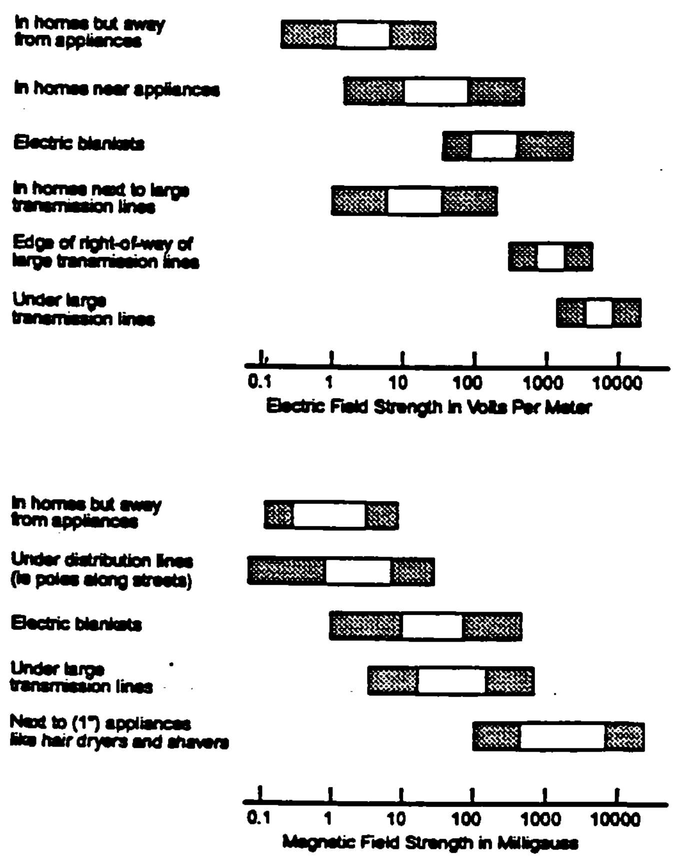

Figure 2-27.

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3.0 Epidemiology of Health Effects and Exposure to EMF

3.1 Introduction

Epidemiology is the study of the distribution and determinants of diseases and injuries in human populations. That is, epidemiology is concerned with the frequencies and types of illnesses and injuries in groups of people and with the factors that influence their distribution. This implies that disease is not randomly distributed throughout a population, but rather that subgroups differ in the frequency of different diseases. Knowledge of disease distributions can be used to investigate causal factors and thus to lay the groundwork for programs of prevention and control (Mausner and Kramer, 1985).

Epidemiologists have organized the complex processes that lead to disease in various ways. One useful way to view the causes of disease is in terms of the agent, the environment, and the host (Friedman, 1980). When a factor must be present for a disease to occur, it is called a necessary agent of that disease. An agent may be a necessary but not sufficient cause of disease because suitable conditions within the host and the environmental must be present for disease to develop. Host factors are usually intrinsic, whereas factors in the environment are extrinsic. Host factors affect susceptibility to disease; environmental factors influence exposure and may indirectly influence susceptibility as well. The interactions of these two sets of factors determine whether or not disease develops (Mausner and Kramer, 1985).

3.1.1 Types of Epidemiologic Studies

Epidemiologic study designs are more fully discussed in Appendix B (Fundamentals of Epidemiology, Section I), and are only briefly described below.

In general, epidemiologic studies (which undertake no manipulation of the study factor) may be categorized as either descriptive or analytic (i.e., etiologic). *Descriptive epidemiologic studies* are usually conducted when little is known regarding the occurrence, the natural history, or the risk factors for a particular disease (Kleinbaum et al., 1982). The objectives of such studies include identification of the patterns of disease occurrence in relation to variables such as person, place, or time and the generation of more specific hypotheses regarding etiologies. Descriptive studies provide essential data to public health administrators who use this information to plan programs for prevention and control of disease. Epidemiologists also rely on descriptive studies to lay the groundwork for hypothesis-testing etiologic studies (Hennekens and Buring, 1987).

Correlational studies, case reports or case series, and cross-sectional studies are included under the general category of descriptive epidemiologic studies. In *correlational studies*, measures that represent characteristics of entire populations are used to describe a particular disease in relation to some factor of interest, such as age, time, utilization of health services, or consumption of a food, medication, or other product. Instead of considering whole populations, as in correlational studies, *case reports* or *case series* describe the experience of a single patient or group of patients with a similar diagnosis. The third major type of descriptive study is the *cross-sectional* or *prevalence survey*, in which exposure and disease status are assessed simultaneously among individuals in a well defined population (Hennekens and Buring, 1987).

Once a disease has been identified and categorized with respect to person, place, and time, *analytic* or *etiologic epidemiologic studies* are often employed to test specific hypotheses, estimate chronic health effects, and to suggest potential means of disease prevention (Kleinbaum et al., 1982). The major types of analytic or etiologic epidemiologic studies include case-control and cohort or follow-up studies. In a *case-control study*, subjects are selected on the basis of whether they do (cases) or do not (controls) have a particular disease. The proportions of subjects within each group having histories of various exposures or other characteristics of interest are then compared. Case-control studies provide a solution to the problems inherent in the study of diseases with extended latency periods. Also, case-control studies permit the evaluation of a wide range of potential etiologic exposures that may be related to a specific disease and of the interrelationships among these factors. Case-control studies are particularly useful in the examination of rare diseases (Hennekens and Buring, 1987).

The second major type of analytic epidemiologic study is the *cohort* or *follow-up study*. In this type of study, a group (or several groups) of individuals is defined on the basis of the presence or absence of exposure to a suspected risk factor for a disease. There are two types of cohort or follow-up studies: *prospective* (or concurrent) and *retrospective* (or historical). These two types of cohort studies differ in terms of when exposure and disease occur in relation to the onset of the study. At the time exposure status is defined, all potential subjects must be free from the disease being studied, and all disease-free eligible participants are followed for a period of time to assess the occurrence of that disease. As a result of this design, cohort studies can provide information on the full range of health effects of a single exposure. When feasible, they are the preferred method of study since the results are less subject to bias than other study types. However, since cohort studies are generally very time-consuming and expensive, they are often conducted only after a hypothesized relationship has been explored and evaluated in a case-control study (Hennekens and Buring, 1987). Therefore, these two types of studies are complementary.

3.1.2 Estimates of Risk in Epidemiologic Studies

Rates of disease and ratios of rates derived from comparisons of exposed and unexposed groups in epidemiologic studies are used to provide estimates of risk. In a follow-up (cohort) study, an actual disease rate can be tabulated separately for both the exposed and nonexposed groups. These rates can then be compared in several ways to develop a quantified expression of risk in relative or absolute terms.

The most common measure of risk in a cohort follow-up study is the relative risk (RR). It is defined as the ratio of the incidence of disease in the exposed group divided by the incidence of disease in the nonexposed group. The relative risk is an indication of the degree of risk for disease (either increased or decreased) among the exposed relative to the nonexposed. This value, therefore, provides an estimate of the importance of the exposure under study. A relative risk of one (1.0) indicates no association between exposure and disease.

The standardized mortality ratio (SMR) is frequently used to estimate risk in epidemiologic studies when the only information available is the number of deaths that have been observed among the study population. It provides a means of comparing the mortality experiences of populations that have different distributions of important variables such as age, sex, or race. To assess whether the "observed" number of deaths is excessive, rates from a standard population are used to calculate the number of "expected" deaths for the study group had they succumbed to the disease at the same rate as the standard population.

The study group is first divided into a number of "strata," which usually include 5- or 10-year age groups within each sex and race or ethnicity category. The expected number of deaths for each stratum is calculated by multiplying the number of persons (or person-years of observation) in that stratum by the corresponding stratum-specific mortality rate in the standard population. The total "expected" number of deaths is then obtained by summing the expected numbers calculated for each stratum. Once this value has been obtained, the SMR is calculated by dividing the observed number of deaths by the expected number (occasionally, the resulting ratio is multiplied by 100 to eliminate the decimal places). When the observed and expected numbers are equal, the SMR is equal to 1.0 (or 100, if that multiplying factor has been used), and no excess (or decreased) risk is present. Values less than 1.0 (or 100) represent "decreased risk," and values greater than 1.0 (or 100) indicate "increased risk" for the study group compared to the standard population (see Appendix B).

A similar ratio can be calculated using morbidity or incidence data, thereby producing a standardized incidence ratio (SIR) which is interpreted in the same manner. An SIR that is equal to 1.0 (or 100) means that the observed and expected numbers of cases are equal, indicating no increased risk for the development of the particular disease. An SIR of 1.5 (or 150) means that there are 50% more cases in the study group than expected.

An entirely different ratio which appears frequently is the proportional mortality ratio (PMR). Although PMR and SMR studies appear superficially similar, they are quite different and are derived from different types of data. Proportional mortality expresses the proportion of all deaths that are due to a particular cause. For example, for deceased individuals who were employed in a particular industry, 20 percent of the deaths may have been due to cancer, whereas heart disease may have accounted for 35 percent of the deaths. Most PMR studies are done when the investigator only has information regarding the people who have died but does not have data on the total number of persons (or person-years) at risk. Under these circumstances, the only items that can be compared are the proportions of all deaths that were due to cancer in one occupation with the proportion due to cancer in another group. Since data for the total population at risk are not available, a mortality rate cannot be determined.

In contrast to *cohort* studies, which determine disease rates for exposed and nonexposed groups, *case-control* studies start with diseased and non-diseased groups and then determine exposure histories for individuals in the two groups. Since this approach does not permit the determination of actual disease rates, a relative risk cannot be determined. One can, however, compare "exposure ratios" between diseased and non-diseased groups and, under certain conditions, these "exposure ratios" can be used to estimate the relative risk by calculating the relative odds of exposure, or odds ratio (see Appendix B).

The odds ratio (OR) provides a reasonable estimate of the relative risk if the disease in question is relatively rare (e.g., specific cancers), if the exposure is relatively common, and if there are no serious biases in the design or conduct of the study. The odds ratio is interpreted exactly the same as the relative risk. If equal to one (1.0), the odds ratio suggests no association between the exposure and the disease.

3.1.3 Assessment of Validity in Epidemiologic Studies

In any scientific study, careful attention must be given to the validity and reliability of the data. All data collection methods involve some degree of inaccuracy and variability. Concern for these threats to data quality is more pronounced in observational studies of human populations, as is the case with most epidemiologic studies.

In assessing the results obtained from epidemiologic studies of human health effects thought to be associated with exposure to powerline-frequency electric and/or magnetic fields (EMF) (or any other suggested etiologic factor), two aspects of study validity must be considered: internal validity, as determined by accuracy and reliability of measurements, and external validity or the generalizability of the results.

INTERNAL VALIDITY

The concept of internal validity addresses the question, "Is this study capable of providing an unbiased and quantitatively accurate estimate of risk?" Threats to the internal validity of a study include: biases in the selection of study groups, errors and biases in measurements and classification of disease or exposure, confounding of the disease-exposure association by other risk factors, and the possibility that apparent associations may be due to chance. Each of these factors must be addressed in evaluating the internal validity of an epidemiologic study and weighing the credibility of any conclusions based thereon.

Bias in Epidemiologic Studies. *Bias* may be defined as a systematic error introduced into an epidemiologic study that results in an inaccurate estimate of the association between exposure and risk of disease (Hennekens and Buring, 1987). Since epidemiologic studies involve free-living human beings, even the most rigorously designed investigation will have the potential for one or more types of bias and/or confounding. A number of sources of bias may distort the association between exposure and disease observed in a particular study (Sackett, 1979). The major sources of bias resulting from the employed methods of study design and analysis may be conveniently grouped under the headings of selection bias, information bias, and confounding bias (Kleinbaum et al., 1982).

Selection bias refers to an error in the estimate of an effect that is due to systematic differences in the characteristics of those who are selected for study and those who are not (Hennekens and Buring, 1987). For instance, a telephone interview survey will exclude households that have no telephone. This exclusion may underestimate the proportions in the population with certain characteristics, such as age, ethnicity, and socioeconomic status; thus, the true proportions remain unknown (Corey and Freeman, 1990). In case-control studies, bias in the selection of study subjects can occur when the procedure used for the selection of cases is different from that used for selection of controls, as when the procedure used to identify disease status varies with exposure status. In cohort studies, selection bias occurs when the exposed group is selected from a population with a different overall probability of disease than that from which the unexposed group is selected. Systematic differences in the way cases and controls choose to participate in either a case-control or a cohort study also represent important sources of bias in epidemiologic studies.

Information bias refers to a distortion in the estimated effect that results from a random or systematic flaw in the measurement or classification of either the exposure status or the disease outcome. *Measurement error* can be either random (due to chance variations) or nonrandom (due to systematic bias). Random errors may be introduced into a study as a result of the variability inherent in most physical measurements. This form of error may be reduced to a certain extent by employing multiple measurements and using the resultant mean value. Nonrandom errors may occur as a result of the improper or inconsistent calibration of field measuring instruments or laboratory equipment. Other sources of nonrandom measurement errors include a defective questionnaire or an interview schedule that fails to elicit the intended responses or an inaccurate diagnostic procedure that either overestimates or underestimates disease status (Kleinbaum et al., 1982).

Misclassification bias is a form of information bias which typically affects the analysis of data in which both the disease and the exposure variables are dichotomous. As with measurement errors, misclassification bias may also be either random or nonrandom.

Random or *nondifferential misclassification* introduces imprecision but may also bias the association towards the null in a study seeking to evaluate an exposure-disease association. Thus, random errors in the estimation of exposure will generally lead to an underestimation of risk, and can introduce a spurious curvilinearity into the estimated dose-response function. For example, in the Radiation Effects Research Foundation (RERF) studies, random errors in the dose estimates resulted in a 10-15 percent underestimation of the relative risk (Schull, 1991). This type of error may be partially overcome by sufficiently increasing the sample size of the study.

By contrast, nonrandom errors in the estimation of exposure can distort or bias the relative risk either upward or downward, and, consequently, represent a serious threat to the validity of a study. *Differential misclassification* occurs when the errors in classifying individuals occur differentially among study groups, thus distorting the comparison of rates and the resulting rate ratios. Differential misclassification of the exposure or disease status may occur in epidemiologic studies, especially when surrogate measures or subjective estimates are used to determine exposure or disease status of the study subjects. This form of bias can occur when knowledge of the disease status of the cases and controls (in a case-control study) influences the exposure classification, or when knowledge of the exposure status of the study subjects (in a cohort study) influences the disease classification of the subjects.

To avoid or substantially reduce this type of bias, well designed studies generally employ some form of blinding to insure that the investigator is unaware of the disease status of the individual when the exposure status is being classified and vice versa. Also, when persons who become lost to follow-up differ, with respect to both exposure and outcome, from those who remain in the study, the observed association can be differentially biased. For instance, a statistically significant increase in lung cancer mortality was observed in a cohort of workers producing urea- and melamine-formaldehyde resins, but the increase could not be specifically attributed to formaldehyde exposure because of incomplete work histories for the workers lost to follow-up (Bertazzi et al. 1986).

Confounding bias in epidemiologic studies is a distortion in the apparent association between a disease and an exposure by a third factor that is causally related to the disease under study and is also associated with the exposure under study but is not a consequence of the exposure. Therefore, the disease may be either partially or totally attributable to the third factor and not to the exposure under investigation. The presence of confounding in a disease-exposure association can be assessed by controlling for the effect of any of the extraneous factors which may be associated with both disease and exposure. Unlike selection bias and information bias, which are primarily introduced by the investigator or study participants, confounding is a function of complex interrelationships between various exposures and disease (Hennekens and Buring, 1987).

Chance in Epidemiologic Studies. Before attempting to assess the causal nature of an association, it is necessary also to determine whether the difference in rates is likely to have been due to chance. Because of the random variations that occur in population samples, the case and control groups (in a case-control study) are unlikely to have exactly the same proportion of exposed and non-exposed persons, even when no association exists between exposure and disease. Likewise, the exposed and non-exposed groups in a cohort study are unlikely to have exactly the same incidence of (or mortality from) a particular disease even though there is no cause-and-effect (or protective) relationship. Determining how large a difference must be to establish convincingly that it is likely to be real and not due to chance, is accomplished through the use of appropriate statistical techniques such as significance testing with p-values and confidence intervals (CI). These techniques are discussed in the tutorial on epidemiologic methods in Appendix B.

EXTERNAL VALIDITY

Assessing the external validity of an epidemiologic study involves an evaluation of the generalizability of the association. It addresses two questions: (1) "Is the association of disease with exposure consistent with causality?" (2) "Is the disease-exposure association observed in a specific study likely to hold for other similarly exposed populations?" When bias, confounding, and chance have all been determined to be unlikely explanations of a particular finding in an epidemiologic study, it is then necessary to decide whether the observed association of disease with exposure can be considered to be causal (Kleinbaum et al., 1982; Hennekens and Buring, 1987). A number of guidelines to assist with the judgment of the causal nature of an environmental association were initially proposed by Hill (1965). These guidelines include the strength of the association, consistency of the data, specificity of the association, temporality of exposure and disease, dose-response gradient, biological plausibility, coherence of the evidence, and the effect of intervention.

Strength of the Association. For epidemiologic evidence, the strength of the association, as measured by the magnitude of the risk ratio, is useful in determining whether the exposure affects the risk of developing the disease. Specifically, the stronger the association (or the greater the risk ratio), the more likely it is that the association is causal. In general, weaker associations do not lend as much support to a causal interpretation (Kleinbaum et al., 1982). Monson (1990) has proposed some guidelines for assessing the magnitude of relative risks. These guidelines suggest that relative risks of less than 2.0 are more likely to be due to bias or confounding, whereas relative risks greater than 5.0 (depending of course on sample size) are more likely to be reflective of a true increase in risk.

Consistency of the Data. Since epidemiology is by its nature observational, it is never possible to achieve the degree of control possible in experimental studies. Evidence to support a judgment of a cause-and-effect relationship cannot be persuasive unless the association is consistently observed in a number of studies. Consistency among multiple studies, conducted by different investigators, at various times, using alternative methods, in a variety of geographic or cultural settings, and among different populations, provides strong evidence for the generalizability of a cause-and-effect relationship (Hennekens and Buring, 1987). Conversely, when multiple studies seem to be producing inconsistent or contradictory results, chance associations, confounding factors, and/or study bias are more likely to be present, and the argument for a cause-and-effect relationship is weakened.

Specificity of the Association. Specificity of the association is another aspect to be considered in weighing the external validity of a study. If the association is limited to a specific exposure and/or to a particular disease, there is a strong argument in favor of causation. However, in chronic disease epidemiology, multiple-causation is generally more likely than single causation. Therefore, if specificity of the association has been demonstrated, a causal interpretation can be made with greater confidence; if specificity does not exist, a causal interpretation must be made more cautiously (Greenland, 1987).

Temporality of Exposure and Disease. The temporal relationship of an association is particularly relevant with diseases of slow development (Hill, 1971) or prolonged latency periods, such as cancer. Does a particular occupational or environmental exposure lead to an increase in some form of cancer? If the association is to be considered causal, then the relevant exposure must precede the occurrence of cancer by a sufficient interval of time to account for the disease latency period. This also holds for diseases with short incubation or latency periods (e.g., symptoms of acute toxicity). If the interval from exposure to onset of disease is too long, the argument for causation is weakened.

Dose-Response Gradient. If the association demonstrates a dose-response gradient, the cause-and-effect hypothesis is supported (Greenland, 1987). For example, the causal association of smoking and lung cancer was strongly supported by the evidence that the mortality rate from lung cancer increased linearly with the number of cigarettes smoked daily (Doll and Hill, 1950).

Biological Plausibility. The causal nature of an association is more readily accepted if there is a biologically plausible hypothesis to support causality. However, biological plausibility is determined, to a certain extent, by the current state of knowledge (Greenland, 1987). Consequently, such plausibility cannot always be demanded of a hypothesis, since the current state of knowledge may simply be inadequate to explain the observations. An impressive number of associations of environmental exposures with cancer was identified from epidemiologic studies prior to knowledge regarding the biological mechanisms. Notable examples include the association of cigarette smoking and lung cancer, and association of specific agents such as asbestos, benzene, and ultraviolet radiation with human cancer. Conversely, the less that is known regarding the etiology of a disease, the less confident one can be in rejecting a causal interpretation on the basis of this guideline (Kleinbaum et al., 1982).

Coherence of the Evidence. Coherence of the epidemiologic, biologic, and other evidence implies that a causal interpretation is not seriously in conflict with current knowledge of the natural history and biology of the disease (Greenland, 1987). For example, mortality from lung cancer was initially higher in males than in females because smoking was more common in males. As more females adopted the smoking habit, mortality rates for lung cancer among females have tended to approach those seen among males (Hammond, 1966).

The Effect of Intervention. The strongest support for the causation hypothesis is provided by experimental studies or intervention studies in human populations (Hill, 1971). If exposure to an agent is truly causal, then removal of the agent should result in a decrease in the disease rate. Since the association of smoking with lung cancer was recognized, many physicians have stopped smoking. This change was followed some 20 years later by a decrease in lung cancer mortality among physicians (Doll and Peto, 1976).

An expanded discussion of epidemiologic study methods is found in Appendix B.

3.1.4 EMF Exposure Assessment in Epidemiologic Studies

The assessment of EMF exposure seems to be the factor of greatest uncertainty in the epidemiologic studies of EMF and cancer. Many studies published to date have been somewhat flawed in methodology, in part due to the use of indirect, imprecise, and unverified surrogate measures of exposure. The possibility for misclassification of the exposure status of an individual can be random or systematic (i.e., nonrandom), thus resulting in either decreased precision or overt distortion in the assessment of an association.

In general, some form of exposure gradient or differential among study subjects is necessary for an effective environmental or occupational epidemiologic study. If exposures were homogeneous, it is unlikely that an exposure-disease association could be investigated. The choice of grouping subjects into dichotomous or multi-stage exposure classifications often influences the results of the statistical analyses (Flegal et al., 1986).

EXPOSURE METRIC

The appropriate direct measure of exposure in epidemiologic studies of EMF is still being debated, and this is an important area of ongoing research. The absence of a mechanism for a biologic effect to explain the EMF-cancer association creates uncertainty about what, exactly, should be the appropriate "exposure metric." Candidates for the exposure metric might include the magnetic field component, the electric field component, a combination of the two, or possibly the orientation of the EMF with respect to the earth's static magnetic field. Certain frequencies may be of greater or lesser significance. Transients (sudden changes in an electric or magnetic field) may be important, and certain field intensities (i.e., the window effect) have been suggested as possibilities to help explain some limited and apparently contradictory experimental data. To date, epidemiologic studies have not reported an association between directly-measured electric or magnetic fields (or other exposure metric) and health effects, but this may be because exposure assessment has been inadequate.

Magnetic fields have recently been regarded as the exposure component likely to be of greatest concern, but this emphasis is not based upon clear-cut epidemiologic evidence of an association between cancer and measured magnetic fields. Electric fields have received less attention in recent studies of cancer and residential exposure because few or no biologic effects have been demonstrated in experimental animal studies. In addition, while electric fields are relatively easily shielded by structures and other barriers, magnetic fields are not. In fact, wiring configuration codes were originally devised to predict magnetic fields rather than electric fields. Regardless, it is somewhat premature to dismiss electric fields as a possible agent, especially in the studies seeking to evaluate occupational EMF exposures.

EXPOSURE MODELS

Exposure models generally consist of some form of algorithm derived to estimate EMF exposure based on a set of known physical parameters such as wiring configuration, distance from wires, average voltage and current, and behavior patterns. The use of exposure models may be superior to the direct use of exposure measurements for current exposures because the influence of such factors as appliance use over time can be factored into a model. Exposure models using available historical information that can be validated using current measurement data are particularly useful for studies dealing with past unmeasured exposures.

EXPOSURE SURROGATES

In retrospective case-control studies, it is often necessary to establish or define certain surrogate measures of exposure which will help to quantitate a likely historical exposure which cannot be directly measured. The use of such surrogate measures to infer potential individual EMF exposure is not uncommon, but the process is fraught with uncertainty. On the other hand, surrogate measures, though potentially inaccurate, may result in less exposure misclassification than when inherently variable, short-term, spot measurements are used to estimate the unmeasurable historical exposure.

Wiring Configuration Codes. The most commonly employed surrogate measure for residential EMF exposure is the electric power transmission or power distribution line wiring configuration code (WCC). In the initial study of childhood cancer in Denver, Wertheimer and Leeper (1979) categorized high-current configuration (HCC) homes as those close to a number of specific types of wiring which had the potential to carry high currents. All other wiring configurations were considered low-current configurations (LCC). In their later study of cancer in adults, Wertheimer and Leeper (1982) expanded their wiring coding system to four categories: very high current configurations (VHCC), ordinary high current configurations (OHCC), ordinary low current configurations (OLCC), and end pole configurations. This latter category referred to houses situated beyond the pole at the end of a secondary line with no distribution wires running past.

In the case-control study of childhood cancer in Denver by Savitz et al. (1988) which attempted to replicate the Wertheimer and Leeper (1979) study, five categories were used for the wiring configuration codes: VHCC, OHCC, and OLCC, plus a very low current configuration (VLCC) and a buried category. Thus, these two studies used similar, but not completely comparable, coding systems.

Field Measurements and Their Correlation with Wire Configuration Codes. An estimate of the reliability of wiring configuration codes can be made by comparing the magnetic field measurements in 432 homes made by Savitz et al. (1988) at times of high and low power usage with the field measurements near 417 homes made by Wertheimer and Leeper (1982). The field measurements made by Savitz et al. (1988) were obtained in a number of rooms inside each house, and an average value for each house was used, while those made by Wertheimer and Leeper (1982) were obtained at a point close to the part of the house nearest the distribution wires. The percent of homes with measured fields greater than 3 milligauss (mG) and the median and maximum values for wire code categories suggest fairly good agreement between the two coding systems, but poor discrimination because of considerable overlap between categories.

Wertheimer and Leeper (1982) suggested that wire codes remain stable over long periods of time and, therefore, might provide better measures of historical field levels, but this suggestion is not based on quantitative evidence. The measurements made by Savitz et al. (1988) in the case-control study in Denver homes mentioned above appear to offer some support for this suggestion, as does the study in the Seattle area by Kaune et al. (1987). In their study, Kaune et al.

(1987) found a slightly stronger correlation between spot measurements and 24-hour averages for measured magnetic fields (r=0.5) than between wiring codes and 24-hour averages (r=0.41). Although this correlation has been interpreted as suggesting fairly good agreement, a very large percent of the actual variation remains unexplained (75-83% when $1-r^2$ is used to estimate the unexplained variation). Wire code surrogate data have recently been correlated with magnetic field levels in a relatively unsophisticated approach to modeling (Flynn, 1990). If magnetic fields are like other environmental agents, a single 24-hour measurement will be a very imprecise indicator of long-term or historical exposure levels at the measurement location. An exposure model based on specific measurement data combined with historical local power consumption trends might provide a better index of past exposure than isolated short-term measurements themselves.

Intuitively, one would expect that, if there is an association between magnetic fields and cancer, the association would be stronger for the more directly measured fields than for wiring codes. The fact that Savitz et al. (1988) found the reverse to be true in their study may suggest that the association of wiring codes with cancer may not be causal, or that spot measurement data do not provide accurate bases for exposure classification. In fact, none of the cancer odds ratios calculated for magnetic fields measured under high and low power usage conditions was statistically significant in the Savitz et al. (1988) study. This lack of association may be due to the smaller number of study subjects for whom data on measured magnetic fields were available, as well as to the variability in the measured data.

It was only when the wire code at the subject's residence two years before diagnosis was used in the analysis that the odds ratio for one category achieved statistical significance. This ratio is somewhat imprecise due to the small number of observations, which included only 8 cases and 2 controls in the VHCC category (Savitz et al., 1988). Since a lower participation rate was observed for controls in the VHCC category than other WCC categories, it has been suggested that the elevated risk ratio could have resulted from differential participation of controls by exposure status. The potential for this type of selection bias is now under study (Poole and Trichopoulos, 1991), as was strongly recommended by participants at the EPRI Workshop on EMF Epidemiology (EPRI Proceedings from Carmel Workshop, 1991).

Job Titles and Industry Codes. For occupational epidemiologic studies, job titles and industry codes are commonly used as surrogate measures for estimating potential occupational EMF exposure. However, the classification scheme has not yet been standardized (Lewis, 1990). Also, the duration of exposure has not been considered in most of the studies using these methods. In addition, potential confounding factors such as socioeconomic status have been described, but not carefully estimated or controlled in most studies.

De Guire et al. (1988) and Vågerö et al. (1985) selected subjects who had ever worked in the telecommunications industry. Olin et al. (1985) studied electrical engineers. Milham (1985b) and Pearce et al. (1989) chose several occupations which they considered to be exposed to EMF. However, Milham excluded electrical engineers because he thought the EMF exposure of electrical engineers was "infrequent" and their potential social class might bias the mortality ratio.

In epidemiologic studies where information was abstracted from death certificates, census codes for occupation were used (Thomas et al., 1986, 1987) to estimate EMF exposure. In the latter study, the job entry in a study subject's work history was assigned a three-digit standard industrial classification (SIC) code for industry (Office of Management and Budget, 1972) and a 1980 Census code for occupation (Bureau of the Census, 1982). In these studies, EMF exposure was estimated indirectly by using a surrogate measure without knowledge of actual EMF exposures. The occupational titles considered as surrogates were assumed to indicate a higher levels of EMF exposure than other job titles, but the intensities of individual exposures were unknown. In the study by Lin et al. (1985), occupations were grouped according to level of likely exposure to EMF. The exposure category for each occupation was determined in consultation with an industrial hygienist, an occupational physician, and a radiation physicist. However, data on duration of occupational exposure were not available.

Preliminary studies are underway to describe the correlation of job title surrogate data with measured occupational EMF exposures (Peters, 1990). In order to measure actual occupational EMF exposures, Peters et al. (1990) quantified exposure to EMF among the electrical occupations and among a representative sample of non-electrical occupations. An EMDEX dosimeter was used to measure electric and magnetic field exposures over an entire work shift at 2.5-second intervals. The study indicated considerable variability in magnetic field exposures within a single job category depending on the different tasks being performed. This finding demonstrated the importance of estimating the average exposure over a typical shift, as well as recording peak and transient exposure patterns. For each job category of non-electrical workers, the average magnetic field exposure over a shift was shown to be both lower and less variable than that for electrical workers.

CONFOUNDING IN EMF STUDIES

Study populations may be exposed to a variety of known or suspected carcinogens as well as to EMF. For example, in studies associating residential EMF exposure to the risk of cancer, some attention should be given to other residential exposures that are known to be associated with cancer, such as radon gas and benzene emissions, which may also be correlated with the estimate of EMF exposure used in the study.

Study of the same Denver subjects used in the Savitz et al. (1988) study of magnetic fields, for example, showed a weak, but statistically significant, association between cancer and traffic density, a surrogate for motor vehicle emissions and benzene exposure (Savitz and Feingold, 1989). Some attempt was made in the Savitz et al. (1988) study to evaluate the effects of other exposures on cancer risk, especially those exposures which may "confound" or distort the possible association between magnetic fields and cancer. A true confounding factor would be one that is related to both wiring codes and cancer. One suggested factor is traffic density, which Savitz et al. (1988) examined, concluding that "although traffic density did seem to be associated with both cancer incidence and wire codes, those associations were not strong enough to confound the association between wire codes and cancer." Although no data were provided to support this assertion, it seems likely that the elevated risk ratios may have resulted from some unrecognized bias, rather than confounding, which was better controlled in the study by Savitz et al. (1988) than in the study by Wertheimer and Leeper (1979).

In general, analysis for potential confounders would be limited by the small sample sizes available for specific cancers and would generally not be very informative. However, the "wire code effect" was reported to be most pronounced among females, older children, those who lived in multi-family housing, low social class, and those whose mothers smoked during pregnancy. These observations could imply effect modification or that other correlates of wire codes are responsible for the reported association.

Additional and expanded discussions of exposure assessment are found in section 2.0, Appendix A, and in the tutorial in Appendix B on exposure assessment in epidemiologic studies.

SELECTION OF CONTROLS IN EMF STUDIES

The published studies of EMF exposure and cancer emphasize the importance of selecting a control or reference population that is truly representative of the study population. The potential for bias due to differential patterns of response in the selection of controls can occur in case-control studies when the procedure for selecting controls does not ensure a representative sample from the underlying population from which the cases are drawn. The method of selecting controls by random digit dialing, as was done in the two major studies of childhood cancer and EMF exposure (Savitz et al., 1988; London et al., 1991), may result in under ascertainment of controls from the lower socioeconomic groups and controls with a greater stability of residence than cases. There is some evidence suggesting that such biases may have occurred in both studies; this possibility is being studied by several investigators (Poole and Trichoupoulos, 1991; EPRI Workshop Proceedings, 1991).

3.2 U.S. Cancer Mortality Rates and Trends

It is instructive at this point to examine the time trends for the various cancers of concern. In the subsequent review of the epidemiologic evidence regarding EMF exposure and adult or childhood cancers (see section 3.3), the sites of concern include: total cancer, leukemia, central nervous system (CNS) cancer, and, to a lesser extent, breast cancer. Since lung cancer has come to represent such a large percentage of total cancers and tends to dominate the overall trend, this site is also considered.

Much of the concern surrounding the EMF issue has arisen from reported increases in various childhood and/or adult cancers. Consequently, cancers have been examined dichotomously by age. For this analysis, the word "childhood" means persons of ages 0 through 19 years and the word "adult" means persons of age 20 and above. Age- and sex-specific cancer mortality rates for the United States were obtained from the American Cancer Society for each of the leading cancer sites and for each year back to 1930 (Silverberg, 1990). From these data, annual, age-adjusted mortality rates were calculated for (male and female) children and adults. A variety of additional terminology, analytical techniques, and data sources are typically utilized in the evaluation and quantification of morbidity and mortality data. Some of the more commonly used data sources and their limitations are reviewed in Appendix B. Also, a number of additional commonly used terms and techniques for analyzing morbidity and mortality data are briefly described in Appendix B or defined in the Glossary.

3.2.1 Total Cancer Mortality

From Figure 3-1, it can be seen that the crude cancer mortality rates in the U.S. for males and females combined have nearly doubled since 1930. However, when the shifting age distribution of the population at risk is taken into consideration through age-adjusted rates, it is apparent that the increase has been a much more modest 19 percent (Figure 3-2). The age-adjusted rates for females have actually decreased by about 10 percent over the period from 1930 to 1987, but the rates for males have gone up 64 percent. When adult cancers are examined separately from childhood cancers, the time-trend patterns are still very similar to the totals for all ages combined, but quantitatively, the adult-only, age-adjusted rates are approximately 60 percent higher (Figure 3-3). The age-adjusted rates for total cancers in children (Figure 3-4) increased 54 percent from 1930 to 1945, but leveled off and then began decreasing so that they are now about 30 to 40 percent lower than in 1930.

3.2.2 Lung Cancer Mortality

Lung cancer in males has been the leading form of cause- and sex-specific cancer mortality in the United States since it surpassed breast cancer in females in the early 1960's. Presently, lung cancers account for about 28 percent of all cancer deaths nationwide. From about 1950 to 1970, lung cancer among males underwent its period of most rapid growth, while the rates among females did not show appreciable increases until around 1965 (Figure 3-5). Over the 57-year period from 1930 to 1987, the age-adjusted lung cancer mortality rates among males and females have increased by 1510 and 1282 percent, respectively. However, since the early 1980's, the rates among males have shown a tendency to stabilize in the range of 72 to 74 deaths per 100,000 population. Lung cancer mortality among children (not shown) is generally very low (in the range of 0.05 to 0.15 deaths per 100,000).

3.2.3 Total Cancer Mortality (Excluding Lung Cancer)

When lung cancer deaths are subtracted from total cancers, the effect on the time trends is impressive (Figure 3-7). Total cancer (minus lung) among males has remained virtually unchanged since about 1945, while among females, the rates have decreased significantly by about 23 percent. Part of this declining trend is due to the steadily decreasing stomach cancer mortality rates, which, in 1930, accounted for about 28 to 38 deaths per 100,000 population for females and males, respectively, while by 1987 they had decreased to the range of 3 to 7 (data not shown).

3.2.4 Leukemia Mortality

Mortality from leukemia underwent a relatively steady increase from 1930 to 1960 (Figure 3-8). Since around 1968, the rates have gradually declined and, in 1987, they accounted for about 8.0 and 4.9 deaths per 100,000 in males and females, respectively. The time trends for adult-only leukemias are very similar to total leukemias except, quantitatively, they are about 30 to 40 percent higher (Figure 3-9). When childhood leukemias are examined separately, it can be seen (Figure 3-10) that mortality rates increased sharply (100 to 200 percent) over the period from 1930 to 1950, plateaued between 1950 and 1960, and then began a sharp and steady decline from 1960 to 1987. Part of this pattern was due to greatly improved chemotherapeutic measures for the childhood leukemias which have increased the expected five-year survival for this disease.

3.2.5 Brain Cancer Mortality

The time trend for brain and central nervous system (CNS) cancer is similar to that for leukemia, with a slightly more gradual rise from about 0.7 in 1930 to 3.2 in 1955 (Figure 3-11). At that point, the increase became even more gradual, with rates reaching 3.9 deaths per 100,000 in 1969. Since then, the rates have remained relatively stable in the range of 3.8 to 4.3 through 1987. There is a slight irregularity in the trend between the years 1978 and 1979. This occurred with the switch from the 8th Revision to the 9th Revision of the International Classification of Diseases (i.e., switching from ICD-8 to ICD-9). Prior to 1979, "Malignant Neoplasms of the Brain" included some secondary neoplasms; since then, only primary tumors have been included. If this is taken into account, there is still a gradual increase occurring (3.8 in 1979 to 4.1 in 1987).

When adult brain and CNS cancers (Figure 3-12) are examined independently of childhood cancers, the trend is similar to the combined rates, but they are about 43 to 51 percent higher. Childhood brain and CNS cancer mortality per 100,000 population increased from 0.25 for males and 0.21 for females in 1930 to about 1.73 for males and 1.28 for females in 1954 (Figure 3-13). The rates then began a gradually decreasing trend which has accelerated since about 1970. By 1987, childhood brain and CNS cancer mortality was back down to 0.75 and 0.60 for males and females, respectively. Whereas brain/CNS cancer and leukemia accounted for less than 10% of all cancer deaths in adults in the 1980's, these sites accounted for more than 50% of all cancer deaths among children.

3.2.6 Breast Cancer Mortality

Breast cancer mortality has remained remarkably stable for females, with only minor fluctuations in the range of 39.8 to 45.0 over the entire period from 1930 through 1987 (Figure 3-14). Male breast cancer mortality has always been below 0.75 deaths per 100,000, and the time-trend has shown a gradual but steady decline to the range of 0.35 to 0.42 in the mid-to-late 1980's.

3.2.7 Selected Cancer Mortality versus Electric Power Consumption

Electric power consumption in the United States is plotted along with cancer mortality for the selected sites of concern in Figures 3.15 through 3.18 in order to compare them with the temporal relationship of tobacco consumption versus lung cancer mortality shown in

Figure 3-6. This comparison provides a superficial, but useful, summary of the secular trends for electric power consumption and cancer mortality, even though it is not known whether electric power consumption is a good predictor of individual magnetic field exposures. In fact, in the United States it is unclear whether or not there has been an increase in exposure to EMF since 1950 concomitant with the increase in electric power consumption.

From Figure 3-15, we see that male adult leukemia and brain/CNS cancer mortality rates were increasing substantially before the exponential growth in U.S. electric power consumption was significantly underway. Then, as electric power consumption began its rapid increase, leukemia and brain/CNS cancer mortality began to level off. Male adult breast cancer mortality has continued a gradual but steady decline in spite of the rapid increases in electric power consumption (Figure 3-15). The mortality time-trends for female adult leukemia and brain/CNS cancer (Figure 3-16) show similar patterns. Female breast cancer mortality has remained relatively stable over the entire period of rapid growth in electric power consumption (Figure 3-16).

Leukemia, brain/CNS cancer, and total cancer mortality, for both male children (Figure 3-17) and female children (Figure 3-18), all show an increasing trend before electric power consumption had begun its major growth. Then, as power consumption rates increased significantly in the 1945 to 1950 time period, childhood leukemia, brain/CNS cancer, and total cancer all leveled off and began to decrease.

It should be emphasized that examination of mortality data is not the preferred method for examining secular changes in population risk for childhood cancers because of the impact of improved treatment for childhood cancers on the mortality rates. Examination of cancer incidence would be preferable, but reliable incidence data for childhood cancers are not available for the extended time period of interest (i.e., 1930 to 1987).

3.3 Epidemiologic Studies Involving EMF Exposures

In 1979, Wertheimer and Leeper published a study reporting a greater number of electrical wiring configurations that presumably carried high current near the former homes of children in Denver who had died of cancer when compared with the former homes of controls. In a second study, published in 1982, the same authors reported an increased cancer mortality among adults who resided at several locations in Colorado which appeared to be associated with high current wiring configurations. These two studies were the first to suggest possible human cancer risks associated with exposure to EMF.

Subsequently, over 80 epidemiologic studies have been published which investigate the potential adverse health effects of residential and occupational EMF exposures. Studies of EMF and cancer reported through early 1991 (and subsequently published) were selected for the health effects literature review detailed in this section. Also reviewed were several unpublished studies for which full reports or manuscripts were available. In addition, several previous review articles on EMF were summarized.

3.3.1 Summary of Previous Reviews

Since the proliferation of epidemiologic studies of EMF and cancer began, an increasing number of review studies have also been published. Eight of these studies were included in our review of the EMF literature (Savitz and Calle, 1987; Aldrich and Easterly, 1987; Ahlbom, 1988; Coleman and Beral, 1988; Nair et al., 1989; Theriault, 1990; Hutchinson, 1991; Jauchem and Merritt, 1991).

Savitz and Calle (1987) reviewed 11 studies of leukemia and occupational exposure to EMF, reporting that there was a "modest" excess risk for total leukemia among men in exposed occupations and an "enhanced" risk elevation for acute leukemia, especially acute myelogenous leukemia. They concluded that, the studies were inherently limited because of the absence of exposure characterization, but that telegraph, radio, and radar operators; power and telephone linemen; and electrical and electronic engineers showed the most consistent results and warranted further study.

Aldrich and Easterly (1987), in addition to reviewing a number of experimental (i.e., animal, plant, and cell tissue) studies of EMF exposure, also reviewed and summarized 14 epidemiologic studies of cancer and birth defects associated with occupational EMF exposures. On the basis of the generally low risk levels observed in these studies, they concluded that if a human cancer risk does exist, it is likely to be very small, perhaps on the order of 2.0 or less, and then only for highly specific groups in the population. These authors suggested that future epidemiologic studies of the possible carcinogenic effects of EMF should take into account other potentially confounding exposures.

Ahlbom (1988) reviewed nine studies which focused primarily on residential EMF exposures, and he concluded that, although the childhood studies seem to indicate an increased risk for cancer, so many methodological and theoretical concerns have been raised against these studies that the findings must be considered highly uncertain. Ahlbom also concluded that the studies on adult cancer and residential exposures, provided little evidence for an association with all cancers together or with leukemia. While it was not possible to determine whether exposure to magnetic fields increases the risk of cancer, the information in this review did suggest that research in this area should be pursued.

Coleman and Beral (1988) reviewed seven studies of cancer and residential EMF exposure resulting from installations transmitting electricity and an additional 11 studies of cancer and occupational EMF exposure. They concluded that there was no clear association between cancer risk and residence near installations transmitting electricity. Combined data from the occupational studies indicated a significant excess of total leukemia and of acute myeloid leukemia, with risk estimates of 1.18 (95% CI, 1.09-1.27) and 1.46 (95% CI, 1.27-1.65), respectively. However, they reported that it was not clear whether the increase was specific to certain types of work within the electrical industry. They also concluded that, from the available data, it was not possible to determine whether the increases in leukemia were due to EMF or to other factors to which the electrical workers were exposed.

In an extensive review of the biologic effects of power-frequency electric and magnetic fields for the Office of Technology Assessment (OTA), Nair et al. (1989) reviewed five studies of childhood cancer and residential EMF exposure, three studies of adult cancer and residential exposure, and about 20 studies of leukemia, brain cancer, and total cancer in connection with occupational EMF exposures. They concluded that there was an indication that occupational exposure in "electrical occupations" was associated with enhanced leukemia risk, but they pointed out that "associated" means "occurs together with" and does not imply a causative link. With brain cancer and total cancer, the evidence was somewhat less substantial, and their overall conclusion was that the available evidence was too weak to allow any firm conclusions.

In a paper prepared for a plenary session of the NIOSH scientific workshop, Theriault (1990) reviewed the epidemiological evidence for the risks of cancer and other adverse health effects associated with occupational exposure to 60/50 Hz EMF. In his review, he grouped the studies into seven categories: 1) cancer hypothesis generating studies, 2) leukemia case-control studies, 3) brain cancer case-control studies, 4) cohort studies of electrical workers, 5) eye melanoma case-control studies, 6) welding and exposure to EMF, and 7) studies of male breast cancer. On the basis of these study groupings, Theriault concluded that:

1) Pooled analysis of 12 of the early proportional mortality ratio (PMR) studies has indicated minimal but significantly elevated risk estimates for total leukemia and acute myeloid leukemia. However, these exploratory studies were limited by study design, small numbers of observed deaths, weak statistical analyses, lack of controlling for confounders, and inaccurate exposure assessments (Theriault, 1990).

2) The five case-control studies of leukemia and occupational EMF exposures conducted subsequently were generally considered to be more informative because of improved study designs and larger numbers of leukemia cases studied. These studies provided support for the possible association of leukemia with occupational EMF exposure, but all were plagued with one major weakness: exposure assessment. EMF exposure was generally inferred from job titles and occupational histories secured through postal questionnaires or transcribed from registration forms rather than from actual measurement (Theriault, 1990).

3) Seven case-control studies on brain cancer and occupational exposures were reviewed; most showed elevated odds ratios for electricity-related occupations. In these studies, the numbers of cases were relatively large, and, in three of the studies, an apparent dose-response relationship was observed. However, as with the leukemia studies, exposures were estimated on the basis of the reported occupations or secured through postal questionnaires (Theriault, 1990).

4) The risk ratios in the cohort studies of electrical workers generally were not as highly elevated as in the case-control studies, and few excesses were statistically significant. Only one study (Milham, 1988) reported a significant excess of acute myeloid leukemia; only one (Matanowski et al., 1989) observed an excess of total leukemia; none reported significant excesses for brain cancer. However, skin melanoma appeared to be fairly consistently elevated in five of the cohort studies (Theriault, 1990).

5) Two case-control studies of eye melanoma were reviewed; Swerdlow (1983) reported an elevated odds ratio (reported as the proportional registration ratio)for electrical and electronic workers while Gallagher et al. (1985) did not find an excess in a similar group of workers (Theriault, 1990).

6) Occupational studies conducted among welders are important with respect to potential health effects of EMF exposure because of the presumably high electric and magnetic field exposures. Review of 15 cancer studies in welders indicated an excess of lung cancer but slightly decreased risk for leukemia (Theriault, 1990).

7) A cohort study of telephone workers by Matanoski (1989) reported a standardized incidence ratio of 6.5 (95% CI, 0.79-23.5) for male breast cancer based on 2 cases observed and 0.3 expected. Also reviewed was a case-control study by Demers et al. (1990) who noted elevated odds ratios for male breast cancer in workers potentially exposed to EMF (OR=1.8; 95% CI, 1.0-3.2). These findings were interpreted as lending support to the hypothesis that EMF may increase cancer risk by interfering with the melatonin hormonal system (Theriault, 1990).

In a review of cancer studies with residential EMF exposure, Hutchinson (1991) reported a statistically significant summary odds ratio of 1.33 (95% CI, 1.06-1.67) for childhood leukemia and a history of residential exposure to EMF. His analysis was based on five previous studies (Wertheimer and Leeper, 1979; Fulton et al., 1980; Tomenius, 1986; Savitz et al., 1988; Coleman et al., 1989). Among the five studies, only one (Wertheimer and Leeper, 1979) reported significant increases in leukemia. The statistical significance of the summary odds ratio (Mantel-Haenszel) may be due to significant heterogeneity of the component odds ratios (Hutchinson, 1991).

The summary odds ratio for childhood CNS cancer and a history of residential exposure to EMF was statistically significant, with an odds ratio of 2.44 (95% CI, 1.70-3.53) in Hutchinson's (1991) analysis. This analysis was based on three studies that examined brain cancer (Wertheimer and Leeper, 1979; Tomenius, 1986; Savitz et al., 1988).

Jauchem and Merritt (1991) reviewed a wide variety of epidemiologic studies and review articles addressing cancer and other effects reportedly associated with exposures to EMF. Because of the numerous inconsistencies and deficiencies of the studies reviewed, they concluded that there is currently no definitive evidence of an association between exposure to EMF and the alleged effects.

3.3.2 Review of Specific Studies

The studies reviewed for this report are divided into three sections according to the circumstances of the presumed EMF exposure: residential exposures and occupational exposures of the cases, and prenatal (or preconception) occupational exposures of the parent(s) of the childhood cases. Reported health consequences associated with exposure to EMF include various cancers in adults and children and adverse effects on the fetus or reproduction. Under residential EMF exposures, studies conducted among both children and adults were reviewed. Among occupational groups potentially exposed to EMF, total cancers (all sites combined), tumors of the brain/CNS, total and various specific leukemias, and other selected cancer types or sites such as melanoma, eye cancer, and breast cancer are reported. In terms of adverse effects on reproduction, a number of outcomes associated with residential and occupational exposure to EMF were reported in the studies reviewed. The following is an outline of this plan of review:

RESIDENTIAL EMF EXPOSURES

<u>Childhood Cancers</u>.

(6 studies, see Table 3.1)

<u>Adult Cancers</u>.

(5 studies, see Table 3.2)

OCCUPATIONAL EMF EXPOSURES

<u>Total Cancer</u>.

(10 studies, see Table 3.3)

<u>Leukemia</u>.

(28 studies, see Table 3.4)

<u>Brain/CNS Cancer</u>.

(18 studies, see Table 3.5)

<u>Melanoma and Other Cancer Sites</u>.

(22 studies, see Table 3.6)

PATERNAL/MATERNAL OCCUPATIONAL EMF EXPOSURES

<u>Childhood Cancers</u>.

(6 studies, see Table 3.7)

<u>Congenital Malformations, Spontaneous Abortions, and/or Intrauterine Growth Retardation</u>.

(6 studies, see Table 3.7)

RESIDENTIAL EMF EXPOSURES

<u>Childhood Cancers</u>. Six major epidemiologic studies examining various childhood cancers and residential EMF exposure were reviewed (Wertheimer and Leeper, 1979; Fulton et al., 1980; Myers et al., 1985; Tomenius, 1986; Savitz et al., 1988; London et al., 1991) (Table 3.1).

Four of these case-control studies examined at total cancers (Wertheimer and Leeper, 1979; Myers et al., 1985; Tomenius, 1986; Savitz et al., 1988). Three of the four studies reported statistically significant results for total cancer. Wertheimer and Leeper (1979) reported an excess in total cancers (OR=2.22; 95% CI, 1.58-3.12) for homes near electrical wiring configurations suggestive of high-current flow. The study further reported that the association "appeared to be dose-related." Tomenius (1986) reported significant results (OR=2.10; $p<0.05$) when magnetic fields at the dwelling were higher than 0.3 microtesla (μT) (i.e., 3.0 mG). Savitz et al., 1988) reported a slight excess for total cancer for HCC wiring codes (OR=1.53; 95% CI, 1.04-2.26) but non-significant results for measured magnetic fields _ 2.0 mG. Meyers et al. (1985) found no increased risk for total cancers.

All six of the studies examined childhood leukemia and residential EMF exposure, but the results appeared to be inconsistent. Two of the studies (Wertheimer and Leeper, 1979; London et al., 1991) reported statistical significance on the basis of wire code configurations with odds ratios of 2.35 (95% CI, 1.55-3.56) and 2.15 (95% CI, 1.08-4.26), respectively. However, when London et al. (1991) analyzed the data on the basis of the measured 24-hour average magnetic field strength in the child's bedroom, the results were not significant (p for trend = 0.74). The remaining studies did not report any significant associations of leukemia with EMF.

Among the six residential EMF studies reviewed, three had no data on childhood CNS or brain cancer, and three reported elevated odds ratios: Wertheimer and Leeper (1979) with an OR of 2.86 (95% CI, 1.64-4.98), Tomenius (1986) with an OR of 3.7 ($p<0.05$), and Savitz et al. (1988) with an OR of 2.04 (95% CI, 1.11-3.76) for high current configuration (HCC) wiring codes. When Savitz et al. (1988) analyzed on the basis of magnetic field strength _ 2.0 mG, the CNS/brain cancer results were not significant (OR, 1.04; 95% CI, 0.22-4.82)

Adult Cancers. Five epidemiologic studies of adult cancers and residential EMF exposure were reviewed(Wertheimer and Leeper, 1982; McDowall, 1986; Preston-Martin et al., 1988; Severson et al., 1988; Coleman and Bell, 1989) (Table 3.2).

Significant results for total cancer were reported in only one of the studies. The case-control study by Wertheimer and Leeper (1982) reported data which produces an odds ratio of 1.28 (95% CI, 1.08-1.52; $p<0.005$) for total cancer. They also reported "significantly high C-ratios" (i.e., the ratio of the number of case-control pairs with the case exposure higher to the number of pairs with the control exposure higher) for lymphomas and cancer of the nervous system, uterus, and breast, but the individual numbers were not presented.

The cohort study by McDowall (1986) reported a significant elevation for lung cancer (SMR, 2.15; 95% CI, 1.18-3.61) when the cohort was grouped by distance from electrical installations, but leukemias (SMR, 1.43; 95% CI, 0.04-7.96) and total cancers (SMR, 1.03; 95% CI, 0.68-1.50) were not significantly elevated.

Four of the five studies yielded inconsistent and weak associations of leukemia in adults with presumed residential EMF exposure (McDowall, 1986; Preston-Martin et al., 1988; Severson et al., 1988; Coleman and Bell, 1989). There was no consistency among studies for the examination of any specific type of leukemia. Two studies focused only on total leukemia (McDowall, 1986; Coleman and Bell, 1989), and the study conducted by Severson et al. (1988) was limited to non-lymphocytic leukemia. Preston-Martin et al. (1988) examined acute and chronic myeloid leukemias and observed non-significant odds ratios which were less than one.

OCCUPATIONAL EMF EXPOSURES

Fifty-one epidemiologic studies which were designed to detect possible associations between various cancer sites and occupational EMF exposure were reviewed (Tables 3.3, 3.4, 3.5, and 3.6). These studies focused on a variety of different occupational groups generally classified as electrical workers, including electricians, electrical engineers, electric power station operators, linemen, and others. They were carried out in different countries and employed a variety of different study designs, including cohort, case-control, and PMR studies.. The reported results were found to be generally inconsistent.

Total Cancer. Ten of the 51 epidemiologic studies examined total cancers associated with presumed occupational EMF exposure (Howe and Lindsay, 1983; Vågerö and Olin, 1983; Barregård et al., 1985; Milham, 1985b; Olin et al., 1985; Vågerö et al., 1985; Törnqvist et al., 1986; Lin, 1987; Milham, 1988; Gubéran et al., 1989) (Table 3.3). One study was based on proportional data (PMR), and the remaining nine studies were of a cohort design.

Of the ten studies examining total cancer, three cohort studies (Howe and Lindsay, 1983; Vågerö and Olin, 1983; Lin, 1987) and one PMR study (Milham, 1985b) showed a weak association between presumed occupational EMF exposure and total cancer. Although the risks were only slightly elevated, they were all statistically significant. One additional study (Törnqvist et al., 1986) demonstrated a weakly positive but non-significant SMR. Four studies (Barregård et al., 1985; Olin et al., 1985; Milham, 1988; Gubéran et al., 1989) reported risk estimates for total cancer and EMF exposure that were less than 1.00.

In comparing the results of the above ten studies, it is important to remember that the definitions for "total cancers" were not identical. In addition, industry codes and job titles for the "exposed" workers differed from study to study. These disparities in definition and methodology, combined with the inconsistencies of the data, make it impossible to determine whether there is a likely causal association between total cancers and occupational EMF exposure.

Leukemia. The possible association of leukemia with occupational EMF exposure has received considerable attention and stimulated numerous occupational epidemiologic studies. Twenty-eight studies which examined the association of leukemia with EMF exposure were reviewed (Table 3.4). Eight of these studies were based on proportional data (PMR or PIR studies), 11 were cohort studies, and 10 were case-control studies, one of which also reported PMR data (McDowell, 1983). Overall, the case-control studies tended to produce the greater number of significant findings (seven out of 10 studies) followed by the PMR/PIR studies (five out of eight) and the cohort studies (five out of 11).

Five of the eight PMR or PIR studies (Milham, 1982; Wright et al., 1982; Calle and Savitz, 1985; Milham, 1985a and 1985b) demonstrated weak, but statistically significant associations. Milham (1982) studied leukemia mortality among workers exposed to EMF and reported a PMR of 1.37 (95% CI, 1.15-1.62). Wright et al. (1982), in a similar study looking at incidence data, found a PIR of 1.73 (95% CI, 1.10-2.59) for acute leukemia and a PIR of 2.07 (95% CI, 1.30-3.14) for acute myelogenous leukemia. Calle and Savitz (1985) observed a PMR of 1.86 ($p<0.05$) for total leukemia and a PMR of 2.57 ($p<0.05$) for acute leukemia among electrical engineers. They also observed a PMR of 2.35 ($p<0.05$) for total leukemia among radio and telegraph operators. In a study of amateur radio operators, Milham (1985a) reported significant elevations in the PMR's for myeloid leukemia and total leukemia (2.81 and 1.91, respectively). In a death certificate study in Washington state, Milham (1985b) observed a PMR of 1.36 ($p<0.01$) for total leukemia and a PMR of 1.62 ($p<0.01$) for acute leukemia among all electrical occupations.

In general, the validity of the findings from a PMR study depends on whether the deaths included in the PMR are representative of all deaths in the total exposed population. A PMR study is a reliable indicator of risk only when the healthy worker effect is of equal strength for the disease of interest (e.g., leukemia) and for all causes of death in the exposed population (Checkoway et al., 1989). In addition, the potential for misclassification exists, in that the information used in most PMR studies is ascertained from death certificates or cancer registries. Accuracy of the information of exposure and case definition (diagnosis) are not guaranteed. PMR studies, therefore, are less reliable as a basis for estimating risks than are other types of epidemiologic studies.

Among the 11 cohort studies, five reported one or more significant finding (Lin, 1987; Törnqvist et al., 1987; Linet et al., 1988; Milham, 1988; Garland et al., 1990). The remaining six cohort studies reported non-significant risk estimates close to (or less than) 1.00. The sample sizes in the cohort studies were generally large enough to achieve adequate statistical power, but were marginal or insufficient when total leukemias were separated into the various leukemia subtypes and when exposed workers were segregated into different job categories.

In seven of the 10 case-control studies reviewed, statistically significant associations were observed in one or more of the specific occupational groups presumed to be exposed to EMF (McDowall, 1983; Gilman et al., 1985; Pearce et al., 1985; Floden et al., 1986; Stern et al., 1986; Preston-Martin and Peters, 1988; Pearce et al., 1989). Excesses for total leukemia were seen in four case-control studies (Gilman et al., 1985; Pearce et al., 1985; Stern, 1986; Pearce et al., 1989) and elevated risks for acute myeloid leukemia were reported in four studies (McDowall, 1983; Milham, 1985a; Flodin, 1986; Pearce et al., 1989).

McDowall (1983) studied acute myeloid leukemia in selected electrical workers and found a relative risk of 2.3 (95% CI, 1.4-3.7) for all electrical occupations. Gilman et al. (1985) observed elevated risks for total leukemia (OR=2.53; $p<0.05$), myelogenous leukemia (OR=4.74; $p<0.05$), and chronic lymphocytic leukemia (OR=6.33, $p<0.05$) among underground coal miners. Pearce et al. (1985) examined all adult male cancer cases in the New Zealand Cancer Registry. Their findings suggested an increase in the risk of leukemia among electronic equipment assemblers (OR, 8.17; 95% CI, 1.49-44.7) and radio/television repairmen (OR, 4.75; 95% CI, 1.59-14.2). Coggon et al. (1986b) noted that five out of 29 patients with acute myeloid leukemia had worked in electrical trades, but the statistical significance of this finding was not reported. Flodin et al. (1986) studied cases of acute myelogenous leukemia and reported an elevated odds ratio of 3.8 (95% CI, 1.5-9.5) for all electrical workers (a category which included electrical technicians, electrical welders, and computer-telephone mechanics). Stern et al. (1986) studied leukemia among naval shipyard workers and reported significantly increased odds ratios for total leukemia among electricians (OR, 3.0; 95% CI, 1.29-6.98) and for myeloid leukemia among welders (OR, 3.83; 95% CI, 1.28-11.5). In this study, a detailed history of occupational radiation exposure was obtained and the analysis controlled for these and other occupational exposures. Preston-Martin and Peters (1988) reported a highly elevated odds ratio (OR, 25.4; 95% CI, 2.78-232.5) for chronic myeloid leukemia associated with prior employment as a welder. Pearce et al. (1989) observed an elevated risk among radio/television repairmen (OR, 7.86; 95% CI, 2.20-28.1) and power station operators (OR, 3.89; 95% CI, 1.00-15.2) but not among electrical linemen.

In general, the case-control studies demonstrated a stronger and more consistent association between leukemia and occupational EMF exposure than did the cohort studies, although, in some cases, the high odds ratios were associated with wide confidence intervals (Pearce et al., 1985; Stern et al., 1986; Preston-Martin and Peters, 1988).

Preston-Martin and Peters (1988) reported a highly elevated odds ratio (OR=25.4) in a study of 137 chronic myeloid leukemia cases, 19 of whom reported prior employment as welders. However, based on an earlier review of 15 cancer studies in welders (with a pooled total of 146 leukemia cases) Stern (1987) described an excess for lung cancer but not for leukemia. The job title groupings used in these studies, however, were not comparable. In general, studies of welders suffer from a major confounding factor which arises from the concurrent exposure to high levels of metal fumes, a number of which are known human carcinogens. Furthermore, since some welders employ gas welding methods (e.g., acetylene, hydrogen, town gas, and propane) instead of arc welding, exposure to EMF in this occupational category may be highly variable.

Increased risks for several different types of leukemia were detected in a study of underground coal miners by Gilman et al. (1985). Törnqvist et al. (1987) also reported an elevated SMR of 2.1 for acute myeloid leukemia among miners and rockblasters. Miners are presumed to be exposed to EMF through overhead lines used for distribution of power to lights and mining equipment and through electrically operated trolleys used for transportation of men and materials. However, magnetic field exposure in underground coal mines is low compared to aboveground measurements in residential areas, and electric fields have not been measured in coal mines (Gilman et al., 1985). Also, a number of significant confounders for this occupational group, such as exposure to radioactive mineral dusts, radon and radon daughters, and diesel exhaust emissions, were not taken into account. Combined, the undocumented exposure levels and presence of possible confounders weaken the argument that the excess leukemias resulted from EMF exposure. Other studies which looked at leukemia mortality among a wide range of occupational groups (Howe and Lindsay, 1983; Blair et al., 1985; Linet et al., 1988) do not confirm the excesses in leukemia among miners.

The findings of an association between leukemia and potential occupational EMF exposures in the studies reviewed are modestly suggestive of a possible causal association. However, the conflicting data and the design limitations of the studies cannot be ignored. Most important among these limitations is the uncertainty of the exposure assessments. In most of the studies reviewed, exposure to EMF was inferred on the basis of job title and/or employment in a specific industry. Furthermore, most studies failed to carefully consider and control for potential confounding factors, such as specific relevant occupational exposures, which may have accounted for some or all of the apparent increases in morbidity or mortality. Most importantly, the majority of the studies with the strongest study design (i.e., the cohort studies) did not report a significant association of EMF exposure with leukemia risk. Few of the studies of electrical workers accounted for potential confounding factors such as exposure to polychlorinated biphenyls (PCB's), solvents (e.g., benzene), or ionizing radiation from radon or radon daughters, from diagnostic radiography, and from x-rays produced by high-voltage cathode ray tubes (CRT's) commonly used prior to the 1970's.

Brain/CNS Cancer. Following leukemia, brain or CNS cancer has been the second most frequent site to be investigated with respect to occupational EMF exposure. Eighteen occupational studies of brain/CNS cancer were reviewed and are listed in Table 3.5. Although different morphologic types were examined in some studies, most did not focus on a specific type of brain/CNS cancer. One of the studies reviewed used proportional (PMR) data, seven were cohort studies, and 10 were of a case-control design.

Milham (1985b), in a death certificate study in Washington state, found a PMR of 1.23 ($p<0.05$) for decedents with occupation coded as any one of nine electrical occupations.

Two of the seven cohort studies of brain/CNS cancer reported significant SMR's or SIR's (Lin, 1987; McLaughlin et al., 1987). In a study of Taiwan Electric Power Company employees, Lin (1987) observed an SMR of 4.10 (95% CI, 1.77-8.08) for brain/CNS cancer. McLaughlin et al. (1987) found an SIR of 1.4 (95% CI, 1.02-1.87) for intracranial gliomas among welders and metal cutters and an SIR of 1.1 (95% CI, 0.98-1.23) among workers in the machinery and electronics industry.

Six out of ten case-control studies reported statistically significant odds ratios (Lin et al., 1985; Thomas et al., 1987; Speers et al., 1988; Loomis and Savitz, 1989; Pearce et al., 1989; Preston-Martin et al., 1989). An exposure-response relationship between CNS cancer and presumed EMF exposure was observed in four of the six studies (Lin et al., 1985; Thomas et al., 1987; Speers et al., 1988; Preston-Martin et al., 1989).

In a study of glioblastoma multiforme and astrocytoma deaths, Lin et al. (1985) grouped occupations according to probability of exposure to EMF. An OR of 2.15 (95% CI, 1.10-4.06) was reported for the "definite" EMF exposure category, and lower OR's were found at the lower levels of probable EMF exposure. Electric and telephone linemen/servicemen seemed to have the highest mortality (SMR, 3.73; 95% CI, 2.24-5.82), but electricians and electronic engineers/technicians were also elevated (SMR's 2.28 and 2.50, respectively). In Thomas et al. (1987), microwave and radio frequency (MW/RF) EMF exposure was estimated on the basis of length of employment in various categories of electronics and electrical jobs. A significantly elevated odds ratio of 2.3 (95% CI, 1.3-4.2) was found among men presumed to be exposed to MW/RF EMF for 5-19 years.

In a study of east Texas residents by Speers et al. (1988), occupations were grouped according to probability of exposure to EMF. Electric and telephone company employees, electricians, electronic engineers, and railroad and telecommunication engineers were among the group categorized as having "definite exposure" to EMF. The OR for the "probable exposure" group was 2.86 ($p<0.04$), and there were six cases and no controls in the "definite exposure" group, producing a significant linear trend with $p<0.01$. In a death certificate study, Loomis and Savitz (1989) reported an OR of 1.5 (95% CI, 1.0-2.1) for brain cancer among all electrical workers combined. Pearce et al. (1989) found an OR of 4.74 (95% CI, 1.65-13.6) for brain cancer among electrical engineers, but the OR for electricians was not significantly elevated. Preston-Martin et al. (1989) examined the occupational and other risk factors for primary brain tumors (gliomas, including astrocytomas, and meningiomas) among males in Los Angeles County, 1980-1984. They found that the odds ratio for prior employment in jobs likely to involve high exposure to electric and magnetic fields was significant only for gliomas and that the risk was greatest for astrocytomas.

Half of the studies reviewed (Olin et al., 1985; Vågerö et al., 1985; Coggon et al., 1986b; Törnqvist et al., 1986; Magnani et al., 1987; Milham, 1988; Gubéran et al., 1989; Reif et al., 1989; Lewis, 1990) failed to demonstrate a statistically significant association between EMF exposure and cancer of the CNS. Furthermore, two case-control studies (Reif et al. 1989; Lewis, 1990) actually showed reduced odds ratios for brain/CNS cancer in the groups presumably exposed to EMF. As with the occupational studies of leukemia, the estimates of potential EMF exposure were based on job titles and/or industry codes. Consequently, the assessment of EMF exposure in the studies of CNS cancer was generally considered to be inadequate. While an apparent dose-response relationship between surrogate measures of EMF exposure and CNS cancer was observed in a few of the studies, the significance of these findings remains questionable, given the uncertainty of the exposure assessments.

Melanoma and Other Cancer Sites. With increasing attention being given to the possibility of an association between occupational EMF exposure and leukemia or brain/CNS cancer, more studies have begun looking for associations with other sites. Twenty-two occupational studies were reviewed which examined presumed EMF exposure and specific cancer sites other than leukemia and brain/CNS cancer (Table 3.6). Two studies used proportional data including PMR's and proportional registration ratios (PRR's), 12 were cohort studies, and eight employed case-control study designs.

Swerdlow (1983) studied total eye cancer as a surrogate for eye melanoma in England and Wales and reported significant PRR's for electrical and electronic workers in 3 out of 8 years studied. However, professional/technical workers (with no specific EMF exposures) were found to have significantly elevated PRR's for 5 out of the 8 years. In a case-control study in western Canada, Gallagher et al. (1985) examined ocular melanomas among electrical and electronic workers and found no increased risk. Significantly elevated SMR's for malignant melanoma (of the skin) were demonstrated in three out of four cohort studies (Vågerö and Olin, 1983; Vågerö et al., 1985; De Guire et al., 1988). Vågerö and Olin (1983) studied various cancers among workers in the electronics industry and reported a relative risk of 1.35 (95% CI, 1.05-1.76) for skin melanoma. Vågerö et al. (1985) examined various cancers among workers involved in the manufacture of telecommunications equipment and found an SMR of 2.6 (95% CI, 1.3-4.5) for melanoma among all workers. De Guire et al. (1988) found 10 cases of skin melanoma among telecommunication workers, producing an SIR of 2.7 (95% CI, 1.35-5.02) for males (no female cases were seen). None of the three case-control studies that examined malignant melanoma among electrical and electronic workers reported significantly increased risks.

Only two out of 11 studies looking at lung cancer among persons presumed exposed to higher-than-normal levels of EMF reported significantly elevated results (Vågerö and Olin, 1983; Milham, 1985b). Vågerö and Olin (1983) studied various cancers among workers in the electronics industry and reported a relative risk of 1.52 (95% CI, 1.35-1.72) for lung cancer in males among all electronics workers. Milham (1985b) examined death certificates in Washington state and observed a PMR of 1.14 ($p<0.01$) for cancer of the lung, trachea, and bronchus among all electrical occupations. Three of the studies reported significantly lower risk for lung cancer among various electrical occupations (Blair et al., 1985; Törnqvist et al. 1986; Milham, 1988).

Two studies examining female breast cancer and EMF exposure, one occupational (Vågerö et al., 1985) and one of home electric blanket use (Vena et al., 1991), reported no increased risk. Matanoski (1989,1991) reported a standardized incidence ratio of 6.5 (95% CI, 0.79-23.5) for male breast cancer among telephone workers. This finding was based on 2 cases observed and 0.3 cases expected. Demers et al. (1990,1991) noted elevated odds ratios for male breast cancer in workers potentially exposed to EMF (OR, 1.8; 95% CI, 1.0-3.2). Most important among the studies of male breast cancer is the study by Tynes and Andersen (1990) who observed 12 cases with 5.8 expected among Norwegian workers with potential EMF exposures (SIR, 2.07; 95% CI, 1.07-3.61). These findings have been interpreted as lending support to the hypothesis that EMF may increase cancer risk by interfering with melatonin production (Theriault, 1990). They may also be interpreted as suggesting the importance of shift-work and its effects on melatonin production as an independent risk factor for male breast cancer.

Only one study (Vågerö and Olin, 1983) out of five studies examining bladder cancer and occupational EMF exposure reported a minimally increased risk (RR, 1.22; 95% CI, 1.02-1.47). Of six studies looking at stomach cancer, only one (Howe and Lindsay, 1983) observed an increased risk (SMR, 2.33; $p<0,05$) for telephone, telegraph, and power linemen and servicemen. Two out of eight studies (Howe and Lindsay, 1983; Vågerö and Olin, 1983) examining cancer of the colon or intestine (excluding rectum) reported significant elevations. One study(Milham, 1985b) out of five considering cancer of the pancreas observed a very minimal but significant increase in risk (PMR, 1.17; $p<0.05$). None of the five studies with data on prostate cancer showed significant risks. Of three studies reviewing liver cancer data, only one (Lin, 1987) reported statistical significance (SMR, 1.54; $p<0.01$). Although not an occupational study, Verreault et al. (1990), in a case-control study of white males with testicular cancer in western Washington, found that the odds ratio for disease among electric blanket users was not elevated with respect to controls.

In general, the weight of evidence from studies examining "other cancer sites" is even weaker than that for leukemia and brain/CNS cancer. Many of the positive findings came out of hypothesis-generating studies which looked at dozens of different occupation or industry codes and possibly 10 to 20 different cancer sites. Under these conditions, statistically significant results are to be expected on the basis of chance alone, and are, at best, weak arguments for possible causation. As mentioned previously, lack of exposure assessment and failure to account for possible confounding factors also weaken the evidence for an association between EMF and "other cancer sites."

PATERNAL/MATERNAL EMF EXPOSURES

Childhood Cancers. Six studies exploring the possible association of childhood neuroblastoma or cancer of the CNS with presumed paternal EMF exposures were reviewed (Spitz and Johnson, 1985; Nasca et al., 1988; Wilkins and Koutras, 1988; Johnson and Spitz, 1989; Wilkins and Hundley, 1989; Bunin et al., 1990) (Table 3.7). Three of the six studies (Spitz and Johnson, 1985; Wilkins and Koutras, 1988; Johnson and Spitz, 1989) showed a statistically significant association between neuroblastoma or childhood cancer of the CNS and paternal occupations with potential EMF exposure. The magnitude of the association reported in these three studies was similar. Wilkins and Hundley (1989) calculated the odds ratios for childhood neuroblastomas using a variety of methods to estimate potential paternal EMF exposure based on occupation and industry codes. While the resulting odds ratios were generally comparable to the previously reported positive studies, they were not statistically significant. The studies associating paternal occupational EMF exposure with cancer in offspring are difficult to interpret since an effect, if real, would imply that EMF acts as a cancer initiating agent. To date, none has suggested a cancer initiating mechanism for EMF. Most investigators believe, instead, that if EMF affects cancer risk at all, it does so by cancer promotion or growth enhancement.

The magnitude of the association of childhood CNS tumors with paternal EMF exposure was not large enough to support a causal inference. In addition, the findings were inconsistent in the studies reviewed (Nasca et al., 1988; Wilkins and Koutras, 1988; Johnson and Spitz, 1989; Wilkins and Hundley, 1989; Bunin et al., 1990) (Table 3.7). Two studies of CNS tumors and one of neuroblastomas reported statistically significant results (Spitz and Johnson, 1985; Wilkins and Koutras, 1988; Johnson and Spitz, 1989). However, the observed paternal occupations thought to be associated with childhood cancer of the CNS in these studies were not specific electrical occupations, but instead represented various job titles. There were no exposure-response relationships observed in these studies.

Congenital Malformations, Spontaneous Abortions, and/or Intrauterine Growth Retardation. Five studies (Hemminki et al., 1980; Nordström et al., 1983; Wertheimer and Leeper, 1986; Nordström et al., 1987; Wertheimer and Leeper, 1989) (Table 3.7) have been conducted to evaluate the potential adverse effects of occupational exposure to EMF on reproduction. Three of these studies demonstrated a statistically significant association between presumed occupational exposure to EMF and adverse effects of reproduction, including spontaneous abortion, frequency of abnormal pregnancy, and congenital malformation (Hemminki et al., 1980; Nordström et al., 1985; Nordström et al., 1987). One study in Italy reported an odds ratio of 5.9 for oligospermia and azoospermia among radio electric workers, but the results were not statistically significant (95% CI, 0.86–40.2).

3.4 Discussion

3.4.1 Studies of EMF and Adverse Health Effects

Since the late 1960's, increasing public attention has been directed toward the electric power companies and the extra-high-voltage (EHV) transmission lines and the lower voltage distribution lines necessary to deliver that power from the generation facilities to the substations and on to the consumers. Initially, the concerns were focused primarily on the adverse aesthetic impact of having large, unsightly towers and wires cluttering the skylines. However, the electric and magnetic fields associated with EHV transmission lines also produced a number of nuisance effects such as audible noises, TV and radio signal interference, and unpleasant shocks when touching ungrounded metal objects (e.g., cars, trucks, or farm vehicles) while standing under the EHV transmission lines (Nair et al., 1989).

With the growth of the environmental movement in the late 1960's and early 1970's, attention began shifting more toward the possibility that power transmission or distribution lines might have an adverse effect on human and animal health. These fears were reinforced when Soviet and eastern European investigators reported an increased number of neurologic, cardiovascular, hematologic, and other nonspecific ailments among workers in EHV switchyards (Asanova, 1966; Sazonova, 1967; Filippov, 1972; Korobkova, 1972). Since negative studies are frequently ignored or minimized, it did little to ease the concerns of the public when Western scientists conducted similar studies and failed to confirm the earlier findings (Strumza, 1970; Roberge, 1976; Issel, 1977; Knave, 1978).

When Wertheimer and Leeper (1979) reported an elevation in leukemia, CNS tumors, and total cancer mortality among Denver children who lived in homes that were evaluated as near "high current configuration" power transmission or distribution lines, widespread attention became focused on the issue of cancer as a possible adverse health effect of exposure to ELF electric and/or magnetic fields. As before, the negative study of Fulton et al. (1980) (which used similar methods to study childhood leukemia cases in Rhode Island) did little to ease public concern over the EMF/cancer issue.

3.4.2 Historical Trends in the Cancer Mortality Ratio

Most authors who are knowledgeable about the historical trends of cancer recognize that the disease did not suddenly begin in the 20th century and that it is not limited to the United States and other technologically advanced countries. However, some tend to cite cancer statistics in a manner which appears to support the hypothesis that the U.S. and the rest of the technological world are in the midst of a cancer "epidemic." Ralph Nader (1981) reports that cancer in the U.S. has increased dramatically in this century. Such a conclusion is based on the changing percentage of all deaths that are attributable to cancer since 1900. The supporting figures are quoted as 3 percent in 1900, 9 percent in 1930, and 20 percent in 1975. Likewise, Larry Agran (1977) reports that only one in every 25 Americans died of cancer in 1900, while nearly one in every five died of cancer in 1975.

Changes in Cancer Mortality Ratio. In 1900, about 47 percent of all deaths were due to infectious diseases; by the 1970's, the proportion had dropped to only 6 percent (Figure 3-19). Over the time period in which the proportion of deaths due to cancer was showing a dramatic rise, influenza, pneumonia, tuberculosis, and other infectious disease causes of mortality were undergoing dramatic reductions. These decreases resulted from a number of factors including improved sanitation procedures, widespread purification of drinking water, and the development of antibiotics and vaccines for many of the potentially lethal childhood and adult infectious diseases. Thus, people who once would have died in childhood or in the prime of their lives as a result of some infectious disease had begun living to a much older age. The average life expectancy at birth increased from about 47 years in 1900 to over 75 years by 1987 (Figure 3-20). These factors resulted in a shift in the age distribution of the entire U.S. population, characterized by a disproportionate increase in the number of people in the older age groups (Figure 3-21). An inevitable consequence of such a shift is an increase in the percentage of people dying of diseases which are typically associated with older age such as heart disease and cancer, although since 1970, age-adjusted mortality due to coronary heart disease and stroke has decreased markedly.

Selecting a Morbidity/Mortality Data Set for Analysis. Since survival times for various cancers may differ considerably from site to site and (with improvements in treatment methods) over time as well, it is usually preferable to look at trends in cancer incidence rates as opposed to cancer mortality rates. However, historical trends in cancer incidence rates cannot be examined unless there has been some sort of long-term registration of all newly diagnosed cases of cancer from the geographical area in question. This long-term data collection process generally requires the extensive case-finding efforts of an active, population-based, cancer registry.

The National Cancer Institute's (NCI's) Surveillance, Epidemiology, and End Result (SEER) Registries (see Appendix B) have been collecting such cancer incidence data from selected geographical locations in the country since the early 1970's; a very few states have cancer registries that go further back than the SEER registries. Consequently, there are no available sources of cancer incidence data that would permit a meaningful time-trend analysis of a large segment of the population back to the early 1930's. The only feasible alternative, then, is to examine cancer mortality data, which are derived ultimately from death certificates, which in turn have been recorded with relative consistency across the U.S. since the early 1930's and, in some states and/or cities, as far back as the early 1900's. Despite the impact of improved treatment on the ratio of incidence to mortality rates, mortality data can be relied on for a useful analysis in this regard. Poole and Trichopoulos (1991) for instance demonstrated that data from the Connecticut Cancer Registry (considered to be the best long-term, population-based data on cancer incidence in the U.S.) do not show a secular increase for childhood leukemia or CNS tumors.

The Cause-Specific Mortality Ratio. In general, the examination of time trends for the various cause-specific mortality ratios (as employed by Agran, 1977 and Nader, 1981) is of limited usefulness. Since the sum of percentages for all causes of death must always equal 100 percent, when the percentage for one cause of death goes down, the percentage for one or more other causes of death must, of necessity, go up. When such a shift in the cause-specific mortality ratios occurs, it is not always clear which change is the cause and which is the effect. Consequently, it is necessary to utilize a more stable and meaningful measure for evaluating time trends for the various causes of death.

Annual or Crude Mortality Rate. One such measure is the annual mortality rate or cause-specific mortality rate which is expressed as the number of people dying from a particular cause per 100,000 population per year. Rather than being normalized to the total number of people who died in a particular year, the annual mortality rate for each cause of death is normalized to the total population from which the deaths occurred. This measure is often referred to as the crude mortality rate to distinguish between this figure and an age-adjusted mortality rate discussed below. However, annual mortality rates also have some weaknesses which can lead to misinterpretations of the mortality data.

The U.S. population has been shifting toward the older age groups (Figures 3.20 and 3.21). As this happens, the crude mortality rates for diseases which are characteristic of the older age groups will increase (Figure 3-1), and it may appear, on superficial analysis, that there is an emerging problem with those diseases (Figure 3-19). Thus, it is necessary to control for differences or changes in age distribution when comparing two different populations or when analyzing one population as it changes over long periods of time (Figure 3-4).

Age-Specific Mortality Rates. One method of controlling for changes in age distribution is to compare the age-specific mortality rates for a particular disease in the two populations. For this analysis, the annual deaths are generally tallied for each five-year or ten-year age group, and the number of deaths for each age group is divided by the population in that age group. The result for each age group is then multiplied by 100,000 and expressed as the number of deaths per 100,000 population per year. Thus, the age-specific mortality rates for any age group of one population can be compared appropriately with the same age group of any other population. However, when the mortality rates are likely to be different depending on race and/or sex, it may also be necessary to look at age-, race, and sex-specific mortality rates for the two populations before a valid comparison can be made.

Age-Adjusted Mortality Rates. Another method of controlling for age distribution differences is to calculate the age-adjusted mortality rate for each population. This method has some advantage over the age-specific mortality rates because the age-adjusted mortality rate is expressed as a single rate for the entire population. However, this characteristic may sometimes conceal a difference in the two populations that the age-specific mortality rates will reveal. For example, if a particular disease were occurring at a higher-than-expected rate for a particular age group in one of the populations, this effect could be canceled by a lower-than-expected rate in some other age group. In this situation, the age-adjusted mortality rates could be the same for the two populations, and the difference would become apparent only if the age-specific mortality rates were compared for each age group.

Interpretation of Observed Trends. When cancer mortality rates are properly adjusted for changes in population age distributions over time, the resulting trends become significantly more meaningful in an epidemiologic context. While the individual mortality rates for some of the cancer sites are in a state of flux, most of the changes are relatively small and have little impact on the total cancer mortality, as some are increasing while others are decreasing. One of the notable exceptions is the time-trend for lung cancer which has undergone a major increase over the past 50 years, placing this site on the top of the list for cancer mortality (Figure 3-5).

While the exact relationship between individual EMF exposure and the crude surrogate measure (total U.S. power consumption trends) has not been clearly established, it is not unreasonable to assume that there should be some degree of positive correlation between the two. If such exposures are indeed causing a significant increase in a number of different types of cancer, then there also should be some sign of correlation between power consumption and cancer mortality trends. In the preceding analysis, none of the long-term cancer mortality trends for the sites of concern show any patterns which would suggest an association with EMF exposure when plotted together with the surrogate measure, unlike the plot of cigarette consumption in pounds per capita together with lung cancer mortality (Figure 3-6). While this form of analysis does not disprove such a possible association, the inconsistency between the hypothesis and the observations suggests that the epidemiologic evidence should be somewhat more substantial before a causal association can be reasonably assumed.

3.4.3 Carcinogen Policy and Regulation

As early as 1964, the "WHO Expert Committee on the Prevention of Cancer," chaired by Sir Richard Doll, concluded "that the majority of human cancer is potentially preventable" (WHO, 1964). In 1969, Higginson estimated that 90 percent of cancers were influenced by "environmental factors" and, thus, were preventable (1969). Subsequently, writers have quoted Higginson's 90-percent figure and equated the term "environmental factors" with "man-made chemicals" or "environmental pollution." It is essential to note that Higginson used the word "environmental" in a much broader sense to indicate all external factors including tobacco and alcohol usage; dietary, social, and cultural habits; reproductive and infectious disease history; radiation exposures; occupational exposures; and exposure to either man-made or natural carcinogens in the air, water, or food.

In 1970, the Ad Hoc Committee on the Evaluation of Low Levels of Environmental Carcinogens made a number of recommendations to the Surgeon General that have since become almost axiomatic among most scientists and regulators when addressing the issue of environmental carcinogens:

1. Any substance that has been shown to cause cancer in animals should be considered carcinogenic and, therefore, a probable or possible cancer risk for humans;
2. No level of exposure to a known chemical carcinogen should be considered toxicologically insignificant for humans (i.e., no no-effect threshold can be assumed);
3. No chemical substance should be assumed safe for human consumption without proper negative lifetime carcinogenic bioassays;
4. In carcinogenic bioassays, negative results should be superseded by positive findings, and positive results should remain definitive unless new evidence conclusively proves prior results were in error; and
5. The principle of a zero tolerance for carcinogenic exposures should be established for all areas of legislation, and only in cases where carcinogenic contamination is unavoidable should exceptions be made to the zero tolerance rule.

These recommendations formed the basis for the FDA's "Delaney Clause" (which, in principle, bans every carcinogenic additive from the food supply) and also gave rise to the generally accepted philosophy that chemicals should be presumed "guilty until proven innocent." In the face of contradictory data (as when one study reports that a substance causes cancer while another reports that it does not), regulatory scientists maintain that "prudence" requires that the positive study should be accepted over the negative. This policy has been extended so that all that is required to establish the carcinogenicity of a chemical is a technically inadequate study, and that such a study may even outweigh a well done study which does not show a cancer effect.

While such a system for interpreting carcinogenic bioassays is not warranted on a strictly scientific basis, as it is clearly biased toward making Type I errors (i.e., taking regulatory action when none is needed), it is also clearly preferable to a system that fails to take any action until there is clear proof that a substance is having a detrimental effect on human health. However, full implementation of the "guilty until proven innocent" philosophy would be tantamount to ignoring the scientific basis for regulation, and it would render meaningless what is now, and has been, a prudent and effective system for protecting public health. Furthermore, it would seriously damage the credibility of regulatory scientists if every chemical that had not been tested for carcinogenicity were suddenly declared to be a suspected carcinogen and, therefore, were to be "banned" from food and drinking water supplies. In recent years, there has been growing recognition of the limitations of the rodent lifetime carcinogenisis bioassay (Lave et al., 1988). Even if all the testing could be done and all the positive substances identified, there would still be a tremendous technological gap which would make it virtually impossible to insure that all of the suspect substances were permanently eliminated from the food and water supplies. Unless all alcohol, tobacco, air pollution, and foods containing natural carcinogens were also banned or eliminated, it is highly unlikely that the removal from the food and water supply of all trace carcinogens that have resulted from humans and their technology would have any appreciable effect on cancer incidence or mortality rates.

3.4.4 Carcinogenic Risk Assessment and Risk Management

Risk managers at federal regulatory agencies are seeking to achieve multiple objectives which include:

- protection of public health from widespread exposure to toxic agents;
- protection of highly exposed and/or sensitive groups from toxic agents on the basis of equity or fairness, even when exposure is not widespread;
- protection of the natural environment and ecosystems from the adverse effects of toxic agents on behalf of both current and future generations;
- responsiveness to public concerns about human health and environmental risks, even when risk assessors are skeptical about the magnitude of the risks posed by toxic agents; and
- economic efficiency achieved by adopting protective regulations when the marginal social benefits of risk management exceed the marginal social costs of risk management (at least where an agency's legislative mandate does not prohibit consideration of economics).

Over the years, an adversarial relationship between the Executive Office of Management and Budget (OMB) and the federal regulatory agencies has developed in part because it is usually impossible to simultaneously achieve all of these objectives. The parties in this adversarial relationship appear to assign differing degrees of importance to the achievement of the various regulatory objectives. Given the different objectives, it should be expected that OMB and the agencies might have different ideas about what is a good risk assessment and what is a good risk management decision.

Federal rules are adopted on the basis of legislative mandates which provide risk managers with varying degrees of discretion. When discretion is restricted, it may reflect congressional determination to achieve specific regulatory objectives. Some statutes (e.g., the Toxic Substances Control Act) authorize risk managers to weigh the risks, costs, and benefits of alternative courses of action even though such factors are not always considered. Other statutes (e.g., the Delaney Clause covering carcinogenic food additives and the National Ambient Air Quality Standards under the Clean Air Act) compel the federal government to base decisions exclusively on health considerations. Still other statutes order risk managers to reduce human health risk to the maximum extent that is technically and economically feasible (e.g., the permissible exposure limits designed to protect worker health under the Occupational Safety and Health Act).

Although regulatory statutes differ markedly, they rarely specify how agencies are to perform risk assessments of human exposures to potentially harmful agents. Risk assessment practices have therefore evolved at federal agencies and become routine through formal and informal agency guidelines. While statutory mandates and risk assessment practices differ among agencies, the various regulatory cultures share a common policy viewpoint: namely, that risk managers should err onthe side of safety when making regulatory decisions in the face of scientific uncertainty.

Risk assessment is an analytical tool rather than an end in itself. Since the tool is used for a wide variety of risk management decisions, it is critical that risk assessors and managers forge a constructive collaboration. Risk assessments should address the needs of risk managers in a rigorous, objective, and timely fashion. Some assessments need to be more refined than others, depending on the importance of the decision.

For chemicals that are known or suspected to cause cancer, federal agencies have adopted standard risk assessment procedures. When data are insufficient to complete a full risk assessment, specific "default" assumptions are considered appropriate . The default assumptions are designed to err on the side of safety in the absence of scientific knowledge. In contrast to more defined risk assessments, these standard assessments do not require extensive case-specific data.

Despite their scientific limitations, standard risk assessments of carcinogens are useful screening tools (i.e., they help identify potential problems and indicate exposures that are not worthy of further concern). They may also provide a basis for regulatory decisions in cases where risks are potentially significant and the estimated costs of risk reduction are too small to justify a more refined risk assessment.

Congress and federal agencies are now considering new approaches to risk assessment. The Committee on Risk Assessment Methodology of the National Academy of Sciences (NAS) is looking into ways to improve the risk assessment process. Another NAS Committee on risk assessment is being formed in response to the mandates of the Clean Air Act Amendments of 1990. The President's Science Advisor, Dr. D. Allan Bromley, has launched an interagency committee to explore improvements in risk assessment practice, while several federal agencies have internal groups working toward the same goal. The EPA is considering revision of its risk assessment guidelines, and the EPA Science Advisory Board recently expressed its intent to offer comments aimed at accelerating EPA's review of the guidelines. Hearings on risk assessment were recently held by a subcommittee of the U.S. House of Representatives, which is another indication of the growing interest in reform of the risk assessment practices.

3.5 Conclusions

Several studies in the United States and abroad have examined the relationship between cancer and exposure to EMF. There is still considerable disagreement regarding which outcomes may be related to exposure of EMF. Leukemia, brain cancer, and skin melanoma are reported in several studies to be associated with exposure to EMF. An unidentified common denominator among these three sites of cancer is suspected, but none has been identified. However, conclusions reached from the available epidemiologic evidence are limited. However, findings of the studies of leukemia remain suggestive because, in several of the epidemiologic studies, an increased occurrence of leukemia is observed among workers and residents presumed to be exposed to EMF.

Cancer of the CNS is the second site given considerable attention as possibly associated with EMF exposures. Findings from studies of CNS cancer also remain inconclusive. Only half of the epidemiologic studies reviewed report an excessive mortality of CNS cancer among workers potentially exposed to EMF. However, an exposure-response relationship is observed most consistently only for the studies of CNS cancer.

Studies have suggested other adverse effects of EMF including other cancer sites, other mechanisms (e.g., paternal exposure), reproductive effects, and neurological effects. To date, these findings also remain suggestive, but not conclusive of a role for EMF exposures in the development or progression of disease.

There is a need for further studies to resolve current inconsistencies in available research results. To contribute to the resolution of these research questions, future studies will need to use more refined methods of assessing EMF exposures, to address the role of potentially confounding exposures as well as sources of bias, and to fastidiously select reference populations.

3.6 Recommendations

The following statements represent some suggestions for future studies. In many of the epidemiologic studies reviewed, adverse health effects have been reported for electrical workers and children with paternal or residential exposure to EMF.

1. While it is clear that something is responsible for a reported difference in cancer risk in the available studies, it is premature to conclude that EMF is the factor involved. In occupational studies, other exposures (e.g., ionizing radiation, solvents, PCB's), which may confound the association between EMF and cancer, have either been neglected or not considered fully. In addition, the healthy worker effect seen in studies of occupational groups when compared to the general population is much more pervasive than differences in exposures at work. It may also imply differences in socioeconomic status and access to medical care, thus resulting in earlier and more accurate diagnosis of disease. In residential studies, the incorporation of EMF exposures from other sources, both inside and outside the home, must be considered, as well as other potential confounders such as exposure to indoor air pollutants.

2. In order to be able to identify a specific disease agent or disease mechanism, there is a need to improve the assessment of EMF exposure for electrical workers and for community residents as well. The assessment of exposure to EMF is the most important issue in future research of this association. Because of the diversity of the cancers and other adverse health effects reported to date, if EMF is truly causing any of these effects, it is reasonable to expect that several mechanisms may be involved. This may be especially true for the childhood cancers which would involve relatively short exposure times and much shorter latency periods compared to adult cancers resulting from lengthy occupational exposures.

3. Assessment of EMF exposure should not be limited to the use of industrial codes and job titles in occupational studies and wiring configurations in residential studies. The exposure to EMF includes transmission and distribution lines, video display terminals, various electrical appliances, and background sources. Estimation of overall exposure is critical when a number of different sources are considered for the same person. Since considerable variability is observed in magnetic field exposure within a single job category depending on different tasks performed, it will be important to estimate the average as well as other characteristics of exposure over an 8-hour shift, and to give some consideration to nonoccupational exposures.

In residential studies, it is important to determine whether wiring configurations, field measurements or some other methods provide the better basis for estimating historical exposures. In occupational studies, the job-exposure matrix approach may prove to be a useful approach. However, it remains to be determined whether the job-exposure matrix approach or personal measurements will provide the better method for estimating historical EMF exposures. If the job-exposure matrix approach is preferred, it will be necessary to develop high-quality data for use in such an approach.

4. Improved methods to measure exposure to electric and magnetic fields are needed, some of which are under development. Future epidemiologic studies should adopt quantitative measures of exposure. The questions to be addressed in accurately assessing EMF exposure are the sources of exposure and the aspects of exposure (frequency, intensity, intermittency, diurnal timing, resonance factors, etc.). Detailed information on the history of EMF exposure needs to be obtained. Identification of appropriate latencies should be pursued. The importance of induction time and the importance of duration of exposure also should be assessed.

5. It is important to consider unrecognized confounders and sources of bias in existing and future epidemiologic studies, even though few confounders are presently known for the cancer sites reported to be associated with EMF exposure. Results from many studies have been severely criticized because of the lack of control for confounding and bias.

6. Particular efforts should be made to avoid possible systematic errors or misclassification in future studies. For instance, while the use of waterbed heaters or electric pads may appear to be independent of electric blanket use (the one tending to preclude the other), in reality they would be negatively correlated. Asking only about use of electric blankets might result in a systematic error. In addition, abstracting histories of EMF exposure from death certificates is a possible source of differential misclassification if the person coding the occupational information is also aware of the cause of death and the research question. Similarly, inquiries regarding a history of EMF exposure in interview studies may result in a recall bias. Such systematic errors could result in overestimating or underestimating the association of exposure to EMF with disease. However, overestimation is much more likely.

7. The use of more than one reference cohort of at-least-equal size to that of the exposed cohort is suggested. Some previous studies have provided conclusions which are of questionable validity because insufficient attention was paid to comparable unexposed populations. The use of multiple reference cohorts would facilitate an assessment of the homogeneity of risk and the tenability of *a priori* judgments (Miettinen et al., 1990). All the reference cohorts should be comparable to the exposed cohort in terms of the *a priori* judgments regarding the relevant issues, except EMF exposure. Comparison of exposed workers with several reference cohorts of unexposed workers may also be helpful to overcome the bias which results from the healthy worker effect.

8. For future studies it will be important to define a clearly exposed population and to quantitate the EMF exposure in this population. Electrical transportation operators in Europe may be an excellent choice of a study population since they are exposed to constant levels of EMF over the work shift.

9. Outcomes due to pre- and post-natal exposures should be examined separately. Children are considered to be more vulnerable than adults to potential carcinogenic effects of EMF, and *in utero* exposures are thought to be more serious than post-natal exposures.

10. The association of cancer with exposure to EMF must be examined in light of current knowledge from previous epidemiologic studies conducted in human populations and from experimental studies involving laboratory animals. Cancer increases postulated from EMF exposure are presumed to be dose-dependent and cumulative. There is a need to delineate the biological basis for hypothesized health effects in humans, and to establish whether a dose-response relationship exists.

11. The results from epidemiologic studies should provide guidance for the design of future laboratory investigations. To fully assess the question of causality, mechanistic investigations in the laboratory are necessary.

12. It will be 3-5 years before the results of the studies currently underway are available. In the meantime, except for studies to pursue specific questions that have been proposed by previous studies, a large undirected expansion of epidemiologic research of EMF is not indicated. Several large epidemiologic studies of the association of EMF with cancer and adverse reproductive outcomes are currently underway in the United States, Canada, and in other parts of the world. Studies in progress include investigations of childhood cancer, specifically leukemia and CNS tumors, and studies of occupationally exposed populations. Although these most recent studies are still hampered by the lack of knowledge regarding the relevant EMF exposure components that may account for the EMF-cancer association, they have been designed to address the major limitations of the earlier studies. The results of these studies will, no doubt, provide valuable information regarding the nature of any associations between EMF and cancer or EMF and adverse reproductive outcomes.

TABLE 3.1. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER INCIDENCE/MORTALITY

CHILDHOOD CANCERS AND RESIDENTIAL EMF EXPOSURES

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Wertheimer & Leeper, 1979	Denver, CO	Children with and without cancer, 1950-73	Wiring configuration codes for PDL near residence	CC	344 total cases, 328 cases used in analysis	HCC wiring configuration at death address*: Total cancer: OR=2.22 (1.58-3.12, p<0.0001) Leukemia: OR=2.35 (1.55-3.56, p<0.0001) Lymphoma: OR=2.39 (1.19-4.76, p<0.02) CNS/Brain: OR=2.86 (1.64-4.98, p<0.0005)
Fulton et al., 1980	Rhode Island	Children with and without leukemia, 1964-78	Wiring configuration codes for PDL near residence	CC	119 total cases, 110 cases used in analysis	High EMF exposure: Leukemia: OR=1.09 (NS)
Myers et al., 1985 (*Abstr*) and 1990	Yorkshire, U.K.	Children with and without cancer, 1970-79	Proximity of residence to HV & representative field monitoring (calculated fields)	CC	374 cases	Residence < 50 meters from EMF source: Total cancer: OR=0.98 (NS) Leukemia: OR=1.14 (NS)
Tomenius, 1986	Stockholm, Sweden	Children with and without cancer, 1958-73	Proximity of residence to HV & monitoring outside house (measured fields)	CC	660 cases	Magnetic fields ≥ 0.3μT: Total tumors: OR=2.1 (N=34, p<0.05) Total cancer: OR=1.8 (N=30, NS) Leukemia: OR=0.3 (N=4, NS) CNS/Brain: OR=3.7 (N=13, p<0.05)
Savitz et al., 1988	Denver, CO	Children with and without cancer, 1976-83	Proximity of residence to HV/PDL, in-house measurements, wiring configuration	CC	356 cases	Magnetic fields ≥ 2.0 mG, diagnosis address: Total cancer: OR=1.35 (0.63-2.90, NS) Leukemia: OR=1.93 (0.67-5.56, NS) Lymphoma: OR=2.17 (0.46-10.31, NS) CNS/Brain: OR=1.04 (0.22-4.82, NS) Soft tissue: OR=3.26 (0.88-12.07, NS) HCC wiring configuration, diagnosis address: Total cancer: OR=1.53 (1.04-2.26, p<0.04) Leukemia: OR=1.54 (0.90-2.63, NS) Lymphoma: OR=0.80 (0.29-2.18, NS) CNS/Brain: OR=2.04 (1.11-3.76, p<0.04) Soft tissue: OR=1.56 (0.68-3.55, NS)

* Odds ratios and 95% confidence intervals calculated on basis of wiring configurations at death address using Miettinen procedure described by Fleiss (1979).

TABLE 3.1. CHILDHOOD CANCERS AND RESIDENTIAL EMF EXPOSURES (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
London et al., 1991	Los Angeles, CA	Childern with and without cancer, 1980-87	Wire configuration codes and magnetic field measurements (24-hour and spot)	CC	232 Leukemia cases 232 Matched controls	Leukemia risk in relation to magnetic field measurements (24-hr. average in child's bedroom): 0.00-0.67 mG: OR=1.00 (N=85) 0.68-1.18 mG: OR=0.68 (N=35, 0.39-1.17) 1.19-2.67 mG: OR=0.89 (N=24, 0.46-1.71) ≥ 2.68 mG: OR=1.48 (N=20, 0.66-3.29) (p for trend = 0.74) Leukemia risk in relation to Wertheimer-Leeper WCC: UGC & VLCC: OR=1.00 (N=31) OLCC: OR=0.95 (N=58, 0.53-1.69) OHCC: OR=1.44 (N=80, 0.81-2.56) VHCC: OR=2.15 (N=42, 1.08-4.26) (p for trend = 0.008)

ABBREVIATIONS USED:

CC - Case-Control Study
CI - Confidence Interval
CNS - Central Nervous System
HCC - High Current Configuration
HV - High Voltage
μT - Microtesla (1μT = 10mG)
mG - Milligauss

NS - Not Significant
OHCC - Ordinary High Current Configuration
OLCC - Ordinary Low Current Configuration
OR - Odds Ratio
PDL - Power Distribution Lines
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio

RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio
UGC - Underground Configuration
VHCC - Very High Current Configuration
VLCC - Very Low Current Configuration
WCC - Wiring Configuration Code

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TABLE 3.2. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER INCIDENCE/MORTALITY

ADULT CANCERS AND RESIDENTIAL EMF EXPOSURES

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Wertheimer & Leeper, 1982	Denver, Boulder, & Longmont, CO, USA	Adults with and without cancer, 1967-75	Wiring configuration codes for PDL + some representative field monitoring	CC	1,179 cases	Total cancer (pair comparisons): C-ratio=139 (N=509, p<0.0001) Total cancer (HCCs to LCCs)*: OR=1.28 (1.08-1.52, p<0.005) Significantly high C-ratios were reported for lymphomas and cancers of the nervous system, uterus, and breast, but data were not presented.
McDowall, 1986	East Anglia, U.K.	Residents living near electricity transformation installations, 1971-83	Proximity of residence to HV lines and substations	Cohort	814 deaths	Distance from electrical installation, 0-14 meters: Total cancer: SMR=1.03 (0.68-1.50, NS) Lung cancer: SMR=2.15 (1.18-3.61) Leukemia: SMR=1.43 (0.04-7.96, NS)
Preston-Martin et al., 1988	Los Angeles, CA, USA	Adults with and without leukemia, 1979-85	Electric blanket use	CC	116 AML 108 CML	Electric blanket users: AML: OR=0.9 (0.5-1.6, NS) CML: OR=0.8 (0.4-1.6, NS)
Severson et al., 1988	Washington State, USA	Adults with and without leukemia, 1981-84	Wiring configuration and 24-hr & spot field measurements in house	CC	114 ANLL cases 133 controls	ANLL risk in relation to longest residence before Diag: VLCC: OR=1.00 (N=42) OLCC: OR=0.60 (N=21, 0.29-1.22, NS) OHCC: OR=0.77 (N=21, 0.35-1.68, NS) OLCC: OR=0.79 (N= 5, 0.22-2.89, NS)
Coleman & Bell, 1989	London, U.K.	Persons with and without leukemia, 1965-80	Proximity of residence to HV lines & stations	CC	771 cases 1432 controls	Total Leukemia (p for linear trend = 0.04): 0-24 meters: RR=1.26 (N=35, 0.77-2.12, NS) 25-49 meters: RR=0.89 (N=62, 0.63-1.28, NS) 50-99 meters: RR=0.99 (N=244, 0.67-1.46, NS) ≥ 100 meters: RR=1.00 (N=430)

* Odds ratio and 95% confidence interval calculated from data presented (HCC group = VHCC + OHCC and LCC group = OLCC + End-pole).

ABBREVIATIONS USED:

AML - Acute Myelogenous Leukemia
ANLL - Acute Nonlymphocytic Leukemia
CC - Case-Control Study
CML - Chronic Myelogenous Leukemia
C-Ratio - (# case-cont. prs. with case exposure higher / # case-cont. prs. with cont. exposure higher) x 100
HCC - High Current Configuration
HV - High Voltage
LCC - Low Current Configuration
NS - Not Significant
OHCC - Ordinary High Current Configuration
OLCC - Ordinary Low Current Configuration
OR - Odds Ratio
PDL - Power Distribution Lines
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio
RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio
VHCC - Very High Current Configuration
VLCC - Very Low Current Configuration

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TABLE 3.3. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER INCIDENCE/MORTALITY

TOTAL CANCER AND OCCUPATIONAL EMF EXPOSURE

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Howe & Lindsay, 1983	Canada	Cancer mortality among 415,201 males of the Canadian Labor Force, 1965-73	Occupation and industry codes (by both 2-digit and 3-digit codes)	Cohort	4,203 total cancer deaths	Telegraph operators: Total cancer: SMR=1.99 (N=9, 0.91-3.78, $p<0.05$)
Vågerö and Olin, 1983	Sweden	Cancer incidence among 54,624 male and 18,478 female workers, ages 15-64, working in the electronics industry in Sweden, at time of 1960 census	Employment in the electronics industry	HP/ Cohort	1,855 total cancer cases in males and 1,009 cases in females	Males employed in electronics industry: Total cancer: RR=1.15 (1.10-1.20) Females employed in electronics industry: Total cancer: RR=1.08 (1.01-1.15)
Barregård et al., 1985	Sweden	Cancer incidence for 157 employees at a chloralkali plant, 1958-83	Job titles, direct measurement, and person-years of exposure	Cohort	6 cancer cases 17 total deaths	Chloralkali plant workers: No increased risk associated with static (DC) magnetic field exposures: Total cancer: SIR=0.78 (0.29-1.70)
Milham, 1985b	Washington State	12,714 deaths among male residents, age≥20, who worked in 9 electrical occupations, 1950-82	Death certificate occupation coded to any one of 9 electrical occupations	PMR	2,649 total cancer deaths (out of 12,714 total deaths)	All electrical occupations: Total cancer: PMR=1.06 (N=2649, $p<0.01$)
Olin et al., 1985	Sweden	Mortality among 1,254 electrical engineering graduates from the Royal Institute of Technology, 1930-79	Graduated with a master of science degree in electrical engineering	Cohort	24 cancer deaths, 108 total deaths	Electrical engineers: Total cancer: SMR=0.5 (N=24, 0.3-0.7)
Vågerö et al., 1985	Sweden	Cancer morbidity among 2,918 workers at three work sites manufacturing telecommunications equipment, 1958-79	Employment at work sites involved in research, development, and manufacturing of telecommunication equipment	Cohort	102 male cancer cases and 37 female cases	Telecommunication workers: Total cancer: Males: SMR=1.03 (N=102, 0.8-1.2) Females: SMR=0.98 (N=37, 0.7-1.44)

TABLE 3.3. TOTAL CANCER AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Törnqvist et al., 1986	Sweden	Cancer incidence among 3,358 power linesmen and 6,703 power station operators, 1961-79	Job title codes	Cohort	236 cases among power linesmen, 463 cases among station operators	Power linesmen: Total cancer: SMR=1.07 (N=236, 0.93-1.21) Power station operators: Total cancer: SMR=0.98 (N=463, 0.89-1.07)
Lin, 1987 (*Abstr*)	Taiwan	Cancer mortality from 733 death certificates of male employees, ages 25-64, of Taiwan Electric Power Company, 1971-85	Employment with Taiwan Electric Power Company	Cohort	733 total deaths including 180 total cancer deaths	Electric power company workers: Total cancer: SMR=1.15 (0.99-1.34, p<0.05)
Milham, 1988	Washington and California	67,829 Licensed amateur radio operators, 1979-84	Amateur radio operators	Cohort	2,485 total deaths	Amateur radio operators: Total cancer: SMR=0.89 (0.82-0.95, p<0.05)
Gubéran et al., 1989	Switzerland	1,916 Painters and 1,948 electricians with residence in Canton of Geneva, 1971-84	Job titles	Cohort	78 cancer cases, 52 cancer deaths	Cancer incidence data: Electricians: Total cancer: SIR=0.92 (N=78, 0.73-1.15) Painters (not specific for EMF exposure): Total cancer: SIR=1.20 (N=159, 1.02-1.41) Cancer mortality data: Electricians: Total cancer: SMR=1.14 (N=52, 0.85-1.50) Painters (not specific for EMF exposure): Total cancer: SMR=1.27 (N=96, 1.03-1.55)

ABBREVIATIONS USED:

CC - Case-Control Study
CI - Confidence Interval
EMF - Electric and/or Magnetic Fields
HP - Historical Prospevtive Study
NS - Not Significant
OR - Odds Ratio
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio
RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio

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TABLE 3.4. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER INCIDENCE/MORTALITY

LEUKEMIA AND OCCUPATIONAL EMF EXPOSURE

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Wiklund et al., 1981	Gothenburg, Sweden	Telephone operators, Telecommunications Administration, listed in the Cancer-Environment Registry in Sweden, 1961-73	Occupation coded as telephone operator	Cohort	12 cases of leukemia	Telecommunications workers: No increased risk for leukemia: SMR=1.03 (0.53-1.79, $p<0.51$)
Milham, 1982 (*Letter*)	Washington State	438,000 deaths of male residents, age ≥ 20 yrs, 1950-79	Occupation coded as any one of 11 electrical occupation groups	PMR	136 total leukemia deaths 60 acute leukemia deaths	All electrical occupations: Total leukemia: PMR=1.37 (N=136, 1.15-1.62, $p<0.01$) Acute leukemia: PMR=1.63 (N=60, 1.25-2.10, $p<0.01$)
Wright et al., 1982	Los Angeles County, CA	Cases of leukemia in white males in Los Angeles County, CA: 1972-79	Occupation coded as any one of 11 electrical occupation groups	PIR	35 cases with leukemia	All electrical occupations: Total leukemia: PIR=1.29 (N=35, 0.90-1.79, NS) Acute leukemia: PIR=1.73 (N=23, 1.10-2.59, $p<0.05$) AML: PIR=2.07 (N=22, 1.30-3.14, $p<0.05$)
Coleman et al., 1983	South-East England	125,887 tumors in males, age 15-74, all sites, registered in the South Thames Cancer Registry, 1961-79	Occupation coded as any one of 10 electrical occupation groups	PIR	113 cases with leukemia	All electrical occupations: Total leukemia: PIR=1.17 (N=113, 0.97-1.41, $p<0.055$) ALL: PIR=1.46 (N=12, 0.75-2.55, $p<0.13$) CLL: PIR=1.29 (N=33, 0.89-1.81, $p<0.09$) AML: PIR=1.23 (N=33, 0.85-1.73, $p<0.14$) CML: PIR=0.91 (N=16, 0.52-1.48, $p<0.41$)
McDowall, 1983	England and Wales	First part: All deaths in males from leukemia compared with all deaths in males, other causes, ages 15-74, 1970-72	Occupation coded as any one of 10 electrical occupation groups	PMR	85 leukemia deaths	All electrical occupations: Total leukemia: PMR=0.98 (N=85, NS) Lymphoid leukemia: PMR=1.00 (N=28, NS) ALL: PMR=1.04 (N=11, NS) Myeloid leukemia: PMR=1.07 (N=49, NS) AML: PMR=1.04 (N=31, NS)
McDowall, 1983	England and Wales	Second part: 537 AML deaths in males, age≥15, 1973. Controls from other cause of death	Occupational and industrial groups presumed to be at greatest risk for EMF exposure	CC	537 AML deaths 1074 controls	All electrical occupations plus any occupation in the electrical or telecommunications industry: RR=2.3 (N=36, 1.4-3.7) All electrical occupations: RR=2.1 (N=30, 1.3-3.6)

TABLE 3.4. LEUKEMIA AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Blair et al., 1985	U.S.	Cancer mortality among 293,958 U.S. Veterans, age 31-84, who held U.S. government life-insurance policies in December 1953 and of whom 107,563 were deceased as of Jan 1, 1970	Usual occupation as reported by subject in questionnaires administered in 1954 and 1957	Cohort	107,563 total deaths from all causes	Electricians: Leukemia: SMR=0.75 (N=5, 0.24-1.74) Electrical engineers: Leukemia: SMR=1.01 (N=10, 0.48-1.86)
Calle & Savitz, 1985 (*Letter*)	Wisconsin	Leukemia mortality to total mortality among Wisconsin white males, age≥20 years, employed in 10 electrical occupations, 1963-78	Occupation coded as any one of 10 electrical occupation groups	PMR	81 total leukemia deaths, including 41 acute leukemia	Electrical engineers: Total leukemia: PMR=1.86 (0.99-3.18, p<0.03) Acute leukemia: PMR=2.57 (1.11-5.07, p<0.02) Radio and telephone operators: Total leukemia: PMR=2.35 (0.86-5.12, p<0.05) Acute leukemia: PMR=3.00 (0.62-8.77, p<0.09) All electrical occupations: Total leukemia: PMR=1.03 (0.82-1.29, p<0.40) Acute leukemia: PMR=1.13 (0.81-1.54, p<0.24
Gilman et al., 1985	U.S.	Leukemia mortality among approximately 19,000 white male underground coal miners	Occupational history, obtained by questionnaire at the time the 4 NIOSH follow-up cohorts were established	CC	40 leukemia deaths and 160 age-matched controls (coming from 6,066 total deaths)	Total leukemia: OR=2.53 (N=40, p<0.05) Acute leukemia: OR=2.85 (N=22, NS) Chronic leukemia: OR=8.22 (N=14, p<0.05) Lymphocytic leukemia: OR=2.32 (N=14, NS) CLL: OR=6.33 (N=11, p<0.05) Myelogenous leukemia: OR=4.74 (N=17, p<0.05) AML: OR=3.80 (N=14, NS)
Milham, 1985a	Washington State and California	1,691 deaths among members of the American Radio Relay League, 1971-83	License class as amateur radio operator	PMR	24 leukemia deaths (1,691 total deaths)	Amateur radio operators: Total leukemia: PMR=1.91 (N=24, 1.22-2.83, p<0.01) Myeloid leukemia: PMR=2.81 (N=16, 1.60-4.56, p<0.01) AML: PMR=2.89 (N=11, 1.45-5.18, p<0.01) CML: PMR=2.67 (N=4, 0.73-6.83, p<0.05)
Milham, 1985b	Washington State	12,714 deaths among male residents, age≥20, who worked in 9 electrical occupations, 1950-82	Death certificate occupation coded to any one of 9 electrical occupations	PMR	2,649 total cancer deaths (out of 12,714 total deaths)	All electrical occupations: Total leukemia: PMR=1.36 (N=146, p<0.01) Acute leukemia: PMR=1.62 (N=67, p<0.01)

TABLE 3.4. LEUKEMIA AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Olin et al., 1985	Sweden	Mortality among 1,254 electrical engineering graduates from the Royal Institute of Technology, 1930-79	Graduated with a master of science degree in electrical engineering	Cohort	24 cancer deaths, 108 total deaths	Graduates with M.S. in Electrical Engineering: Leukemia: SMR=0.9 (N=2, 0.1-3.2)
Pearce et al., 1985	New Zealand	546 male leukemia cases, age≥20 yrs, registered with the New Zealand Cancer Registry, 1979-83	Occupation coded as any one of 8 electrical occupation groups	CC	546 leukemia cases, 2184 controls with other types of cancer	All electrical occupations: OR=1.70 (N=18, 0.97-2.97, p<0.06) Electronic equipment assemblers: OR=8.17 (N=4, 1.49-44.7, p<0.02) Radio/television repairmen: OR=4.75 (N=7, 1.59-14.2, p<0.01) Remaining jobs not significantly associated with leukemia
Coggon et al., 1986b	Cleveland, Humberside, and Cheshire (including the Wirral), U.K.	2,942 Male residents of study area, ages 18-54, diagnosed with cancer, 1975-80	Occupation and industry obtained from postal questionnaire	CC	29 acute myeloid leukemia cases, 2,942 total cancer cases used as controls	Electrical and electronic workers: AML: N=5 (RR not reported)
Flodin et al., 1986	Sweden	AML cases among residents, age 20-70 yrs, diagnosed in five medical clinics in Sweden, 1977-82	Occupation coded as any one of 3 electrical occupation groups, controlling for gamma radiation exposure from all sources	CC	59 AML cases 354 controls	All electrical workers: AML: OR=3.8 (N=8, 1.5-9.5)
Stern et al., 1986	New Hampshire	Leukemia mortality among 24,545 white male on-shore workers at the Portsmouth Naval Shipyard, 1952-77	Detailed shop and job history controlling for radiation and solvent exposure	CC	53 leukemia deaths 212 controls	Electricians: Total leukemia: OR=3.00 (N=11, 1.29-6.98) Myeloid leukemia: OR=2.33 (N=6, 0.77-7.06) Lymphatic leukemia: OR=6.00 (N=5, 1.47-24.5) Working in electrical shop: Total leukemia: OR=2.57 (N=10, 1.11-5.96) Myeloid leukemia: OR=2.12 (N=5, 0.64-7.10) Lymphatic leukemia: OR=3.80 (N=5, 1.13-12.8) Welders or working in welding shop: Total leukemia: OR=2.25 (N=7, 0.92-5.53) Myeloid leukemia: OR=3.83 (N=6, 1.28-11.5)

TABLE 3.4. LEUKEMIA AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Törnqvist et al., 1986	Sweden	Cancer incidence among 3,358 power linesmen and 6,703 power station operators, 1961-79	Job title codes	Cohort	236 cases among power linesmen, 463 cases among station operators	Power linesmen: Leukemia: SMR=1.25 (N=10, 0.60-2.30) Power station operators: Leukemia: SMR=0.96 (N=16, 0.55-1.57)
Lin, 1987 (*Abstr*)	Taiwan	Cancer mortality from 733 death certificates of male employees, ages 25-64, of Taiwan Electric Power Company, 1971-85	Employment with Taiwan Electric Power Company	Cohort	733 total deaths including 180 total cancer deaths	Electric power company workers: Leukemia/lymphoma: SMR=2.00 (1.17-3.21, p<0.01)
Törnqvist et al., 1987 (*Abstr*)	Sweden	Cancer incidence in 147,134 persons in 14 occupational groups	Job titles	Cohort	325 leukemia & 401 CNS cancer	Electrical engineers & technicians: Total leukemia: SIR=1.3 (1.0-1.8) CLL: SIR=1.7 (1.1-2.5) Miners and rockblasters: AML: SIR=2.1 (1.0-1.8) [sic]
Juutilainen et al., 1988	Finland	Finnish Cancer Registry and Central Statistical Office of Finland	Occupation codes	Cohort	17 cases of leukemia	All electrical occupations combined: Total leukemia: SIR=1.23 (N=17, 0.72-1.97) Linemen and cable jointers: Total leukemia: SIR=3.13 (N=4, 0.85-8.00)
Linet et al., 1988	Sweden	5,351 leukemia cases registered in the Swedish Cancer-Environment Registry, 1961-79	Occupation codes	Cohort	5,351 leukemia cases	Electrical workers: ALL: SIR=1.0 (N=4, NS) CLL: SIR=1.2 (N=52, NS) ANL: SIR=1.1 (N=42, NS) CML: SIR=1.1 (N=27, NS) Electric line workers: CLL: SIR=1.9 (N=13, p<0.05) Mining and quarrying industry (not specific for EMF exposure): CLL: SIR=1.3 (N=27, NS) ANL: SIR=1.2 (N=19, NS) CML: SIR=1.1 (N=9, NS) Miners, quarrymen, and related workers: (not specific for EMF exposure): ALL: SIR=1.0 (N=1, NS) CLL: SIR=1.4 (N=21, NS) ANL: SIR=1.5 (N=17, NS) CML: SIR=1.4 (N=9, NS)

TABLE 3.4. LEUKEMIA AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Milham, 1988	Washington and California	67,829 licensed amateur radio operators, 1979-84	License class as an amateur radio operator	Cohort	2,485 total deaths	Amateur radio operators: Total leukemia: SMR=1.24 (0.87-1.72, NS) Myeloid Leukemia: SMR=1.40 (0.83-2.20, NS) AML: SMR=1.76 (1.03-2.85, $p<0.05$) CML: SMR=0.86 (0.17-2.50, NS)
Obrams, 1988	U.S.	222 leukemia deaths among employees of AT&T, employed 2 yrs or more, 1975-80	Job titles	Nested CC	126 male leukemia deaths 96 female leukemia deaths	Leukemia deaths: Cable splicer: OR=0.95 (0.47-2.04, NS) Outside line tech: OR=0.67 (0.36-1.27, NS) Installation: OR=1.04 (0.66-1.60, NS) Central office: OR=1.20 (0.71-1.85, NS)
Preston-Martin and Peters, 1988	Los Angeles County, CA	137 patients, age 20-69, with chronic myeloid leukemia diagnosed 1979-85	Prior employment as a welder	CC	137 chronic myeloid leukemia cases and 137 age-, race-, and sex-matched controls	Prior employment as a welder: CML: Adjusted* OR=25.4 (N=19, 2.78-232.5) * Adjusted for other variables in conditional logistic regression analysis (Other variables in model include: rad dose to bone marrow from diagnostic radiography, ever lived on a farm, and self or first degree relative with Down's syndrome or thalassemia minor).
Gubéran et al., 1989	Switzerland	1,916 painters and 1,948 electricians with residence in Canton of Geneva, 1971-84	Job titles	Cohort	78 cancer cases, 52 cancer deaths	Cancer incidence data: Electricians: Leukemia: SIR=1.25 (N=2, 0.15-4.52) Cancer mortality data: Electricians: Leukemia: SMR=1.43 (N=2, 0.17-5.16)
Loomis and Savitz, 1989 (*Abstr*)	16 States, U.S.	Deaths from leukemias among males with known occupation, 1985	Usual occupation and industry recorded on death certificate	CC	1,694 leukemia deaths (including 474 AML deaths) controls from all other causes of death	All electrical workers: Total leukemia: OR=0.9 (0.6-1.3, NS) AML: OR=0.9 (0.5-1.8, NS) Electrical and electronic technicians: Total leukemia: OR=1.9 Electricians: Total leukemia: OR=1.8

TABLE 3.4. LEUKEMIA AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Pearce et al., 1989	New Zealand	All male cancer patients, age≥20 years, registered in New Zealand Cancer Registry, 1980-84	Job title	CC	534 leukemia cases 19,904 total cancer cases as controls	Electrical engineers: Total leukemia: OR=1.54 (0.38-6.27, NS) Radio/television repair: Total leukemia: OR=7.86 (2.20-28.1) Power station operators: Total leukemia: OR=3.89 (1.00-15.2) Linemen: Total leukemia: OR=2.35 (0.97-5.70, NS) Total electric workers: Total leukemia: OR=1.62 (1.04-2.52) Chronic leukemia: OR=2.12 (1.19-3.76) Acute leukemia: OR=1.25 (0.62-2.54, NS)
Gallagher et al., 1990 (*Letter*)	British Columbia, Canada	Leukemia deaths among male residents of British Columbia, 1950-84	Occupation	PMR	65 deaths from leukemia	Age 20 yr and older: Electrical engineers: Total leukemia: PMR=1.70 (N=8, 0.73-3.35) Electrical & electronic assemblers & repairmen: Total leukemia: PMR=2.08 (N=5, 0.67-4.86) Metal mill workers (not specific for EMF): Total leukemia: PMR=1.60 (N=12, 0.82-2.80)
Garland et al., 1990	San Diego, CA	Leukemia cases in white male US Navy personnel, recorded at the Naval Health Research Center, San Diego, CA, 1974-84	Occupation	HP Cohort	102 cases of leukemia	Total leukemia (compared with SEER population): Electrician's mate: SIR=2.4 (N=7, 1.0-5.0) Sonar technician: SIR=1.6 (N=3, 0.3-4.8) Electronics technician: SIR=1.1 (N=5, 0.4-2.5) Radioman: SIR=1.1 (N=4, 0.3-2.7)

ABBREVIATIONS USED:

ACO - Astrocytoma
ALL - Acute Lymphocytic Leukemia
AML - Acute Myelogenous Leukemia
ANL - Acute Nonlymphocytic Leukemia
CC - Case-Control Study
CI - Confidence Interval
CLL - Chronic Lymphoid Leukemia
CML - Chronic Myelogenous Leukemia
CNS - Central Nervous System
EMF - Electric and/or Magnetic Fields
GBO - Glioblastoma
HP - Historical Prospevtive Study
MW - Microwave
NS - Not Significant
OR - Odds Ratio
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio
PRR - Proportional Registration Ratio
RF - Radio Frequency
RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio

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TABLE 3.5. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER INCIDENCE/MORTALITY

BRAIN/CNS CANCER AND OCCUPATIONAL EMF EXPOSURE

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Lin et al., 1985	Maryland	951 brain tumor deaths in adult white male Maryland residents, age≥20 years, 1969-82	Usual occupation and industry recorded on death certificate	SMR/ CC	951 deaths from total brain tumors 519 glioblastoma multiforme and astrocytoma (GBM & AST) deaths	Electrician: GBM & AST: SMR=2.28 (N=13, 1.21-3.90) Other brain: SMR=1.70 (N=8, 0.73-3.35) Electric or electronic engineer & technician: GBM & AST: SMR=2.50 (N=18, 1.48-3.95) Other brain: SMR=2.07 (N=12, 1.07-3.61) Utility (electric & telephone) lineman/serviceman: GBM & AST: SMR=3.73 (N=19, 2.24-5.82) Other brain: SMR=1.90 (N=8, 0.82-3.75) All electrical occupations: GBM & AST: SMR=2.78 (N=50, 2.06-3.66) Other brain: SMR=1.90 (N=28, 1.27-2.75) Glioblastoma and astrocytoma risk with occupations grouped by categories of estimated EMF exposure: Definite: OR=2.15 (N=27, 1.10-4.06) Probable: OR=1.95 (N=21, 0.94-3.91) Possible: OR=1.44 (N=128, 1.06-1.95)
Milham, 1985b	Washington State	12,714 deaths among male residents, age≥20, who worked in 9 electrical occupations, 1950-82	Death certificate occupation coded to any one of 9 electrical occupations	PMR	2,649 total cancer deaths (out of 12,714 total deaths)	All electrical occupations: Brain cancer: PMR=1.23 (N=101, p<0.05)
Olin et al., 1985	Sweden	Mortality among 1,254 electrical engineering graduates from the Royal Institute of Technology, 1930-79	Graduated with a master of science degree in electrical engineering	Cohort	24 cancer deaths, 108 total deaths	Graduates with M.S. in Electrical Engineering: Brain cancer: SMR=1.0 (N=2, 0.1-3.7)
Vågerö et al., 1985	Sweden	Cancer morbidity among 2,918 workers at three work sites manufacturing telecommunications equipment, 1958-79	Employment at work sites involved in research, development, and manufacturing of telecommunication equipment	Cohort	102 male cancer cases and 37 female cases	Telecommunications workers: Nervous system: Males: SMR=1.0 (N=5, 0.3-2.3)

TABLE 3.5. BRAIN/CNS CANCER AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Coggon et al., 1986b	Cleveland, Humberside, and Cheshire (including the Wirral), U.K.	2,942 Male residents of study area, ages 18-54, diagnosed with cancer, 1975-80	Occupation and industry obtained from postal questionnaire	CC	97 Brain/CNS cancer cases, 2,942 total cancer cases used as controls	Electrical engineering industry: Brain/CNS: RR=1.9 (N=3, NS) Electrical and electronic workers: Brain/CNS: RR=2.0 (N=7, NS)
Törnqvist et al., 1986	Sweden	Cancer incidence among 3,358 power linesmen and 6,703 power station operators, 1961-79	Job title codes	Cohort	236 cases among power linesmen, 463 cases among station operators	Power linesmen: Nervous system: SMR=1.49 (N=13, 0.80-2.56) Power station operators: Nervous system: SMR=0.97 (N=17, 0.57-1.56)
Lin, 1987 (*Abstr*)	Taiwan	Cancer mortality from 733 death certificates of male employees, ages 25-64, of Taiwan Electric Power Company, 1971-85	Employment with Taiwan Electric Power Company	Cohort	733 total deaths including 180 total cancer deaths	Electric power company workers: Brain/CNS: SMR=4.10 (1.77-8.08, p<0.01)
Magnani et al., 1987	Cleveland, Humberside, Cheshire, & the Wirral, U.K.	1,265 male residents of study areas, ages 18-54, who died of any 1 of 5 cancers under study, 1959-63 and 1965-79	Occupation and Industry codes plus job-exposure matrix	CC	1,265 total deaths due to Brain/CNS cancer & 4 other sites; 4,470 age, sex, and residence matched controls	Electrical engineering: Brain/CNS: RR=0.9 (0.2-4.3) Electrical & electronic workers: Brain/CNS: RR=1.3 (0.7-2.5)
McLaughlin et al., 1987	Sweden	3,394 incident cases of intracranial glioma registered with the Swedish Cancer-Environment Registry, 1961-79	Occupation and industry codes	Cohort	3,394 incident cases of intracranial gliomas	Electrical occupations or industries: Electricians and electronic workers: SIR=0.9 (N=75, 0.71-1.13, NS) Welders and metal cutters: SIR=1.4 (N=46, 1.02-1.87, p<0.05) Machinery and electronics industry: SIR=1.1 (N=313, 0.98-1.23, p<0.05) Other electronics: SIR=1.2 (N=86, 0.96-1.48, NS) Non-electrical occupations with significant elevations: Biologists: SIR=2.3 (N=13, 1.23-3.93, p<0.05) Medical professionals: SIR=1.7 (N=26, 1.11-2.49, p<0.05) Potters, kilnmen, and glass workers: SIR=1.6 (N=25, 1.04-2.37, p<0.05)

TABLE 3.5. BRAIN/CNS CANCER AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Thomas et al., 1987	Northern New Jersey; Philadelphia, PA; and southern Louisiana	435 death certificates listing brain or other CNS tumors as cause of death in white males, age ≥ 30 years, 1978-81	Occupation and industry codes, grouped by likely exposure to MW/RF radiation	CC	435 deaths from brain tumors, 386 controls who died from other causes	All male electrical & electronic workers ever exposed to MW/RF radiation: RR=1.6 (N=69, 1.0-2.4) Design, manufacture, repair, or installation of electrical or electronic equipment: RR=2.3 (N=44, 1.3-4.2) Engineers, teachers, technicians, repairers, and assemblers with no MW/RF exposure: RR=3.9 (N=28, 1.6-9.9)
Milham, 1988	Washington and California	67,829 licensed amateur radio operators, 1979-84	Amateur radio operators	Cohort	2,485 total deaths	Amateur radio operators: Brain/CNS: SMR=1.39 (0.93-2.00, NS)
Speers et al., 1988	East Texas	202 deaths from glioma among male residents of 40 counties in east Texas, 1969-78	Usual occupation and industry of employment as recorded on death certificate	CC	202 CNS tumor deaths (gliomas) 238 controls	Electricians and electronics workers: All combined: OR=2.11 (0.77-5.81, NS) Grouped by estimated EMF exposure category: None: OR=1.00 (N=92) Possible: OR=1.15 (N=68, 0.73-1.81) Probable: OR=2.86 (N=11, 0.8-10.3) Definite: OR=∞ (N=6, control=0) Occupation/industry not specific for EMF exposure: Utility workers: OR=13.1 (1.33-129.0) Trucking industry: OR=6.65 (1.05-42.2)
Gubéran et al., 1989	Switzerland	1,916 painters and 1,948 electricians with residence in Canton of Geneva, 1971-84	Job titles	Cohort	78 cancer cases, 52 cancer deaths	Cancer incidence data: Electricians: Brain: SIR=1.18 (N=2, 0.14-4.25) Painters (not specific for EMF exposure): Brain: SIR=1.43 (N=3, 0.29-4.17) Cancer mortality data: Electricians: Brain: SMR=1.54 (N=2, 0.19-5.56) Painters (not specific for EMF exposure): Brain: SMR=0.53 (N=1, 0.01-2.93)
Loomis and Savitz, 1989 (*Abstr*)	16 States, U.S.	Deaths from malignant brain tumors or leukemias among males with known occupation, 1985	Usual occupation and industry recorded on death certificate	CC	1,095 brain cancer deaths	All electrical workers: Brain: OR=1.5 (1.0-2.1) Electrical and electronic technicians: Brain: OR=3.1 Electric power repairers and installers: Brain: OR=2.4

TABLE 3.5. BRAIN/CNS CANCER AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Pearce et al., 1989	New Zealand	All male cancer patients, age≥20 years, registered in New Zealand Cancer Registry, 1980-84	Job title	CC	431 brain cancer cases, 19,904 total cancer cases as controls	Electrical engineers: OR=4.74 (1.65-13.6) Electricians: OR=1.91 (0.84-4.33, NS) Total electric workers: OR=1.01 (0.56-1.82, NS)
Preston-Martin et al., 1989	Los Angeles County, CA	272 Brain/CNS cancer cases among black & white males, ages 25-69, 1980-84	Job titles and occupations involving high likelyhood of exposure to EMF	CC with matched pairs	202 glioma cases, 70 meningioma cases	All electrical occupations (employed > 5 years): Gliomas: OR=1.8 (0.7-4.8) Meningiomas: OR=0.7 (0.1-5.8) Astrocytomas: OR=4.3 (1.2-15.6) Risk for gliomas increased with increase in number of years worked: (p for trend = 0.008).
Reif et al., 1989	New Zealand	452 Brain/CNS cancer cases among males, age≥20, in New Zealand Cancer Registry, 1980-84	Current or most recent occupation at the time of registration	CC	452 brain/CNS cancer cases & 19,452 cases of other cancers used as controls	Electrical workers: Brain: OR=0.78 (N=8, 0.39-1.59) Occupational groups not specific for EMF exposure: Plumbers and welders: Brain: OR=2.02 (N=8, 0.99-4.12) Sheet and structural metal workers Brain: OR=2.10 (N=11, 1.15-3.82) Livestock farmers: Brain: OR=2.59 (N=11, 1.41-4.75)
Lewis, 1990	Coastal Texas and Southern Louisiana	Incident cases of neuroglial tumors, white and non-white males, ages 20-79, diagnosed 1980-84	Occupational history obtained by interview	CC	375 cases of neuroglial tumors of the CNS (confirmed pathologically), 450 controls	No increased risk by occupation: Ever employed in an electrical occupation: OR=0.65 (0.40-1.09) Usual occupation listed as electrical: OR=0.76 (0.33-1.73) No increased risk by estimated exposure categories: High: OR=0.80 (N=37, 0.40-1.64) Medium: OR=0.88 (N=3, 0.06-21.8) Low: OR=0.45 (N=20, 0.19-1.03)

ABBREVIATIONS USED:

AST - Astrocytoma
CC - Case-Control Study
CI - Confidence Interval
CNS - Central Nervous System
EMF - Electric and/or Magnetic Fields
GBM - Glioblastoma Multiforme
MW - Microwave
NS - Not Significant
OR - Odds Ratio
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio
RF - Radio Frequency
RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio

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TABLE 3.6. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER INCIDENCE/MORTALITY

OTHER SITES (Eye, Breast, Testis, Skin Melanoma, etc.) AND OCCUPATIONAL EMF EXPOSURE

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Howe & Lindsay, 1983	Canada	Cancer mortality among 415,201 males of the Canadian Labor Force, 1965-73	Occupation and industry codes (by both 2-digit and 3-digit codes)	Cohort	4,203 total cancer deaths	Linemen and servicemen (telephone, telegraph, and power): Intestine (except rectum): SMR=3.53 (N=8, 1.52-6.96, p<0.01) Stomach cancer: SMR=2.33 (N=6, 0.86-5.07, p<0.05) Miners, quarrymen, and related workers: Lung: SMR=1.00 (N=31, NS) Stomach: SMR=1.07 (N=10, NS) Intestine: SMR=0.75 (N=6, NS) Pancreas: SMR=1.04 (N=6, NS) Prostate: SMR=0.28 (N=1, NS) Bladder: SMR=0.39 (N=1, NS) Brain: SMR=1.15 (N=4, NS)
Swerdlow, 1983	England and Wales	All cases of eye cancer in persons age≥15, registered in any of the 14 population-based regional cancer registries, 1962-77	Occupational order listed as electrical and electronics worker	PRR	2,159 cases of eye cancer in males, 2,125 cases in females	Electrical and electronic workers: Eye cancer in males: 1971: PRR=1.67 (N=1, NS) 1972: PRR=7.14 (N=5, p<0.01) 1973: PRR=2.63 (N=5, NS) 1974: PRR=4.44 (N=4, p<0.05) 1975: PRR=5.41 (N=4, p<0.05) Professional, technical workers, and artists (not specific for EMF exposure): Eye cancer in males: 1971: PRR=2.39 (N=16, p<0.01) 1972: PRR=4.00 (N=6, p<0.01) 1973: PRR=2.29 (N=11, p<0.05) 1974: PRR=2.18 (N=12, p<0.05) 1975: PRR=2.70 (N=10, p<0.01)
Vågerö and Olin, 1983	Sweden	Cancer incidence among 54,624 male and 18,478 female workers, ages 15-64, working in the electronics industry in Sweden, at time of 1960 census	Employment in the electronics industry	HP/ Cohort	1,855 male cancer cases and 1,009 female cancer cases	All electronics workers: Males: Lung: RR=1.52 (N=273, 1.35-1.72) Larynx: RR=1.46 (N=36, 1.05-2.03) Bladder: RR=1.22 (N=122, 1.02-1.47) Colon: RR=1.20 (N=138, 1.02-1.43) Skin melanoma: RR=1.35 (N=59, 1.05-1.76) Females: Cervix uteri: RR=1.14 (N=417, 1.04-1.26)

TABLE 3.6. OTHER SITES (Eye, Breast, Testis, Skin Melanoma, etc.) AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Blair et al., 1985	U.S.	Cancer mortality among 293,958 U.S. Veterans, age 31-84, who held U.S. government life-insurance policies in December 1953 and of whom 107,563 were deceased as of Jan 1, 1970	Usual occupation as reported by subject in questionnaires administered in 1954 and 1957	Cohort	107,563 total deaths from all causes	Electricians: Stomach: SMR=1.22 (N=9, 0.56-2.31) Intestines: SMR=0.74 (N=11, 0.37-1.33) Rectum: SMR=0.75 (N=4, 0.20-1.90) Lung & Bron: SMR=1.18 (N=36, 0.83-1.64) Prostate: SMR=0.87 (N=11, 0.44-1.56) Bladder: SMR=1.40 (N=7, 0.56-2.88) Lymphoma: SMR=0.87 (N=7, 0.35-1.80) Electrical engineers: Stomach: SMR=0.63 (N=7, 0.25-1.29) Intestines: SMR=1.06 (N=26, 0.69-1.55) Rectum: SMR=0.80 (N=7, 0.32-1.66) Lung & Bron: SMR=0.68 (N=27, 0.45-0.99) Prostate: SMR=0.96 (N=20, 0.58-1.48) Bladder: SMR=1.53 (N=12, 0.78-2.65) Lymphoma: SMR=1.29 (N=16, 0.74-2.10) Telegraph, telephone, & powerline servicemen: Intestines: SMR=1.39 (N=12, 0.72-2.44) Lung & Bron: SMR=1.29 (N=23, 0.82-1.94) Prostate: SMR=1.07 (N=8, 0.46-2.10)
Gallagher et al., 1985	Western Canada	All cases of occular melanoma in persons age 20-79 registered in cancer registries of British Columbia, Alberta, Saskatchewan, and Manitoba, 1979-81	Job and industry titles from detailed occupational history	CC	65 cases of occular melanoma & 65 age- and sex-matched controls	Electrical and electronic workers: Occular melanoma: No increased risk Government workers (primarily indoor managerial) (Not specific for EMF exposure): Occular melanoma: OR=3.5 (N=43, p=0.006)
Milham, 1985b	Washington State	12,714 deaths among male residents, age≥20, who worked in 9 electrical occupations, 1950-82	Death certificate occupation coded to any one of 9 electrical occupations	PMR	2,649 total cancer deaths (out of 12,714 total deaths)	All electrical occupations: Pancreas: PMR=1.17 (N=174, p<0.05) Lung, trachea, and bronchus: PMR=1.14 (N=789, p<0.01) Lymphoma: PMR=1.64 (N=51, p<0.01)
Olin et al., 1985	Sweden	Mortality among 1,254 electrical engineers from the Royal Institute of Technology, 1930-79	Graduated with a master of science degree in electrical engineering	Cohort	24 cancer deaths, 108 total deaths	Graduates with M.S. in Electrical Engineering: Intestines: SMR=0.8 (N=3, 0.2-2.5) Pancreas: SMR=0.9 (N=3, 0.2-2.5) Lung: SMR=0.4 (N=4, 0.1-1.1) Melanoma: SMR=3.2 (N=3, 0.7-9.4)

TABLE 3.6. OTHER SITES (Eye, Breast, Testis, Skin Melanoma, etc.) AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (*Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values*)
Vågerö et al., 1985	Sweden	Cancer morbidity among 2,918 workers at three work sites manufacturing telecommunications equipment, 1958-79	Employment at work sites involved in research, development, and manufacturing of telecommunication equipment	Cohort	102 male cancer cases and 37 female cases	Telecommunications workers: Lung (males): SMR=0.9 (N=10, 0.4-1.6) Colon (males): SMR=1.5 (N=10, 0.7-2.7) Kidney (males): SMR=1.9 (N=10, 0.9-3.5) Prostate (males): SMR=1.2 (N=15, 0.7-1.9) Melanoma (males): SMR=2.5 (N=8, 1.1-4.9) Breast (females): SMR=0.6 (N=7, 0.3-1.3) Melanoma (females): SMR=2.8 (N=4, 0.8-7.2) Melanoma (total): SMR=2.6 (N=12, 1.3-4.5)
Coggon et al., 1986a and 1986b	Cleveland, Humberside, and Cheshire (including the Wirral), U.K.	2,942 Male residents of study area, ages 18-54, diagnosed with cancer, 1975-80	Occupation and industry obtained from postal questionnaire	CC	198 stomach, 176 colon, 167 rectum, 738 bronchus, 64 melanoma, 97 lymphoma cases with 2,942 total cancer cases used as controls	Electrical engineering industry: Stomach: RR=0.9 (N=4, NS) Colon: RR=1.2 (N=6, NS) Rectum: RR=0.7 (N=4, NS) Lung & Bronchus: RR=0.6 (N=10, NS) Melanoma: RR=1.3 (N=2, NS) Lymphoma: RR=1.4 (N=4, NS) Electrical and electronic workers: Stomach: RR=1.3 (N=7, NS) Colon: RR=1.2 (N=8, NS) Rectum: RR=0.9 (N=6, NS) Lung & Bronchus: RR=0.8 (N=16, NS) Melanoma: RR=0.7 (N=2, NS) Lymphoma: RR=1.7 (N=7, NS)
Törnqvist et al., 1986	Sweden	Cancer incidence among 3,358 power linesmen and 6,703 power station operators, 1961-79	Job title codes	Cohort	236 cases among power linesmen, 463 cases among station operators	Power linesmen: Stomach: SMR=1.20 (N=25, 0.77-1.77) Lung/trachea: SMR=0.66 (N=17, 0.38-1.05) Kidney: SMR=1.33 (N=15, 0.74-2.19 Power station operators: Stomach: SMR=0.95 (N=42, 0.69-1.29) Lung/trachea: SMR=0.71 (N=40, 0.50-0.96) Kidney: SMR=1.26 (N=29, 0.84-1.81)
Lin, 1987 (*Abstr*)	Taiwan	Cancer mortality from 733 death certificates of male employees, ages 25-64, of Taiwan Electric Power Company, 1971-85	Employment with Taiwan Electric Power Company	Cohort	733 total deaths including 180 total cancer deaths	Electric power company workers: Liver: SMR=1.54 (1.20-1.95, p<0.01)

TABLE 3.6. OTHER SITES (Eye, Breast, Testis, Skin Melanoma, etc.) AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Magnani et al., 1987	Cleveland, Humberside, Cheshire, & the Wirral, U.K.	1,265 male residents of study areas, ages 18-54, who died of any 1 of 5 cancers under study, 1959-63 and 1965-79	Occupation and Industry codes plus job-exposure matrix	CC	1,265 total deaths due to kidney, esophageal, pancreas, melanoma, & CNS cancer; 4,470 age-, sex-, and residence-matched controls	Electrical engineering: Pancreas: RR=0.8 (0.2-3.9) Kidney: RR=15.2 (N=4, 1.7-136.0) Electrical & electronic workers: Esophagus: RR=1.4 (0.6-3.4) Pancreas: RR=0.6 (0.2-1.6) Melanoma: RR=1.2 (0.2-5.9) Kidney: RR=1.7 (0.7-4.6)
De Guire et al., 1988	Montreal, Canada	9,590 workers at telecommunications company, 1976-83	Job titles and person-years of observation	Cohort	10 male cases of malignant melanoma of skin	Telecommunication workers: Malignant melanoma of the skin: SIR=2.70 (N=10, 1.31-5.02)
Milham, 1988	Washington and California	67,829 licensed amateur radio operators, 1979-84	License class as an amateur radio operator	Cohort	2,485 total deaths	Amateur radio operators: Stomach: SMR=1.02 (0.68-1.45, NS) Large intestine: SMR=1.11 (0.89-1.37, NS) Liver: SMR=0.65 (0.33-1.17, NS) Respiratory: SMR=0.66 (0.58-0.76, $p<0.05$) Prostate: SMR=1.14 (0.90-1.42, NS) Kidney: SMR=0.94 (0.57-1.48, NS)
Gubéran et al., 1989	Switzerland	1,916 Painters and 1,948 electricians with residence in Canton of Geneva, 1971-84	Job titles	Cohort	78 cancer cases, 52 cancer deaths	Cancer incidence data: Electricians: Lung: SIR=0.96 (N=16, 0.55-1.57) Bladder: SIR=0.67 (N=3, 0.14-1.95) Painters (not specific for EMF exposure): Lung: SIR=1.47 (N=40, 1.05-2.00) Bladder: SIR=1.71 (N=13, 0.91-2.93)
Pearce et al., 1989	New Zealand	All male cancer patients with known occupation, age≥20 years, registered in New Zealand Cancer Registry, 1980-84	Job title	CC	19,904 total cancer cases	Total electrical workers: Stomach: OR=1.06 (N=25, 0.70-1.59) Colon: OR=1.06 (N=52, 0.79-1.41) Rectum: OR=1.16 (N=38, 0.83-1.62) Liver: OR=1.52 (N=7, 0.71-3.25) Pancreas: OR=0.91 (N=12, 0.51-1.62) Lung: OR=0.88 (N=89, 0.69-1.11) Melanoma: OR=0.70 (N=24, 0.46-1.08) Prostate: OR=0.96 (N=52, 0.71-1.29) Testis: OR=0.78 (N=12, 0.41-1.47) Bladder: OR=1.00 (N=35, 0.67-1.50)

TABLE 3.6. OTHER SITES (Eye, Breast, Testis, Skin Melanoma, etc.) AND OCCUPATIONAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Demers et al., 1990 (*Abstr*) and 1991	U.S.	227 Males with breast cancer from 10 population-based SEER registries, 1983-87	Occupation	CC	227 incident cases of breast cancer in males 300 controls from medicare list	Any exposed job: Breast cancer (males): OR=1.8 (N=33, 1.0-3.7) Electricians, telephone linemen, electric power workers, power plant operators: Breast cancer (males): OR=6.0 (N=13, 1.7-21.5) Radio broadcast and communication workers: Breast cancer (males): OR=2.9 (N=7, 0.8-10.2)
Tynes and Andersen, 1990	Norway	37,953 Male workers, age≥20 years, with 824,321 person-years possible EMF exposure, 1961-85	Job title	Cohort	12 cases of male breast cancer from Cancer Registry of Norway	All electrical occupations: Breast cancer (males): SIR=2.07 (N=12, 1.07-3.61)
Verreault et al., 1990	13 Counties of Western Washington	White males, ages 20-69 yrs, with testicular cancer diagnosed 1981-84	History of electric blanket use	CC	182 cases of testicular cancer, 658 controls from same geographic areas	Electric blanket ever used in prior 10 years: Testicular cancer: RR=1.0 (N=57, 0.7-1.4) Seminomas: RR=0.7 (N=27, 0.5-1.2) Nonseminomas: RR=1.4 (N=30, 0.9-2.3) Risk by cumulative electric blanket use (months): 0 months: RR=1.0 (N=125) 1-24 months: RR=0.9 (N=30, 0.5-1.3) 25-120 months: RR=1.2 (N=27, 0.7-1.9)
Matanoski et al., 1991	New York state	50,582 Telephone workers in one state-wide company, 1976-80	Job titles	Cohort	2 Cases of breast cancer in males from 206,067 person-years of observation	Central office technicians (Average daily magnetic field exposure = 2.5 mG): SIR=6.5 (N=2, 0.79-23.5) Cable splicers (Average daily magnetic field exposure = 4.3 mG): SIR=0 (N=0)
Vena et al., 1991	Western New York State	Postmenopausal women, ages 41-85, 1987-89	Electric blanket use	CC	382 cases of female breast cancer and 439 controls	Electric blanket used to warm bed only: OR=0.64 (N=28, 0.39-1.05, NS) Used to warm bed and sometimes throughout night: OR=0.64 (N=30, 0.40-1.05, NS) Used continuously throughout night, not every night: OR=1.31 (N=68, 0.88-1.95, NS) Used daily in season through the night for 10 years: OR=1.25 (N=32, 0.73-2.16, NS)

ABBREVIATIONS USED:

CC - Case-Control Study
CI - Confidence Interval
EMF - Electric and/or Magnetic Fields
HP - Historical Prospevtive Study
MW - Microwave

NS - Not Significant
OR - Odds Ratio
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio
PRR - Proportional Registration Ratio

RF - Radio Frequency
RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio

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TABLE 3.7. MAJOR EPIDEMIOLOGIC STUDIES OF CANCER OR ADVERSE REPRODUCTIVE OUTCOMES

CHILDHOOD ADVERSE EFFECTS AND PATERNAL/MATERNAL EMF EXPOSURE

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Hemminki et al., 1980	Finland	Women in metal industry compared with all Finnish women	Maternal occupation	Cohort	195 spontaneous abortions	Electrical workers of Union of Metal Workers: Spontaneous Abortions (rate per 100 births): All Finnish women: 10.3 Electrical workers: 16.5, p<0.001 Before joining Union: 10.1 After joining Union: 14.6, p<0.001
Nordstrom et al., 1983	Sweden	542 Employees at Swedish power plants	Paternal occupation	Cohort	26 complicated malformations	Paternal exposure to high voltage: Increased frequency of abnormal pregnancy outcome (p<0.001).
Spitz & Johnson, 1985	Texas	Childhood deaths due to neuroblastoma	Paternal occupation	CC	157 deaths from neuroblastoma in children	Electrical workers (father): OR=2.13 (N=17, 1.05-4.35) Electronics workers (father): OR=11.8 (N=6, 1.40-98.6)
Wertheimer & Leeper, 1986	Colorado	1,256 families giving birth in 1982	Usage of electric blankets and heated waterbeds	Cohort	130 retarded growth, 5 congenital defect, and 24 abortions	Proportion of births with above-median gestation significantly greater in exposed group. Five congenital defects reported in 193 users vs one in 335 non-users. Abortion rates were 6.3-7.8% in users and 4.2% in non-users.
Nordstrom et al., 1987	Sweden	Employees at Swedish power stations	Paternal occupation	Cohort	482 employees responded to questionnaire providing data for 26 mallfunctions among 866 pregnancies.	An increased frequency of congenital malformations was found (p<0.001) among offspring of fathers who worked at high voltage substations.
Nasca et al., 1988	New York State	Incident cases of primary CNS tumors in children	Paternal occupation	CC	338 cases with primary CNS tumor	Definition for paternal EMF Exposure: Narrow: OR=1.70 (N=15, 0.80-3.59, NS) Broad: OR=1.61 (N=19, 0.83-3.11, NS)
Wilkins & Koutras, 1988		Childhood deaths due to brain cancer	Paternal occupation at time of childs birth	CC	491 deaths from brain cancer	Electrical assembling, installing, and repairing: OR=2.7 (N=19, 1.2-6.12)

TABLE 3.7. CHILDHOOD ADVERSE EFFECTS AND PATERNAL/MATERNAL EMF EXPOSURE (Continued)

Investigator and Date	Location of Study	Population Studied	Method Used for Exposure Estimate	Type of Study	Number of Cases or Study Subjects	Results (Including SMR's, SIR's, PMR's, PIR's, OR's, or RR's, and 95% CI's and/or p-values)
Buiatti et al., 1989	Florence, Italy	Residents in attending clinic	Paternal occupation	CC	112 cases	Radioelectric workers: Oligospermia and azoospermia: OR=5.89 (N=5, 0.86-40.2, NS)
Johnson, 1985; Johnson & Spitz, 1989	Texas	Childhood deaths due to CNS tumors	Paternal industry and occupation	CC	499 deaths from CNS tumors in children	Paternal industry with potential EMF exposure: OR=1.64 (N=25, 0.96-2.82, NS) Electronics manufacturing: OR=3.56 (N=7, 1.04-12.2) Paternal occupation with potential EMF exposure: OR=1.44 (N=28, 0.88-2.38, NS) Electricians: OR=3.52 (N=7, 1.02-12.1)
Wertheimer & Leeper, 1989	Oregon	Oregon state birth records for 1983 & 1985	Ceiling cable electric heating in homes	Cohort	380 abortions of which 143 were traced (37.4%), 142 cases used in analysis	Increased fetal loss rate during October-January season when EMF exposure is presumed to increase.
Wilkins & Hundley, 1990	Ohio	Childhood neuroblastoma incident cases	Paternal industry and occupation	CC	101 cases of neuroblastoma	Occupational EMF exposure as defined by: Hsieh et al.: OR=1.1 (N=24, 0.5-2.3, NS) Deapen & Henderson: OR=1.6 (N=4, 0.3-9.1, NS) Lin et al.: Narrow: OR=1.9 (N=6, 0.4-9.7, NS) Broad: OR=0.7 (N=19, 0.3-1.5, NS)
Bunin et al., 1990	Pennsylvania	Childhood neuroblastoma incident cases	Paternal occupational histories obtained by telephone interview	CC	104 cases of neuroblastoma	Paternal EMF exposure prior to conception: Workers: OR=1.6 (0.5-6.2, NS) Assemblers: OR=4.0 (0.4-19.2, NS) Paternal EMF exposure during pregnancy: Workers: OR=0.4 (0.1-1.6, NS)

ABBREVIATIONS USED:

CC - Case-Control Study
CNS - Central Nervous System
EMF - Electric and/or Magnetic Fields
NS - Not Significant
OR - Odds Ratio
PIR - Proportionate Incidence Ratio
PMR - Proportionate Mortality Ratio
RR - Risk Ratio or Relative Risk
SIR - Standardized Incidence Ratio
SMR - Standardized Mortality Ratio

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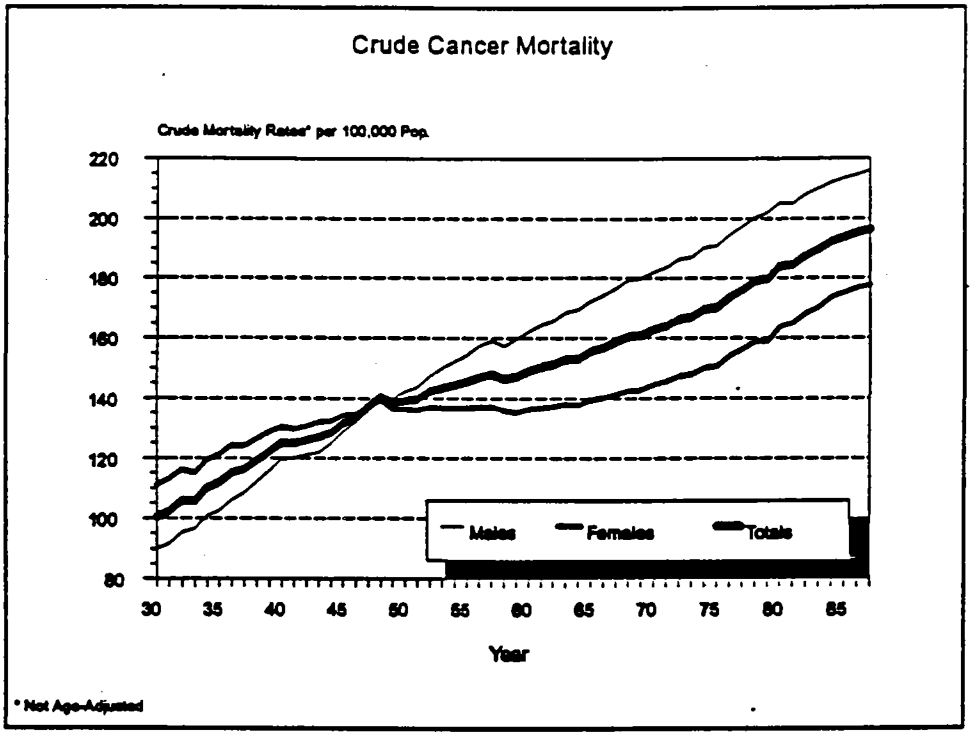

Figure 3-1 - Crude Cancer Mortality Rates, 1930-87 Male/Female/Total, Adults and Children.

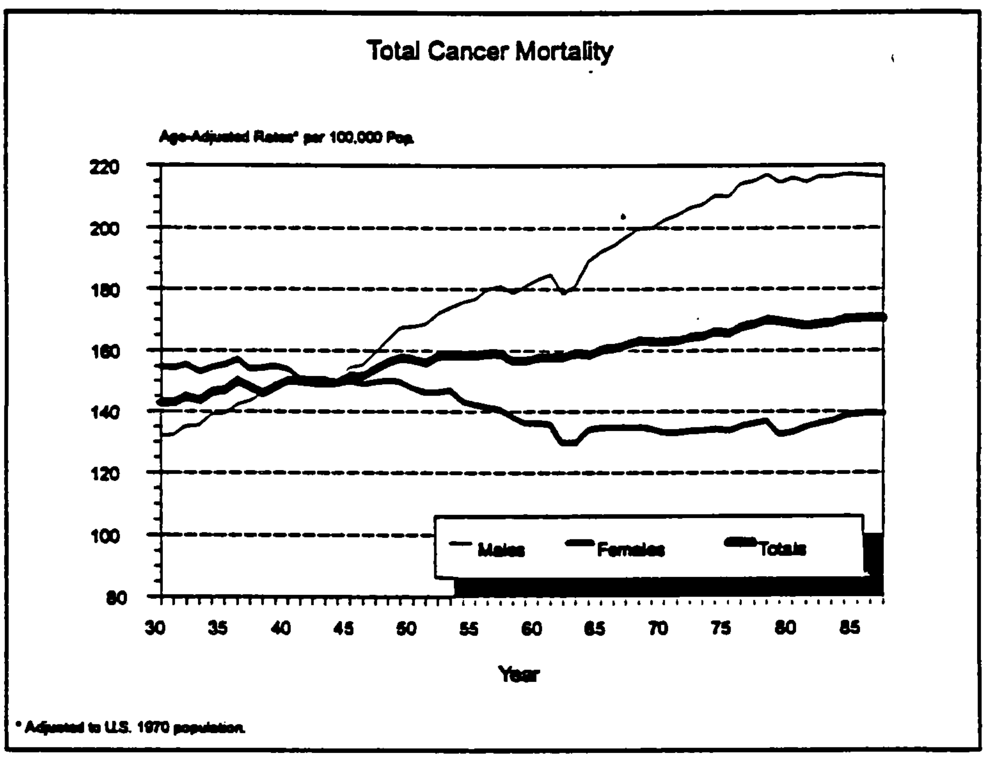

Figure 3-2 - Total Cancer Mortality, Rates, 1930-87 Male/Female/Total, Adults and Children.

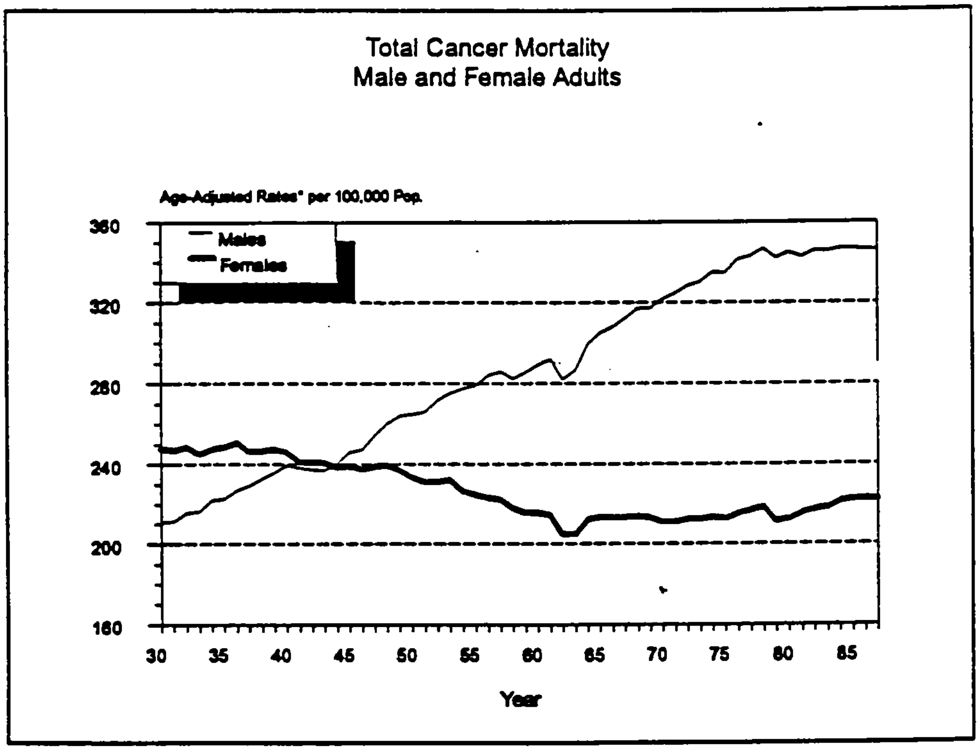

Figure 3-3 - Total Cancer Mortality, 1930-87, Male and Female Adults.

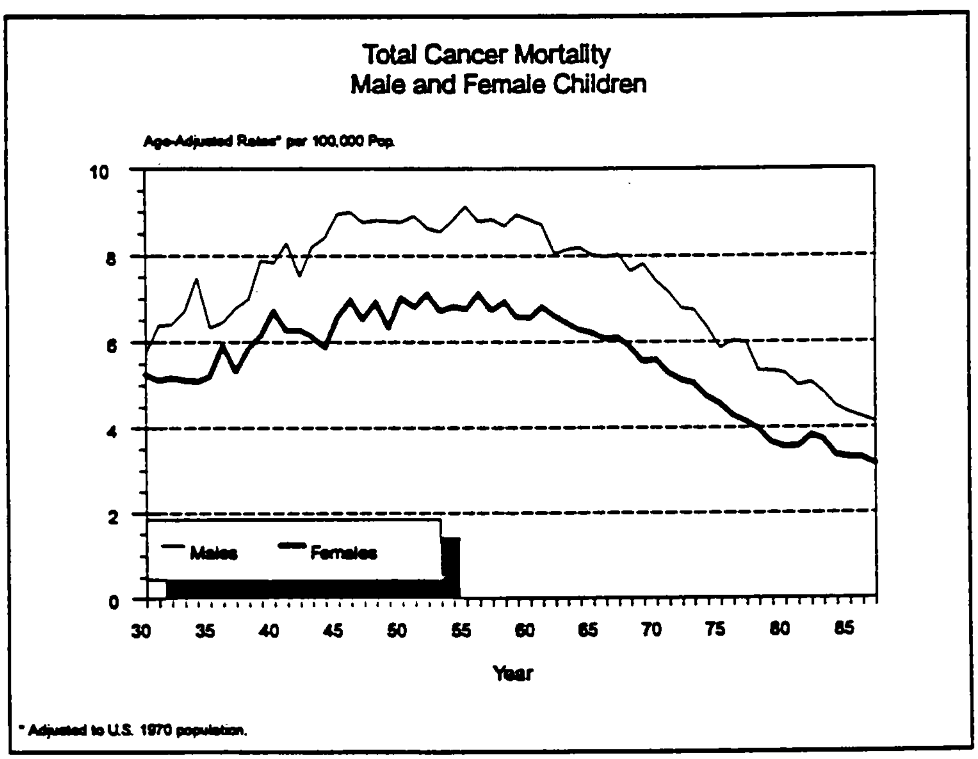

Figure 3-4 - Total Cancer Mortality, Male and Female Children.

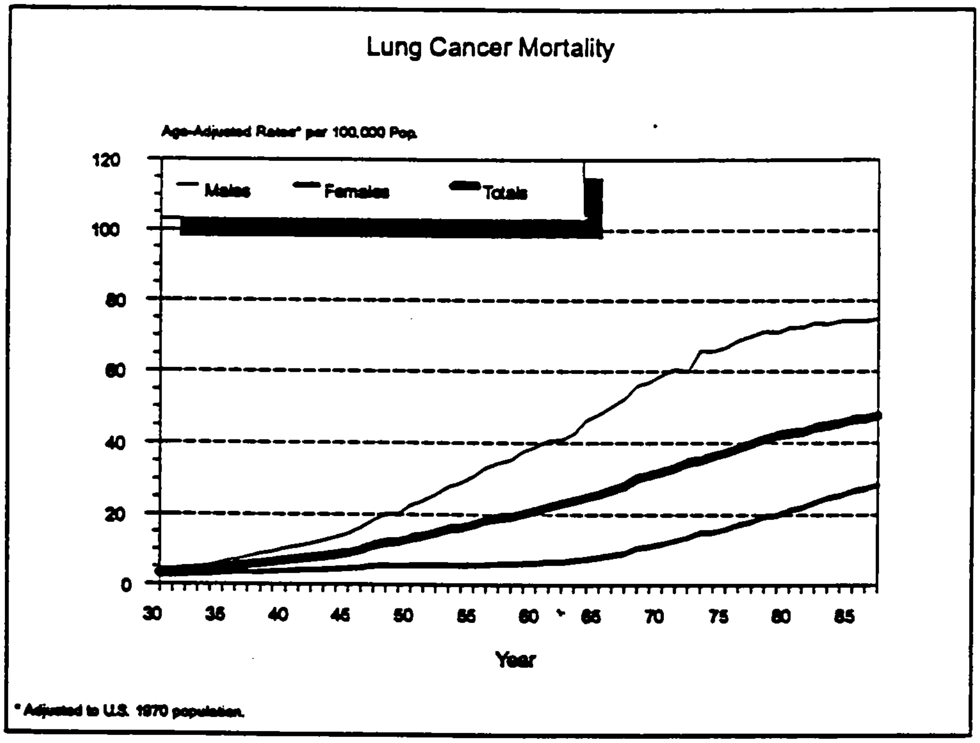

Figure 3-5 - Lung Cancer Mortality, 1930-87, Male/Female/Total Adults and Children.

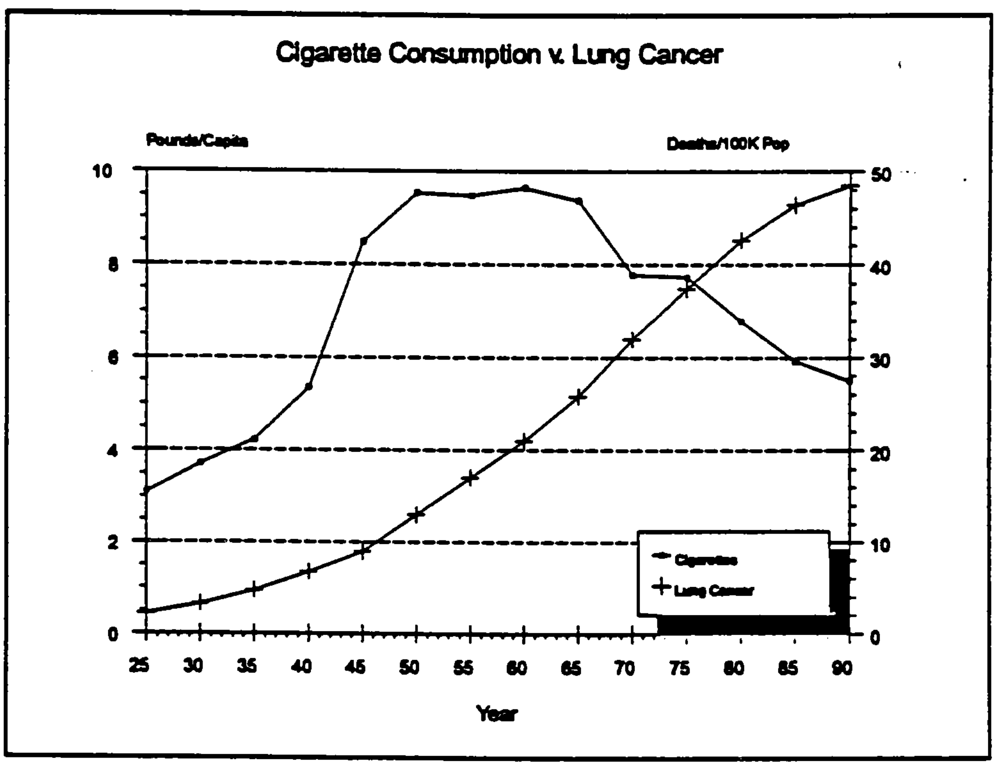

Figure 3-6 - Cigarette Consumption v. Lung Cancer.

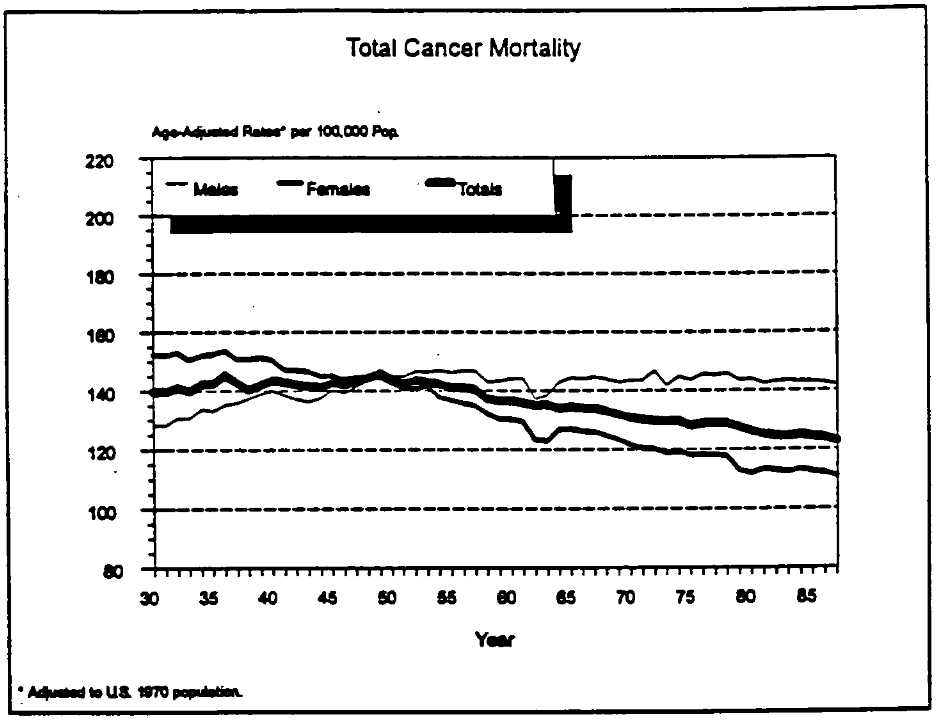

Figure 3-7 - Total Cancer Mortality (Minus Lung), 1930-87, Male/Female/Total Adults and Children.

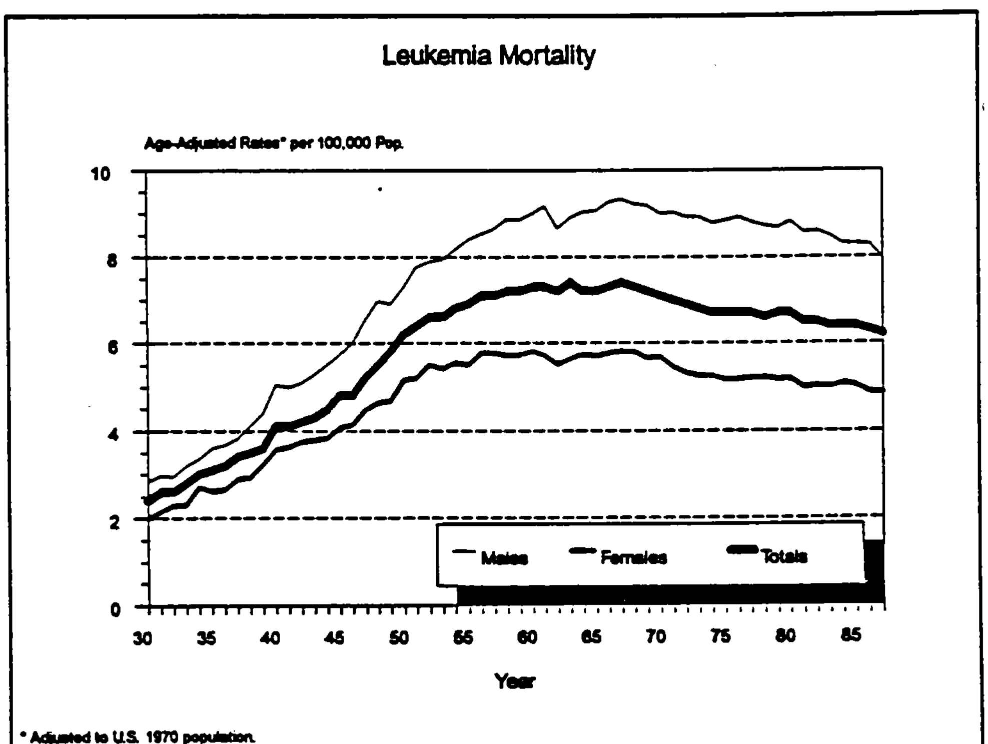

Figure 3-8 - Leukemia Mortality, 1930-87, Males/Females/Total Adults and Children.

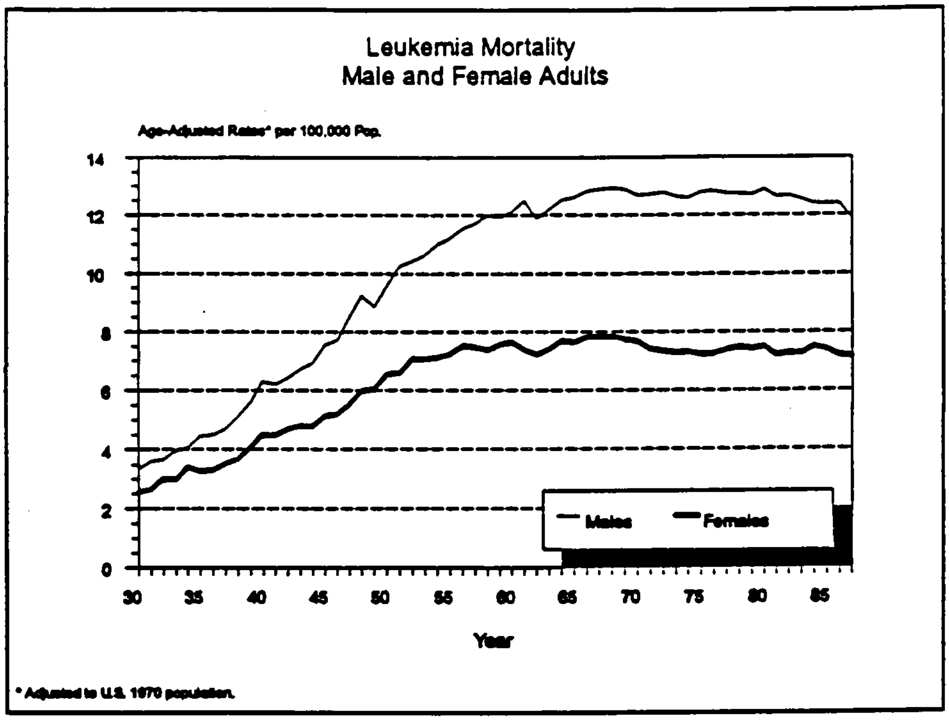

Figure 3-9 - Leukemia Mortality, 1930-87, Male and Female Adults (20-+85 yrs).

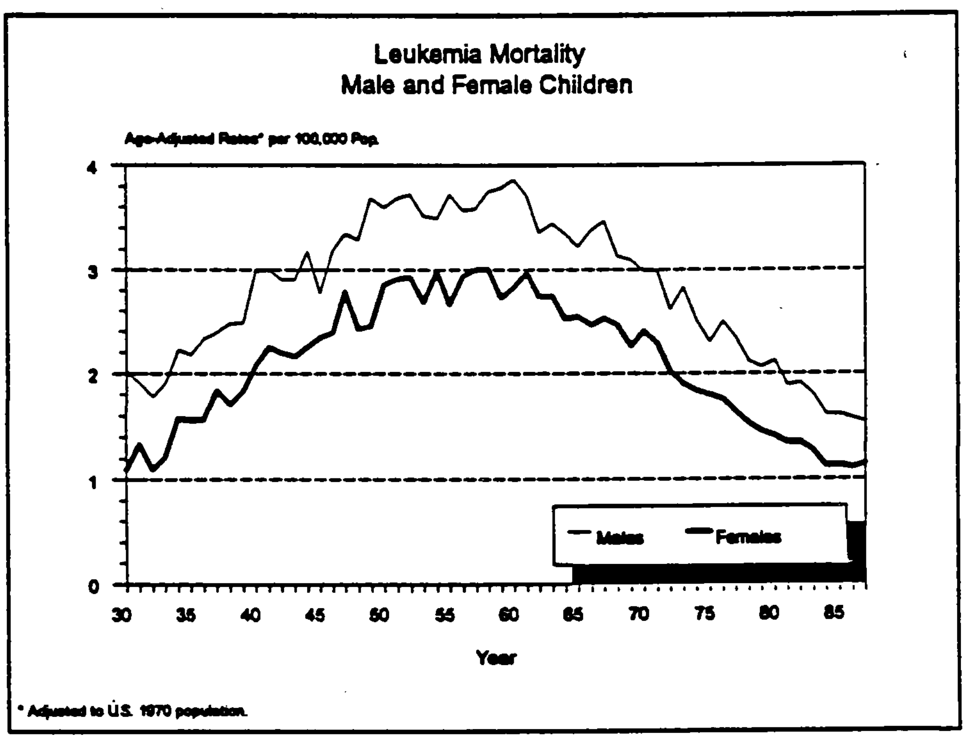

Figure 3-10 - Leukemia Mortality Rates, 1930-87, Male and Female Children (0-19 yrs).

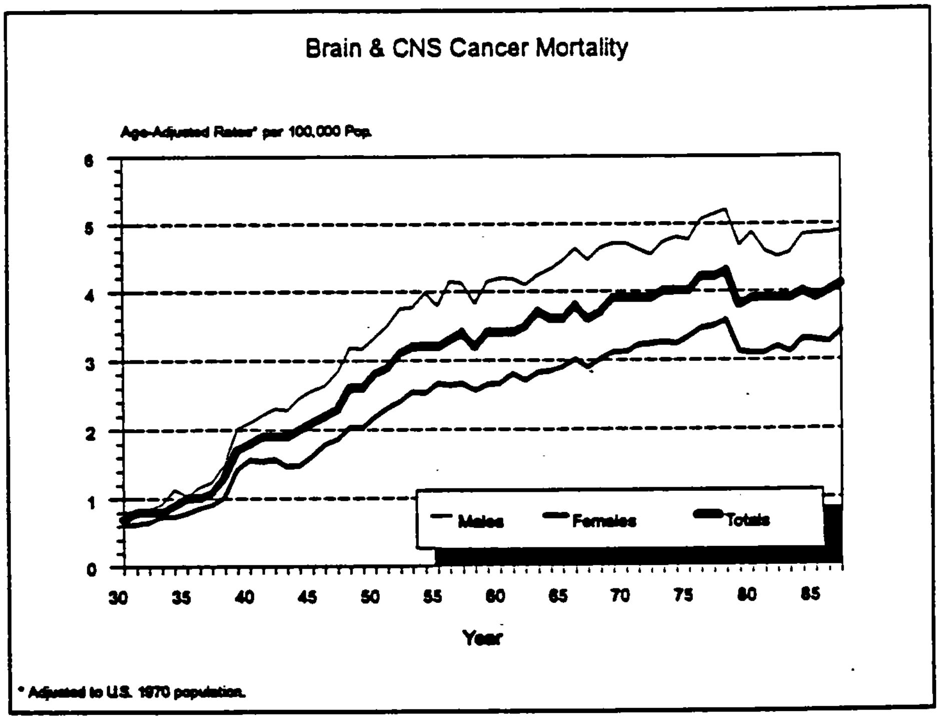

Figure 3-11 - Brain and CNS Cancer Mortality, 1930-87, Males/Females/Total Adults and Children.

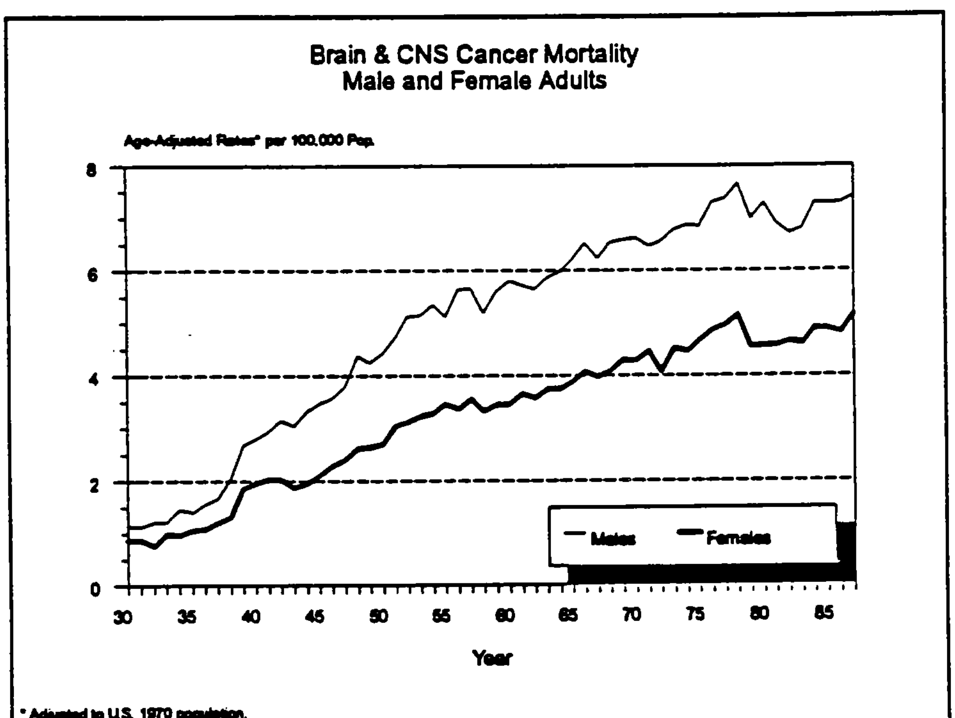

Figure 3-12 - Brain and CNS Cancer Mortality, 1930-87, Male and Female Adults (20-85+ yrs).

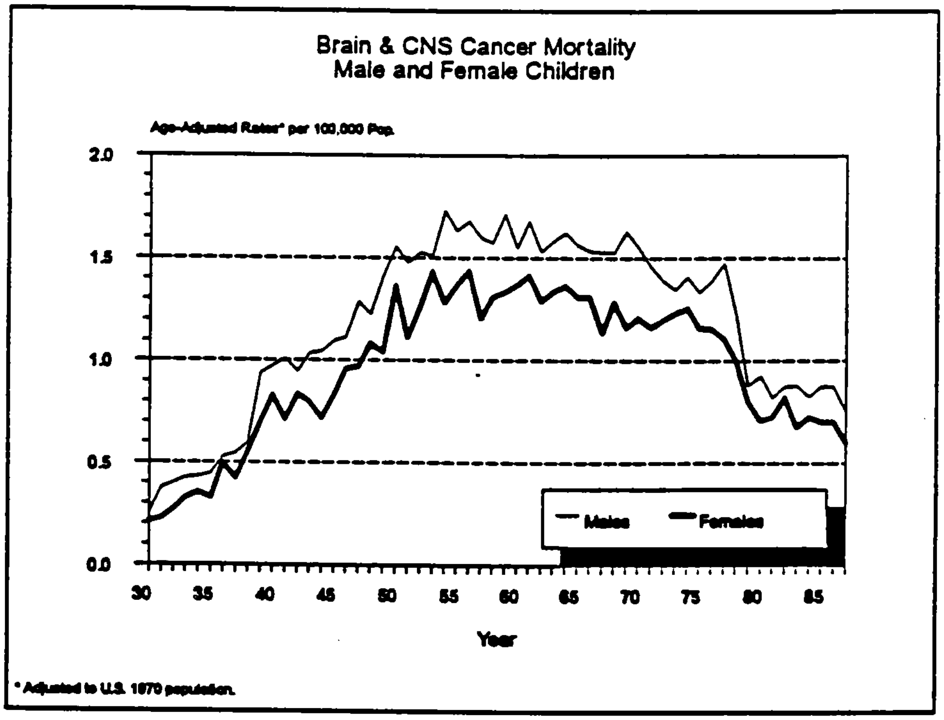

Figure 3-13 - Brain and CNS Cancer Mortality, 1930-87, Male and Female Children.

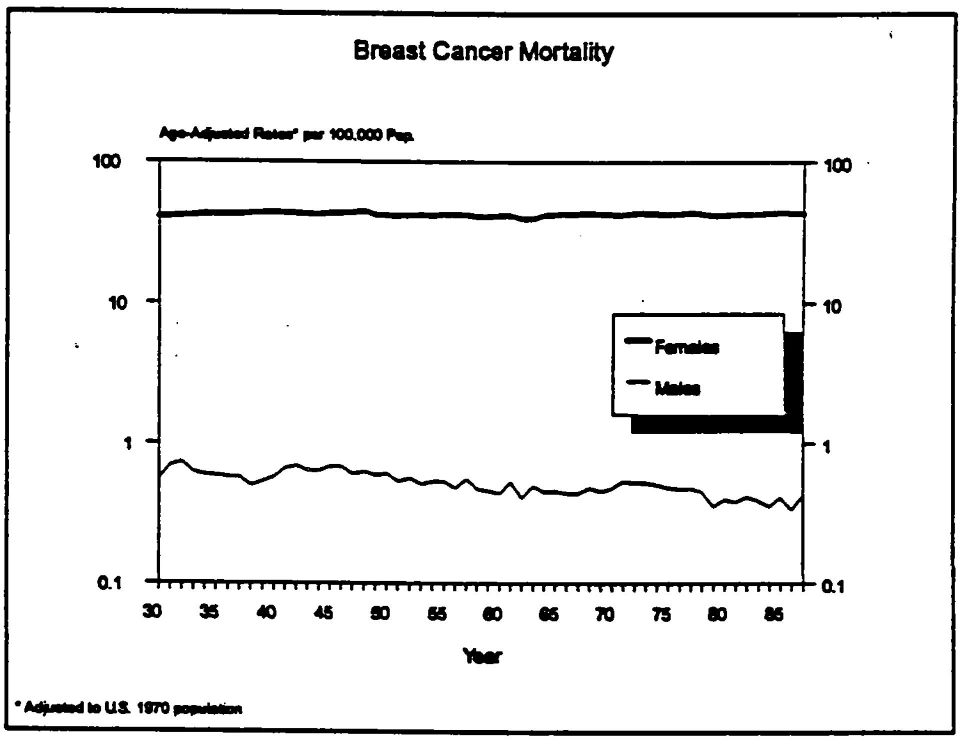

Figure 3-14 - Breast Cancer Mortality, 1930-87, Male and Female Adults (20-85+ yrs).

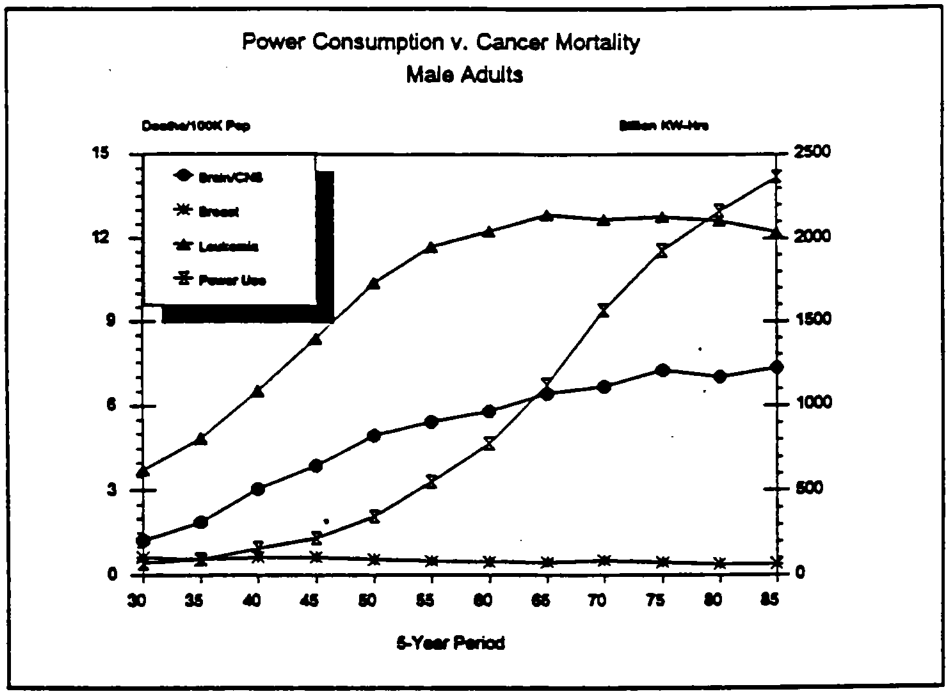

Figure 3-15 - Power Consumption v. Cancer Mortality, 1930-87, Male Adults (20-85+ yrs).

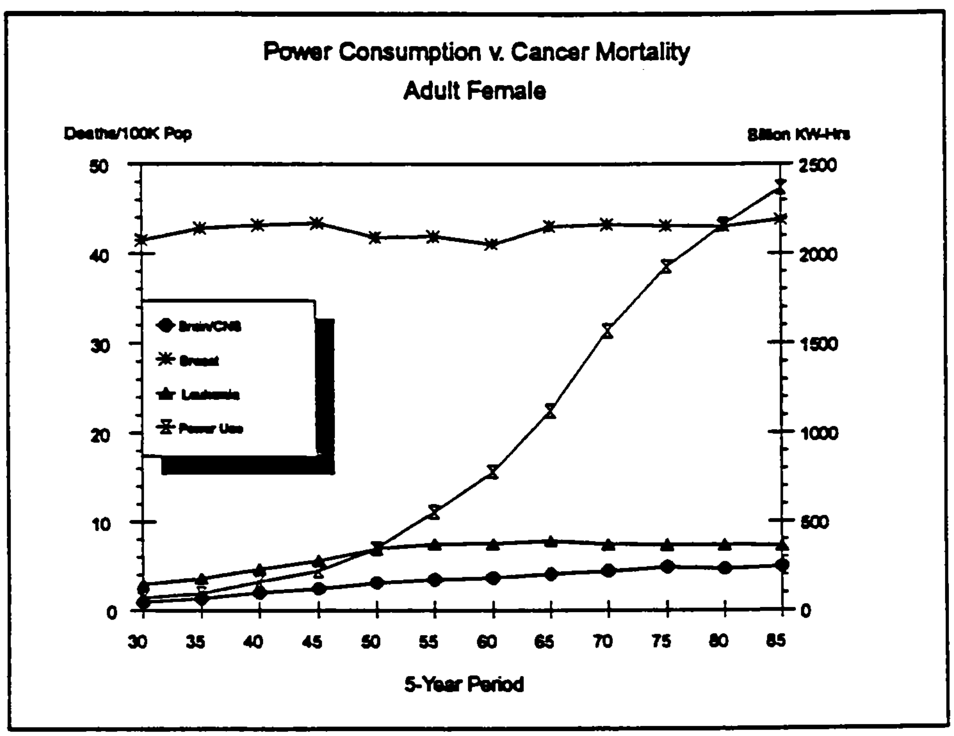

Figure 3-16 - Power Consumption v. Cancer Mortality, 1930-87, Female Adults (20-85+ yrs).

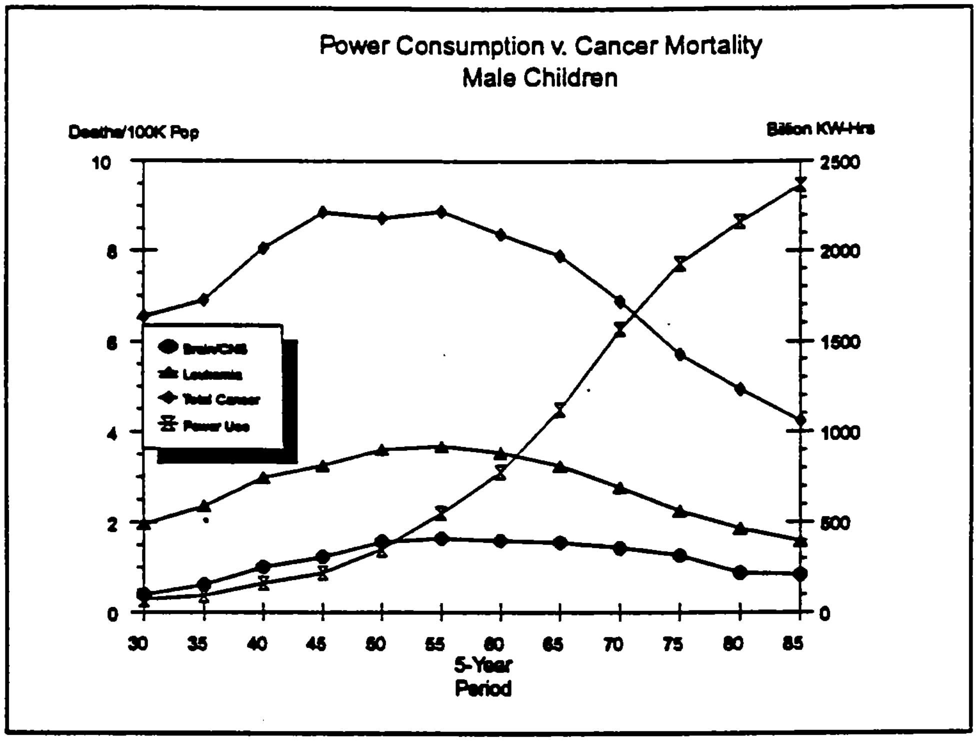

Figure 3-17 - Power Consumption v. Cancer Mortality, 1930-87, Male Children (0-19 yrs).

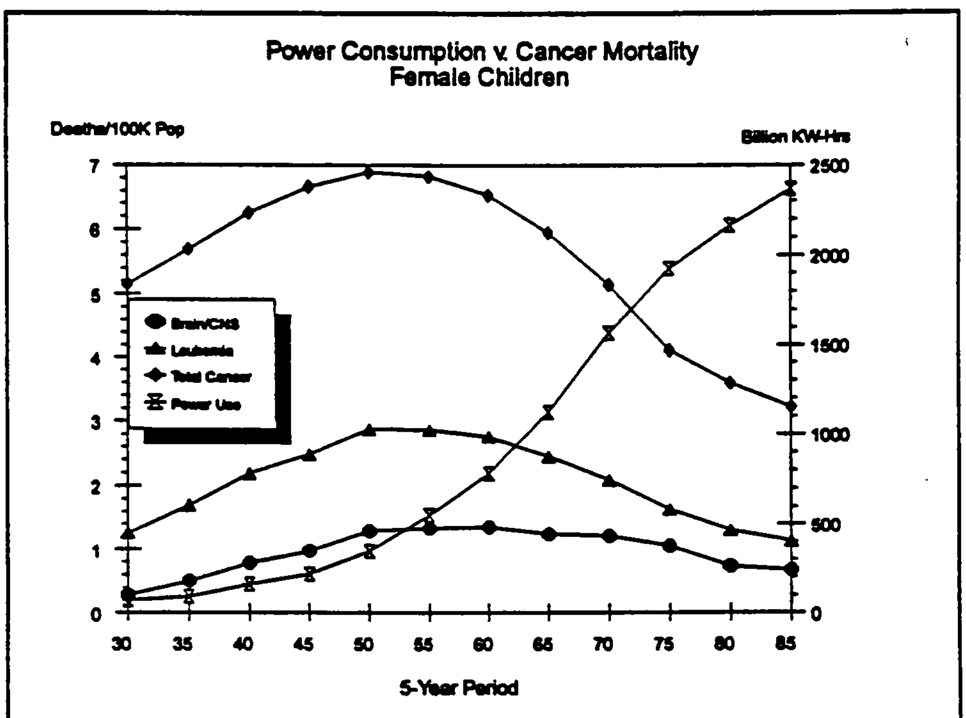

Figure 3-18 - Power Consumption v. Cancer Mortality, 1930-87, Female Children (0-19 yrs).

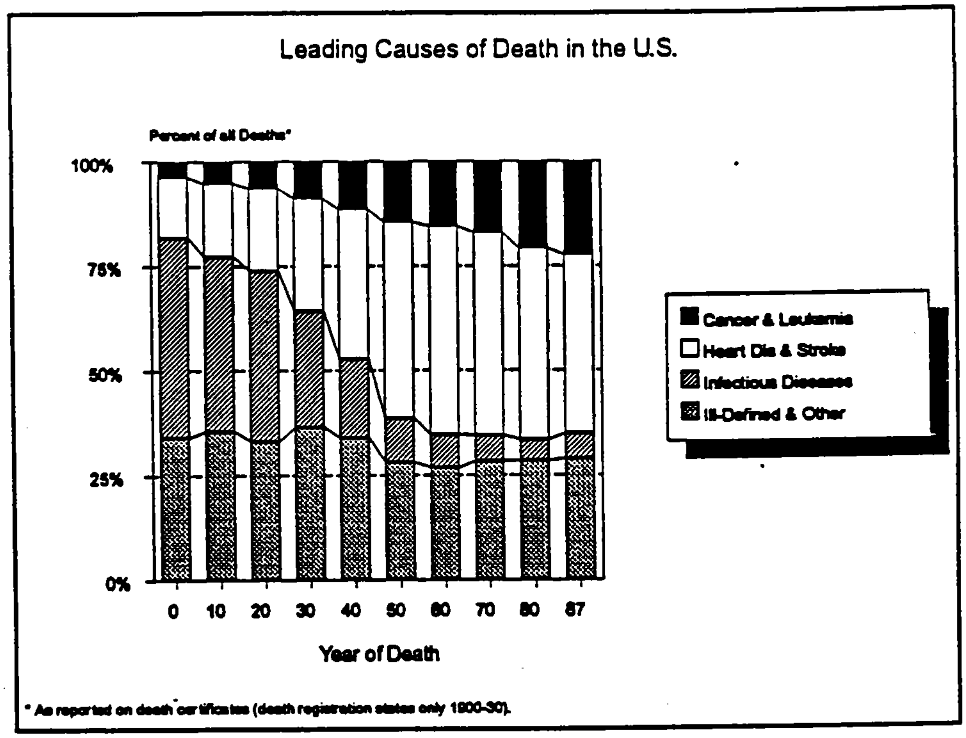

Figure 3-19 - Leading Causes of Death in the U.S. During Each Decade from 1900 to 1987.

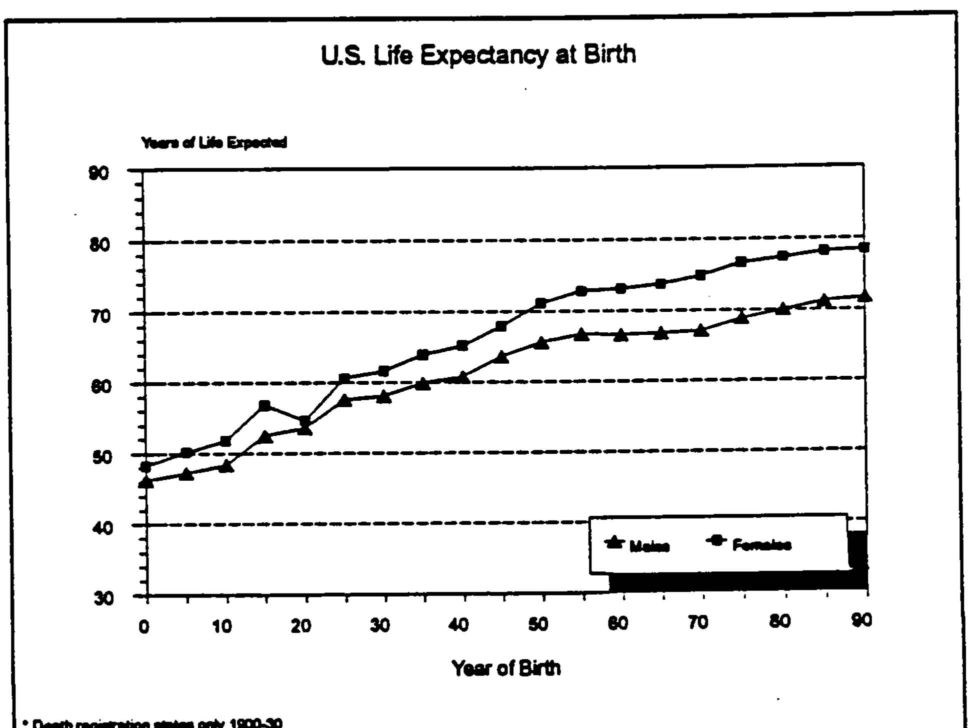

Figure 3-20 - U.S. Life Expectancy at Birth, Males and Females, 1900-1990*.

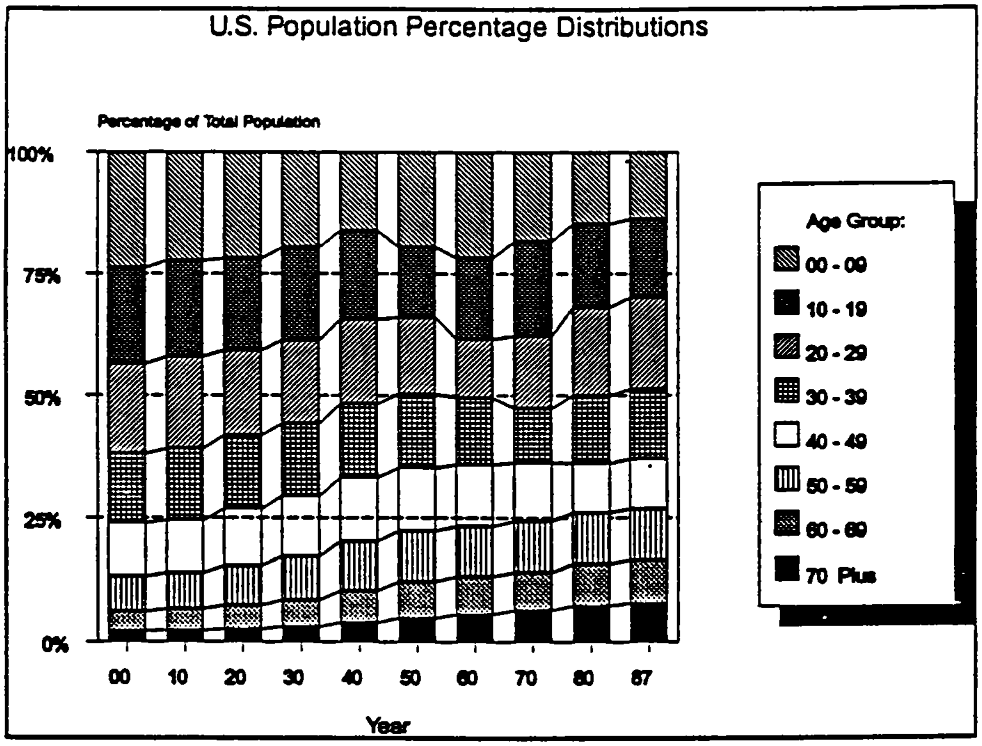

Figure 3-21 - U.S. Population Distributions, 1900 - 1987

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4.0 EXPERIMENTAL STUDIES

4.1 Introduction

Research on the biological effects of electric and magnetic fields (EMF) can be divided into two basic categories: (1) epidemiologic research, previously discussed in section 3.0, and (2) laboratory experimentation comprising in vivo (alive) studies of EMF effects on humans, lower animals (e.g., rats, baboons, etc.), and in vitro (test tube) studies at the cellular level.

Although, laboratory studies generally provide a greater opportunity to control extraneous variables as compared with epidemiologic and field studies, there still exist many opportunities for sources of error to enter into the best designed laboratory study. It is possible that EMF scientific literature, like all scientific literature, contains some false positives (i.e., showing effects, when they truly do not exist) and some false negatives (i.e., showing no effects, when they truly do exist). Although the results of existing EMF research raise a number of interesting questions, the complexity of study findings and the possibility of these errors make it difficult to sort through the literature, interpret the evidence, and draw definite conclusions with respect to EMF effects.

While the quantity and quality of EMF research have improved dramatically in recent years, the EMF effects data base is still in a relative "state of infancy" when compared to the research literature on other environmental exposure risks (e.g., ionizing radiation). Continued experimentation will help to reduce the current level of complexity and inconsistency inherent in EMF findings, while increasing the "robustness" (strength) of test results and confidence in researchers' conclusions. Continued study should include: standardized and broad-based replication of studies, expansion of the number of experimental species exposed to EMF, a high level of quality control maintained across disciplinary lines (i.e., biology, chemistry, engineering, etc.) and, a balanced and flexible cross-section of epidemiologic, in vitro and in vivo studies.

The Committee examined a number of data sources on the biological effects of electric and magnetic fields. Topics included EMF effects on animal and human behavior, cancer, growth and development, endocrine and immune system functions, and biological mechanisms. In an effort to discern and evaluate the often subtle effects of EMF, and to mitigate the potentially confounding effects of naturally-occurring environmental variables, the Committee concentrated on results of in vivo and in vitro controlled laboratory experimentation. Consequently, this report does not address the results of field studies involving crops, livestock, and naturally-occurring vegetation and wildlife.

This review and evaluation used three types of literature sources:

1. Literature summaries and background papers prepared by regulatory agencies, scientific or medical societies. Due to their completeness, these documents were drawn upon heavily to support data evaluations and conclusions regarding specific biological effects. The following summaries and background papers were among those reviewed by the Committee:

   - Congress of the United States Office of Technology Assessment (OTA), 1989.
   - World Health Organization (WHO), 1984.
   - American Institute of Biological Sciences (AIBS), 1985.
   - Florida Electric and Magnetic Fields Science Advisory Commission, 1985.
   - New York State Power Lines Project Scientific Advisory Panel, 1987.
   - Creasey and Goldberg, 1989.
   - Report to the California State Legislative by the California Public Utilities Commission in cooperation with the California Department of Health Services. 1989.
   - Report by T. Sykes and Ping Li for the Washington State Institute for Public Policy. 1990.
   - Oregon Energy Facility Siting Council. 1990.

2. Secondary sources written or edited by members of the scientific community, and public testimony presented by medical/research experts recognized by their peers via professional honors and awards as well as professional appointments. These sources were also used to corroborate statements

and conclusions presented in the aforementioned literature summaries and background papers.

3. Primary research reports published in scientific journals. These sources were consulted primarily to validate statements and conclusions regarding biological effects presented in literature summaries and background papers referenced in the Committee's report.

During the course of this review and evaluation, the Committee found that the EMF scientific literature contains results of laboratory studies that were performed under a variety of conditions, which increases the complexity of reaching conclusions regarding potential EMF effects. Some of these conditions are presented as follows; studies were performed:

- using a variety of animals, human subjects, and tissues;
- using different age groups and sex differences;
- using EMF frequencies other than the 60 and 50-Hz frequencies used to transmit and distribute electricity in the United States and Europe;
- some considered the natural DC magnetic field and others did not;
- exposing animals and tissues to higher fields than would normally be present in nature, even after scaling the exposures to account for the differences in the lower animal's body size as compared to humans; and
- using different exposure durations (e.g., acute and chronic) which may have over or under-exposed the animal or tissue as compared to what happens in nature.

In an attempt to structure the broad spectrum of existing literature, and create a better understanding of the EMF data base, the Committee categorized the report's experimental laboratory studies evaluation into five major sections: (1) Behavior, (2) Cancer, (3) Growth and Development, (4) Endocrine System and Immunity, and (5) Biological Mechanisms. These major section headings are subdivided further to address specific research topics and discuss separately the results of in vivo and in vitro studies.

Reviewers of this document are advised that the results from these laboratory studies should be considered together with epidemiologic study results. Each provides information that is needed to evaluate the overall EMF health issue. Epidemiologic studies provide scientific observations on humans that could not be obtained from human laboratory tests, and conversely, laboratory studies provide information from tests performed on lower animals, that cannot be performed on human subjects.

4.2 Summary

The Committee believes that based on its evaluation of existing research literature, there is at this time no conclusive evidence to suggest that EMF due to electric power transmission lines pose a human health hazard. Results of the studies reviewed are summarized in Tables 4.1 to 4.5 A point-by-point synopsis of the scientific findings which led the Committee to this evaluative judgement is presented herein, followed by detailed accounts of experimental results and conclusions. The Committee feels that this evaluation basically is corroborated in other EMF literature summaries and background reports prepared by expert scientific and research panels (e.g., World Health Organization, American Institute of Biological Sciences, State of Florida Electric and Magnetic Fields Science Advisory Commission, Office of Technology Assessment, The California Public Utilities Commission in cooperation with the California Department of Health Services, Washington State Institute for Public Policy, and New York State Power Lines Project Scientific Advisory Panel.)

A number of the in vitro studies reviewed, reported some degree of effects on cells exposed to EMF, while many others have reported no effects. Although cellular changes may occur in vitro, these changes may not express themselves in the whole animal. For example, when a cell is perturbed by an external agent, other cellular processes may compensate for the change, so that there are no overall adverse effects on the organism. Although the results of these in vitro studies are complex and inconclusive, the growing number of positive findings has suggested that under specific conditions even weak EMF can produce changes at the cellular level.

As is the case with in vitro studies, some in vivo studies have shown positive effects of exposing the whole animal to EMF, while other studies have reported no effects. Although it is not certain that the effects observed in lower animals exposed to EMF will also be expressed in humans, the assumption made when dealing with human health is that similar effects may also be manifested in humans. This relationship is not always assumed when extrapolating observed cellular effects to whole animals.

The results of the laboratory studies evaluated by the Committee are inconsistent and in some cases inconclusive, but enough information has been reported so the following observations can be made:

- It appears that many variables can possibly affect the results of laboratory studies, including frequency, field intensity, exposure duration, earth's static magnetic field, and frequent periods of exposure (that is chronic exposure may be less perturbing than a pattern that involves frequent periods of exposure and non-exposure). Undoubtedly, these variables play an important part in the inconsistences reported in the literature.

- It has been shown that animals, including humans, can detect fields under certain conditions and this stimulus results in certain physiological changes. Also, under given conditions animals may avoid electric fields, but such actions have been shown to be mostly transient, sometimes lasting only a few minutes. Electric fields have not caused continued aversive (avoidance) behavior, except at fields high enough to produce an electric shock. It is felt that these behavioral effects recorded in the literature do not constitute a health risk.

- It is generally accepted that power-frequency fields do not cause damage to genetic material (e.g., DNA, chromosomes), as in the case with higher (ionizing) frequencies. However, changes have been observed in the rate of DNA synthesis and in the production of altered proteins, by interfering with the transcription by the RNA. The specific mechanism responsible for these changes or the significance of these changes on the whole organism is unknown.

- It is generally accepted that power-frequency fields are not cancer initiators, since they do not cause genetic damage. However, scientists have suggested that EMF can be a cancer promoter. Two general classes of in vitro studies are being performed to test the promotion theory. One is the use of a biochemical marker (i.e., ornthnithine decarboxylase-ODC), and the other is the study of cell membrane modulators which control or inhibit calcium efflux or cause an internal redistribution of calcium, that may stimulate promotion of cancer. No firm conclusions can be drawn on the promotion theory at this time. Hypotheses are only now being advanced. Indirect results are compatible with the hypothesis that EMF may be a cancer promoter. Additional information is clearly needed.

- Most of the EMF studies reviewed found no effects during embryonic development (i.e., teratogenic effects) or during post-natal growth. A few studies do show effects, some of which occurred only under "pulsed" fields, which are not normally associated with 50 or 60-Hz AC transmission lines. Overall these laboratory studies tend to lead to the conclusion that there is no effect on development or growth from EMF. However, several recent studies performed on chicken eggs exposed to "pulsed" fields have shown possible teratogenic effects when exposure occurs during early embryonic development. Reports on chicken teratogenesis, however, have shown contradictory results, and studies using chicken embryos are of limited use in predicting teratogenic hazards in humans.

- Based on several studies, EMF exposure apparently causes changes in the function of the endocrine system of animals. For example, reduction in nighttime melatonin production and alteration of an animal's biological rhythms have been recorded in animals exposed to 60-Hz electric fields. These observed changes are within the range of normal changes observed in function of the endocrine system when stimulated from other external stimuli (e.g., temperature, noise, light/dark). Numerous physiological effects have been hypothesized, due to melatonin reduction. However, the potential effects of EMF on endocrine functions needs further investigation.

- Exposure to EMF has been theorized to affect the animal's immune system. Whole animal studies (i.e., in vivo) have not shown such an effect. However, certain cellular studies (i.e., in vitro) have shown effects, while others have not. This inconsistency may be due to the "window effect." That is, effects may be observed at certain frequencies and intensities, but not at those below or above the "window". No definitive conclusions can be drawn from the existing data base. However, since the immune system is a major surveillance mechanism that protects the host animal from a variety of diseases, it is important to further explore effects of EMF on the functions of the immune system. Hypotheses need to be developed and tested before any definitive conclusion can be drawn.

- Since power-frequency fields (i.e., 50 and 60-Hz) at environmental levels are not sufficiently intense to break chemical bonds or warm the tissue, many scientists have felt that insuffiicent energy could be transferred to biological systems to induce any changes. However, recent studies have suggested that under certain conditions these low intensity fields can induce changes at the cellular level. The actual biological mechanism is unknown, but various ones have been postulated. All of the proposed mechanisms are speculative at this time. More mechanistic research is needed to test the plausibility of human health effects. If a mechanism is established at the cellular level, this will support the results from the positive epidemiologic and in vivo laboratory studies.

4.3 Effects on Animal and Human Behavior

A review of extant research literature evaluating EMF effects produced by high-voltage AC powerlines on animal behavior can be divided into four main topics: detectability, avoidance, activity, and performance. Observable and/or undetectable and subtle effects of EMF on the biochemical/physiological integrity of whole organisms may cause changes in these behavioral areas, some of which may be disruptive to the animal. As stated by Salzinger (1989), "the exquisite sensitivity of behavior makes it an effective early warning system for illness."

4.3.1 Detectability

Results of experiments performed on the ability of various test animals to detect EMF have shown that such fields can be sensed by certain species under certain conditions. Stern et al. (1983) and Stern and Laties (1985) reported that rats detected electric fields as low as 3 kV/m, and as high as 10 kV/m. Kato et al. (1989) reported that the body hair and whiskers of rodents vibrated when the animals were exposed to electric fields; however, such sensitivity has been shown to be extremely weak as opposed to sensitivities to visual, audio, touch, smell, and taste stimuli (Terrace, 1988). Stell and Adey (1988) found that Sprague-Dawley rats exposed to 60-Hz electric fields and monitored for detection of fields, as a function of circadian rhythm activity exhibited no differences in detection performance during high or low activity periods. Their data did not indicate a difference in the rat's ability to detect an electric field up to 25 kV/m, during different phases of their circadian rhythm cycle.

Perception of EMF in humans typically is accompanied by movement of hairs on the back of the neck, arms, and/or hands, in response to the electric and magnetic force of the fields. Kato et al. (1989) reported that when hair follicle receptors are excited by an electric field, the hairs actually vibrate.

In relation to the ability of humans to detect an electric field, Terrace (1988) noted that various studies have reported threshold levels ranging from 9 to 27 kV/m. Deno and Zaffanella (1975, as cited in Stern et al, 1983) reported humans being able to detect electric fields between 5 and 15 kV/m. Graham and Cohen (1985) found that 90% of seated humans could detect an electric field of 9 kV/m. Also, 20 Hz is the frequency reported at which the greatest sensitivity to EMF has been observed in humans. This frequency is much lower than the frequency used for AC power line transmission (50 and 60-Hz).

Tucker and Schmitt (1978) found that, out of 200 humans, none could perceive a magnetic field of 7.5 - 15 gauss. Graham and Cohen (1985) found that humans could not detect magnetic fields up to 0.4 gauss.

4.3.2 Avoidance

The fact that certain animals and humans can detect the presence of EMF does not provide the information necessary to predict whether the organism will find that stimulus pleasant, annoying, or innocuous. Given that an animal could in some way detect the presence of EMF, and that detection resulted in physical discomfort and/or physiological distress, an avoidance behavior response might be expected. However, experimental results to date are inconclusive. With respect to avoidance, Hjeresen et al. (1980) showed that as electric field strengths increased, rats avoided electric fields of 75 kV/m. However, a subsequent re-analysis of the data showed that the rats avoided these fields only during their sleep/rest periods (i.e., light part of the 12 hour light/12 hour dark cycle). Hjeresen et al. (1982) observed similar results in female miniature pigs exposed to 30 kV/m; that is, the pigs avoided the fields during their sleep/rest period. However, Creim et al. (1982, cited in California Public Utilities Commission 1989) using the same apparatus as in Hjeresen et al. (1982) study, observed no effects on rats exposed to electric fields up to 100 kV/m.

Stern and Laties (1987) found that, under many conditions, even in a 100-kV/m electric field (60 Hz), these fields were not a very aversive stimuli for rats. In a saccharin-flavored water experiment, Creim et al. (1984) concluded that exposure of moderate duration to 60-Hz electric fields (133 kV/m or less) did not produce taste-aversion learning in rats. In a number of instances, reactions to electric fields have been shown to be transient, sometimes lasting only a few minutes (Hackman and Graves, 1981; Graves et al., 1977 cited in Florida Electric and Magnetic Fields Science Advisory Commission, 1985). Researchers typically attribute this initial response to the animals' recognition of an environmental change, (i.e., "what-is-it?") to which the animal rapidly adjusts (Hackman and Graves, 1981; Rosenberg et al., 1981).

Based on a review of recent research summaries and background papers, the Committee finds that exposure of laboratory animals (primarily rodents) to a variety of electric fields has failed to produce any conclusive evidence of physical discomfort or internal distress. Further, electric fields have not been shown to be aversive stimuli, unless the field is intense enough to produce electric shocks. Results of conditioning studies have failed to yield any evidence that EMF can motivate an animal to avoid such fields, or that such fields can cause conditional feelings of internal unpleasantness or stress. Finally, studies using biological indicators as direct measures of stress have failed to yield any evidence that EMF are aversive stimuli. These conclusions basically coincide with findings reached by the Office of Technology Assessment (OTA, 1989), by testimony given by Dr. H. S. Terrace (Terrace, 1988) and the excellent summary prepared by Salzinger in the California Public Utilities Commission Report (1989).

4.3.3 Activity

Another area of research drawing the attention of behavioral scientists is the possible effect(s) of EMF on general animal activity as controlled by circadian rhythms and physiochemical regulators. To date, there is a general lack of consistency in these studies regarding EMF effects. Some studies have reported no effects (Smith et al., 1979; Graves et al., 1985) while others report a variety of effects (Hjeresen et al., 1980 and 1982; Rosenberg et al., 1981 and 1983). In Salzinger's summary report (California Public Utilities Commission Report, 1989), he states that there is some increase in activity in exposed adult animals and some evidence of reduction in activity when the exposure takes place pre- and/or perinatally.

Smith and Justesen (1977, cited in California Public Utilities Commission Report, 1989) reported a slight increase in the motor behavior of mice in the presence of 60-Hz magnetic fields; however, this increased activity was not sustained and was observed only at the onset of field charge. Davis et al. (1984) found no changes in mice activity levels in the presence of DC or AC magnetic fields. Groh et al. (1988) found that a response to an electric field (especially observed phase shifts in light/dark-induced circadian rhythms) depended on field strengths (>25 to 35 kV/m), a seasonal light/dark effect sensitivity, and exposure during susceptible phases of the circadian cycle. They observed a threshold of 25 to 35 kV/m below which the majority of mice showed no consistent, measurable response, and a maximized effect above 100 kV/m, but no simple dose-dependent response for activity, or respiration. They concluded that, based on results of their experiments, all known potential long-term health risk effects of high-intensity electric fields could be attributed to their actions as circadian regulators.

Working with social groups of baboons, Rogers et al. (1988) found that exposure to 60-Hz electric fields produced changes in posture and positions, usually at the onset of field charge. They suggested that the animals reacted (huddled together) perhaps to reduce field strength, and to increase shielding, all protective responses to perceived stimuli. However, these reactions were not consistent across all experiments and were temporary in nature. The huddling effect was found to be dependent on the strength of the fields. After three days of exposure, proximity values (i.e., baboon locations relative to one another) returned to normal, and re-exposure of previously exposed animals produced no effects. Rogers et al. (1988) concluded that exposed animals reacted to the field as a threat by huddling at the beginning of exposure, "learning" after some time that there was no danger, and returning to normal patterns.

Based on a review of behavioral research performed to date, the Committee concludes that positive results from research on EMF effects on activity show that observed responses appear to be transient orienting responses (i.e., responses to stimuli not previously encountered). Under normal environmental conditions, there appears to be no indication that exposure to EMF alters circadian rhythms. Where effects on circadian rhythms have been reported, findings have come from studies concluded under unnatural laboratory conditions that attempt to eliminate any cue to time of day. Additionally, exposures reported to be capable of altering circadian rhythms have been much higher than those that would be encountered in the immediate vicinity of a high-voltage transmission line.

The Committee's findings parallel the conclusions drawn by the American Institute of Biological Sciences (1985) in their post-1977 literature review on biological and human health effects of extremely low frequency electromagnetic fields, by Terrace (1988) in his summary of research regarding EMF effects on activity, and by the Office of Technology Assessment (1989) in their literature review of the biological effects of power frequency electric and magnetic fields. These publications concluded that none of the subtle effects of electric and magnetic fields reported in the scientific literature constitute a definite health risk, and that observed behavioral effects appear to represent an initial awareness response to an external stimulus, to which the organism quickly adjusts. Although 60-Hz fields appear to have an effect on the periodicity of physiological functioning, it has not been proven that these effects are harmful or even prolonged.

4.3.4 Performance

A large number of research studies have evaluated the effects of EMF on the performance of learned behavior in animals, including humans. Again, study results have been inconclusive. Coelho et al. (1987) found that performance rates of tension, foraging, and grouping stereotype behavior in baboons exposed to 30 kV/m and 60 kV/m were significantly elevated during the exposure period as compared to pre and post-exposure periods. However, some of these same researchers found that baboons exposed for six weeks to 30 kV/m or 60 kV/m electric fields exhibited only transitory behavioral changes (Rogers et al., 1988). Behavior patterns returned to normal in one to three weeks after exposure. The threshold for electric field detection was 13 kV/m, and no effects were detected for acquisition, performance or response to food offerings. Orr et al. (1987) reported that responses of baboons to food reward were affected by 30 kV/m and 60 kV/m (60 Hz) electric fields upon initial field exposure, but responses returned to normal within a few days.

Salzinger et al., 1987 (as cited in Salzinger, 1989) found no effects on the performance of a memory task by adult male rats exposed for 72 hours to 60-Hz electric and magnetic fields of 1 gauss and 30 kV/m. However, when these same experiments were performed on adult female rats exposed while pregnant (22 days) and for the first eight days of life, a trend toward a reduction in response rate was evident in the offspring.

The effects of 60-Hz EMF on performance of human subjects have been studied by a number of researchers. Gibson and Moroney (1974) attempted to evaluate the effect of EMF on human performance as measured by a battery of standard intellectual tests in the presence and absence of such fields. In each instance, EMF failed to produce any decrement in performance. Gamberale et al. (1987) examined 26 utility linemen in the laboratory over two days, measuring behavioral performance, EEG, mood scales, subjective symptoms and various blood chemistry parameters. No statistical difference was observed between exposed and control groups which could be attributed to exposure to EMF. In two double-blind experiments, exposing male humans to an electric field of 9 kV/m and a magnetic field of 200 mG, Graham et al. (1988) reported a slowing of the heart rate and changes in the central nervous system. These changes tended to occur soon after field onset or offset, suggesting that changes in exposure may be more important than exposure duration. However, exposure to higher levels (12 kV/m, 300 mG), resulted in no consistent significant differences between the exposed and control groups. They postulated that exposure may interact with biological systems only in certain limited "windows" of stimulation, i.e., for a particular frequency, some field intensities may produce an effect but intensities below or above the "window" do not.

A number of researchers have reported similar results, i.e., that EMF effects observed at a particular field strength appear to be "tuned out" by changing the field frequency or intensity.

This apparently unusual relationship between EMF and biological system interaction tends to complicate the usually clear correlation between a measure of exposure to a physical/chemical agent "dose" and the consequent effect.

The apparent "window" nature of these effects may imply that effects seen at particular frequencies may not be observed at other, higher or lower values. Similarly, the often-applied "more is worse" relationship between dose and effect used so often when applied to chemical exposure does not appear to hold, since for a number of experiments larger values of an applied field have not caused a larger, or in some cases any effect, compared to a reduced field.

Alternatively, changes in conditions of exposure, or changes associated with differences in field onset or offset, may be relatively more important than either duration or intensity of exposure to a steady-state field. For example, OTA (1989) reported that background static field conditions (i.e., how a field is applied relative to earth's natural static magnetic field) may influence the observed effects of an applied EMF.

The Committee feels that based on the results of studies reviewed, it appears that EMF effects observed under laboratory conditions have no long-lasting effects on lower animals or humans in short-term memory or cognition. However, possible effects on learning needs further investigation. Effects such as slightly slower reaction times and transient slowing of heart rate can be attributed to orienting responses which can be evoked by a variety of natural stimuli as well as EMF.

4.3.5 Conclusions

The Committee feels that, after a review of existing research literature, we can conclude that EMF behavioral research to date has shown no effects of any significance to human health risks related to psychological functions/behavioral response.

When detected, EMF appear to elicit a "something's there" recognition response, similar to normal reactions to previously unencountered stimuli. No research to date has presented any conclusive evidence that these fields, detected or not, produce any deleterious and/or long-lasting impacts on lower animal or human behavior. These views are shared by other scientific and research agencies such as the Office of Technology Assessment (OTA, 1989), and The American Institute of Biological Sciences (AIBS, 1985).

4.4 Cancer

4.4.1 Cause - Effect Relationships

Determining the cause of the various human cancer types and their specific location (i.e., organ) has been and is continuing to be a difficult task. The discussion in section 3.0 (National Cancer Rates) provides information on various cancer rates since 1950. Our understanding of the cause-effect relationships of various cancers has greatly increased over the past 30 years. We know that certain risk factors are associated with certain cancer types. For example, smoking is related to lung and oral cancers, the sun's rays (i.e., ultraviolet) to skin cancer and a high-fat diet to cancer of the breast and colon tract. However, research to determine an association between EMF exposure and cancer is still in the infancy stage, when compared to the volumes of research literature on other environmental exposure risks (e.g., at least 50 years of data on ionizing radiation). The literature does not contain years of scientific studies covering the 50 and 60-Hz frequencies, from which definitive conclusions can be drawn. Various cancer types and locations in the body (i.e., organs) have been attributed to EMF exposure. However, it appears, based on the aforementioned epidemiologic studies, that possible cancer types attributed to EMF are being narrowed somewhat to leukemias in children, and tumors of the central nervous system in adults.

4.4.2 Carcinogenesis Models

An integral part of defining any possible relationship between cancer and EMF is the establishment of a plausible biological mechanism. It has been proposed by certain scientists that EMF may promote cancer after another agent has initiated the cancer forming process. The carcinogenesis process has been described using both a two-stage model, and a three-stage model.

Stage 1 is the "initiation," which results in a permanent (i.e., non-reversible) change or mutation of the cell's genetic material (i.e., DNA). Initiation is caused by carcinogenic agents, like ionizing radiation and certain chemicals. Stage 2 is called "promotion," in which the initiated cells expand into a visible tumor after repeated exposure to the promoting agent (e.g., phorbol esters). These changes may not be permanent, and can be reversed in some cases. In the two stage model, the tumor may be benign or malignant. In the three stage model, the benign tumor becomes malignant by passing through a third stage called "progression."

4.4.3 Cancer Initiation

Generally, it is relatively accepted by most scientists that EMF are not cancer initiators, i.e., cells exposed to EMF have not shown any change or mutation in the DNA material, a requirement of an initiator. Human lymphocytes (i.e., white blood cells) showed no effects when exposed to 60-Hz fields (Cohen, 1986; Cohen et al., 1986a; 1986b as cited in Creasey and Goldberg; Livingston et al. 1986). No effects were observed in mouse bone marrow cells (Carstensen, 1987) and Chinese hamster ovary cells (Reese et al. 1988) exposed to EMF. Also, it was the conclusion of the New York State Powerlines Project Scientific Advisory Panel (1987), that it was unlikely that electric and magnetic fields damage human chromosomes.

However, other studies have attributed DNA damage to EMF exposure. Nordenson and Hansson (1987) reported chromosome damage in human amniotic cells exposed to 50-Hz sinusoidal and 20-kHz sawtooth magnetic fields. But no chromosome damage was observed in switchyard workers during a study by Bauchinger et al. (1981). d'Ambrosio et al. (1985) found an increased percentage of chromosome aberrations in bovine peripheral blood lymphocytes (i.e., white blood cells) exposed to 50-Hz electric fields for 72 hours. El Nahas and Oraby (1989, cited in Creasey and Goldberg, 1989) exposed Swiss male mice to 100, 170, 220, and 290 kV/m 50-Hz electric fields for 24 hours. The high exposure was to scale up to humans. They found no increase in micronuclear polychromatic erythrocytes (i.e., red blood cells) in the bone marrow exposed to 100 kV/m, but significant increases occurred in those mice exposed to the higher fields. Since the exposure system was not described in great detail, the observed effects may have been due to "microshocks" at the higher exposure levels.

Study results are inconsistent and a few researchers do report effects on genetic material. It is possible that effects may be observed at a field of 50 Hz, but not at 60 Hz, a possibility stated by Creasey and Goldberg (1989) in their summary report; Extremely Low Frequency - Electric and Magnetic Fields and Cancer: A Literature Review. However, given the present status of the EMF data base, it is the position of the Committee that EMF are not cancer initiators. Permanent changes in DNA material or abnormalities caused by damage to cellular DNA production or repair mechanisms would provide evidence that EMF acts as a cancer initiator. However, to date researchers have been unable to demonstrate any conclusive detrimental differences between the DNA structure and function of EMF-exposed and unexposed cells. This conclusion concurs with Rosen's (1988) position in his review of electric and magnetic field health concerns, wherein he states: "Studies of genetic damage are relevant to the initiation stage. Changes in DNA production or repair, or the occurrence of abnormalities, would be manifest as permanent changes in the DNA material. To date, data demonstrate no difference between cells exposed to electric and/or magnetic fields and sham conditions."

4.4.4 Cancer Promotion

EMF apparently are not cancer initiators; however, certain scientists believe that EMF are possible cancer promoters, i.e., they begin the second stage of the cancer-forming process (tumor formation). Certain studies have not shown EMF to be a cancer promoter. However, the current data base is insufficient to either accept or reject the promotion hypothesis. Most in vivo studies have transplanted tumors into normal animals, or exposed these animals to known cancer initiators and then exposed them to EMF. As stated by Creasey and Goldberg (1989) "no studies have been done that expose normal animals to extremely low frequency (ELF) EMF and follow the spontaneous development of tumors." They recommend using rodent strains having a high natural incidence of malignancies to test the promotion hypothesis. These animals are genetically predisposed toward cancer and genetic factors are considered to constitute the initiation step. For example, mice with a high frequency of mammary cancer (e.g., the C3H strain), and rats prone to leukemia (e.g., the ACT strain) might be suitable models.

<u>In Vitro Studies.</u> The growth enzyme ornithine decarboxylase (ODC) has been used as an indirect marker of the promotion step in carcinogenesis. It has been shown that ODC production increased in those cells exposed <u>in vitro</u> to EMF, depending on amplitude, frequency and exposure duration (Byus and Adey, 1988). This increase, however, does not necessarily mean that since ODC increased, these cells are on their way to becoming a tumor and EMF are cancer promoters. A variety of stimuli, which do not play a role in carcinogenesis, will induce ODC activity (e.g., drugs, hormones). In addition, the enhancement of ODC activity by EMF was much less than for known promoters, such as phorbol esters. However, it is firmly established that all cells that are becoming tumors have increased ODC activity, and have lost their ability to control the activity of the enzyme.

Frazier et al. (1989) tested the hypothesis that EMF can promote transformation of initiated cells. They exposed cells (i.e., C3H10T1/2) to various exposure combinations; and initiator (i.e., 60Co irradiation), a known promoter [i.e., 12-0-tetradecanoyl-phorbol-13-acetate (TPA)] and to 0.1, 0.75 or 6.0 G of 60-Hz AC magnetic fields. The radiation exposures significantly increased the transformation frequencies and, as predicted, TPA increased transformation frequencies of irradiated cells by approximately 10 times. However, exposure to the magnetic fields did not significantly alter transformation frequencies of either initiated or promoted cells as compared to sham-exposed cells, an indication that magnetic fields are not carcinogenic promoters.

Other <u>in vitro</u> studies have shown that cells exposed to EMF undergo changes in enzyme activity (Cain et al. 1987) and cell-to-cell communication (Fletcher et al. 1987), changes that are similar to those caused by known cancer promoters (e.g., phorbol esters). Phillips et al. (1986 cited in the California Report, 1989) observed enhanced growth rates in malignant human colon cancer cells exposed to EMF, but Cohen (1987) could not duplicate the same results. Also, Adolphe et al. (1987 as cited in Creasey and Goldberg, 1989) observed no effect on growth of malignant human uterine cervical cancer cells in culture exposed to 50-Hz EMF. Goodman et al. (1989) observed induced quantitative changes in messenger RNA (MRNA) and proteins in human cells (HLGO) exposed to sinusoidal signals with repetition rates at 60 Hz and 72 Hz.

Although the results of in vitro studies are far from proving or disproving that EMF are cancer promoters, such findings cannot be ignored and additional information is needed.

In Vivo Studies. There have been several in vivo studies using various animals for testing the EMF-cancer promotion hypothesis. The majority of studies have shown no effects, with a few experiments even showing beneficial effects. Leung et al. (1988b) reported no significant differences between electric field exposed and unexposed rats in the number of rats that developed mammary tumors, but did find an increase in the number of mammary tumors per tumor-bearing rats exposed to 7, 12-dimethylbenzene (a) anthracene (DMBA) and 60-Hz (40 kV/m) electric fields as compared with those only exposed to the tumor inducing chemical. Chandra and Stefano (1978) found no effect on the growth characteristics of mouse mammary tumors exposed to magnetic fields before (i.e., in vitro) or after being transplanted (i.e., in vivo) into healthy mice. Thomson et al. (1988) observed no effect on the incidence or progression of P388 leukemia cells implanted in mice exposed to 60-Hz magnetic fields. Batkin and Tabrah (1977 cited in the California Report, 1989) actually reported a decrease in mouse tumor growth in response to 60-Hz magnetic field exposure.

4.4.5 Conclusions

The Committee is of the opinion that the present literature indicates that EMF are not cancer initiators, but indirect results are compatible with the hypothesis that EMF may be cancer promoters. The results neither prove nor disprove the cancer promotion hypothesis. Additional information is clearly needed.

4.5 Development and Growth

4.5.1 Teratogenic Effects

Numerous laboratory studies have been performed to evaluate the effects of EMF exposure on the development and growth rates of lower animals. Teratogenic effects are those that occur during embryonic development, and if effects occur, they are manifested in the malformation of the off-spring. Various in vivo studies using different test animals have been performed to determine if teratogenic effects occur due to EMF exposure.

Graves et al. (1985) exposed over 20,000 chicken embryos to 60-Hz electric fields from 0.1 to 100 kV/m, and looked for effects during incubation, at hatching and after hatching. They observed no significant change in growth, development or overall health of the exposed chicken embryos. Sikov et al. (1987) reported malformations in Hanford miniature swine offspring of EMF-exposed sows. Durfee et al. (1975, cited in the Florida Report, 1985) exposed chicken embryos to fields of 0.001 to 3.6 kV/m at a frequency of 45 Hz to 75 Hz during and after incubation and observed no effects on fertility, hatchability, survivability, weight gain, or behavior. Sandstrom et al. (1987) exposed fertilized hen eggs, during the first two days of development, to magnetic fields with an asymmetrical saw-tooth waveform, with no observed significant increase of abnormalities. However, Delgado et al. (1982) reported abnormalities in chicken embryos exposed to low frequency pulsed magnetic fields (fields which are turned on quickly for only a brief period - not normally found associated with transmission lines) during early development. Ubeda et al. (1983) also observed effects in chick embryos exposed during the first 48 hours of development to pulsed electric and magnetic fields. Subsequent independent studies were unable to replicate these teratogenic effects (Sisken et al. 1986; Maffeo et al. 1984).

In an attempt to resolve the contradictory results from these studies, the U.S. Office of Naval Research and the U.S. Environmental Protection Agency sponsored the "henhouse project". This project consisted of replicating the same experiment at six independent laboratories around the world. Each laboratory exposed chicken eggs to extremely weak unipolar pulsed magnetic fields with the same set of characteristics, and evaluated the same set of parameters: egg fertility, and embryo abnormalities in development and growth. When the data were combined for all six laboratories, an overall increase in the proportion of abnormal chick embryos was found for the exposed embryos. However, the exact proportion of abnormalities in the exposed population varied from lab to lab. Two of the six laboratories reported a significant increase in the proportion of abnormal embryos, while four labs observed no effects (Berman et al. 1988a, 1988b). Since these results were reported for pulsed magnetic fields, not usually associated with powerline transmissions, implications of these findings for lower animals and humans exposed to 60-Hz fields are highly uncertain. This conclusion was drawn in the summary report prepared by the Office of Technology Assessment (1989). In addition, the chicken embryo has been rejected as a standard model to be used in evaluating the teratogenic potential of chemicals and, therefore, may not be a good model for evaluating the teratogenic potential from EMF exposures.

An important consideration in the use of chick embryos to monitor for possible teratogenic effects of EMF may be the criticality of time of exposure relative to embryonic development. For example, Martin (1988) observed effects when exposure to pulsed EMF occurred during the first 24 hours of incubation, but found no effects if the embryos were exposed later in their development. Also, as stated by Creasey and Goldberg (1989) genetics may play an important part in the variability of study results, since it is known that chickens of the same strain are not necessarily genetically similar. Supporting this possibility is Martin's (1989) finding that effects were observed in one strain (i.e., White Leghorn) of chick embryo, exposed to pulsed fields, but not in another (i.e., Arbor Acre). Another point that makes interpretation of the data more difficult is the observation made by Chernoff (1989) that there is a high incidence of abnormal embryos found in the control eggs in many investigations. Thus, the results observed may be due to unrecognized factors, unrelated to EMF.

4.5.2 Reproductive Effects

Seto et al. (1983) exposed rats to an electric field of 80 kV/m for 21 hr/day until approximately 120 days of age. There was no statistically significant effect on food and water uptake. However, there were significant growth pattern effects from four to eight weeks of age, which were not observed beyond eight weeks. Stuchly et al. (1987) found no statistical differences between rats exposed to magnetic fields of an unsymmetrical sawtooth waveform, and those not exposed. Sikov et al. (1978, 1984) exposed rats to electric fields prior to mating, and continued exposure of the pregnant females and observed no effects on fetal length or weight or on internal or external malformations. However, they did observe more stillbirths in the exposed group in one of their experiments. Rommerein et al. (1984) exposed rats to an electric field and found no difference between the exposed group and the unexposed group (i.e., sham group) in incidence of malformations in the off-spring of the first generation. However, when the first generation was rebred, a significant increase in malformed fetuses were observed in the exposed group, but no such malformations were observed in a second replication. Lotz and Saxon (1984) reported reduced weight in male Rhesus monkeys (1 to 54 months old), chronically exposed to EMF, but no weight reductions in females.

Smith et al. (1981) exposed mice to very low electric fields and monitored the growth and development of over 1400 mice in 128 litters. Neither fertility, number of mice born, litter size, nor sex ratio was affected. Benz et al. (1987, as cited in OTA, 1989) reported no effect on 3,000 mice exposed to EMF over three generations.

Aaronson (1988) in his review of the biological effects of EMF concludes the following, regarding growth and development research to date: "There is no reproducible scientific basis for implicating power frequency electric and/or magnetic fields as being causative of genetic damage that is reflected in growth and development."

4.5.3 Conclusions

In summary, most of the EMF studies reviewed by the Committee show no effect during embryonic development or during post-natal growth. A few studies do report effects, with some showing effects under "pulsed" magnetic fields, which are not normally found associated with 50 and 60-Hz AC transmission lines. Certain studies show effects using one strain, but no effects with another. Also, high incidence of effects are observed in the controls of various studies, making interpretation of the data, more difficult. Overall, these laboratory studies tend to lead to the conclusion that there is no proven detrimental effect on development or growth from EMF.

4.6 Endocrine System and Immunity

Proper functioning of an animal's endocrine (hormone) system depends on the precisely coordinated operation of all endocrine organs. An upset to any part of the system could trigger visible and measurable deleterious effects. From a health perspective, potential effects of EMF on endocrine function is an important question.

4.6.1 Hormonal Effects

Carmaciu et al. (1977, as cited in Carstensen, 1987) reported that initial increases in the adrenal hormones epinephrine and norepinephrine (which control vasoconstruction and mediate transmission of nerve impulses) in rats, apparently caused by exposure to 200 kV/m electric field for 6 to 72 hours, stabilized quickly. No further increases were noted during a subsequent 12 day chronic exposure period. Additionally, there were no detectable neurological or neuroendocrine changes correlated with these increased hormonal increases. Since no deleterious effects were observed, the researchers concluded that the elevated neuroendocrine secretions induced by electric field exposure were within the normal response experience for the test animals. Free et al. (1981) showed that prolonged exposure of rats to a strong 60-Hz electric field (i.e., 68 kV/m, 80 kV/m) slightly lowered the plasma corticosterone levels together with that of testosterone and prolactin. They concluded that 60-Hz electric fields may bring about subtle changes in the endocrine system of rats, and the changes may be related to alterations in episodic rhythms. Jolley et al. (1983) found a reduction in insulin and calcium release by isolated rabbit islets of Langerhans tissue. Udintsev et al. (1986, as cited in Creasey and Goldberg, 1989) showed that exposure to an alternating magnetic field (50 Hz; 200 gauss) activated the hypothalamo-hypophyseal-adrenal system (affecting behavior, metabolism, maintenance of body temperature, etc.) in rats. Levels of steriods and adreno corticotrophic hormone (ACTH) were elevated as well as plasma and tissue free fatty acids and phospholipids, but prolonged repeated exposures inhibited the activity of the endocrine system. Evidence of increased lipid peroxidation after chronic exposure to EMF is postulated to represent a type of stress reaction (Creasey and Goldberg, 1989).

In vitro studies performed by Lymangrover et al. (1987), using adrenal rat tissue, showed that 60-Hz fields greatly stimulated cellular response to ACTH. Kartashev and Ivanova (1988) reported activation of the adrenal and thyroid systems in mice; however, Quinlan et al. (1985) failed to show any generalized activation of the hypothalamo-hypophyseal-adrenal system in exposed rats. Although, they did observe a statistically significant increase in growth hormone production. Michaelson and Lu (1988) showed that rats exposed to an electric field of 80 kV/m for four hours at 71 hour intervals exhibited no persistent changes in adrenal gland function (as measured by corticosterone production), and no indication of physiologic or neuroendocrine stress. A study by Leung et al. (1988a) reported that rats exposed to electric fields exhibited a statistically significant increase in the incidence and severity of chromodacryorrhea (a gland secretion indicative of stress). The authors suggested that rats exposed to electric fields are subjected to a chronic low-level stress. Michaelson (1987) monitored hormone balance in acclimatized (unstressed) and non-acclimatized (stressed) rats subjected to 50, 80, or 100 kV/m sustained or interrupted electric fields (60 Hz) for various times up to five hours, as well as daily exposure repetition for five successive days, or at 48-72 hour intervals. Utilizing a highly consistent and sensitive hormone assay system, he reported that sustained and intermittent 80 kV/m exposure may elicit subtle regulatory adjustments of endocrine levels, but that these levels were within the threshold for a recognized physiological stressor. He concluded that within the constraints of the exper'mental design, there appeared to be no perturbation of the endocrine system in the rats subjected to the fields applied, and expressed doubt that prolonged exposure would cause further detrimental effects, since adaptation and biological variability would help to moderate such influences on endocrine balance.

4.6.2 Circadian Rhythms

Recent research has suggested that EMF can affect endocrine balance and function by altering an organisms' circadian (24 hrs.) and ultradian (less than 24 hrs.) biologic rhythms. These rhythms are biologic processes controlled by both external stimuli (i.e., light/dark periodicity) and hormones. The internal clocks or pacemakers for these rhythms are believed to be located in the hypothalamus gland, and can be influenced by specific external stimuli including temperature, noise, light/dark, etc. Results to date appear to show that EMF can influence these rhythms. Groh et al. (1988) reported that the circadian rhythms (i.e., phase shift, dyschronion, torpor) of rats and mice were effected when exposed to electric fields of 100 kV/m. Animals raised under an 8:16-hour light-dark cycle were less sensitive to electric field exposures than animals raised under a 16:8-hour light-dark cycle. In a summary report by Groh (1989), he concludes that EMF are circadian zeit gerbers (environmental cues). However, the importance of EMF as an environmental cue relative to other more widely recognized external stimuli, such as light, is unknown.

Much work is presently being done to determine the possible effect of EMF exposure on the functions of the pineal gland. The gland is located at the base of the brain in man and functions as a neuroendocrine transducer, converting neurological input to hormonal output, primarily melatonin. An excellent review on the known functions of the gland and the possible EMF exposure effects are given by Reiter (1990) and Wilson and Anderson (1990).

Melatonin production has a circadian variation, high at night and low during the day. Exposure to light of sufficient intensity during the dark cycle leads to an immediate drop in mealtonin in several species, including man. However, every species seems to have a different light inhibition threshold. In man, the pineal gland receives its indirect sensory input from the retina. The gland functions in the endocrine system as an inhibitor on most other endocrine glands. Reiter (1990) in his review, concludes that the functions of the pineal gland is to keep the animal in appropriate synchrony with its external environment. The gland continually apprises the animal of the environmental state and adjusts its physiology accordingly.

Wilson et al. (1981 and 1986) reported that exposure of rodents to 60-Hz electric fields (i.e., 39 kV/m effective field) can upset the pineal gland's circadian rhythm. They reported that prolonged exposure (30 days) of rats to an electric field significantly reduced the nighttime rise in melatonin and serotonin-N-acetyl transferase. The onset of the effect occurred within three weeks after exposure initiation, and recovery was observed in less than three days after exposure cessation. Anderson et al. (1987) and Reiter et al. (1988) found that rats exposed to electric fields of 10, 65, or 130 kV/m from conception to 23 days of age showed a reduction and time-shift of peak nighttime pineal melatonin. However, no dose-response relationship was observed. Young adult rats exposed for three weeks to 60-Hz electric fields resulted in desynchronization of pineal gland rhythms, and statistically significant decreases in nighttime levels of melatonin and serotonin N-acetyl transferase (a blood vessel constriction enzyme) when compared to control animals. Changes were also noted in pineal serotonin and N-aceytl serotonin levels. Rats exposed to 10, 65, or 130 kV/m 60-Hz electric fields from conception to 22 days showed stable but significantly suppressed melatonin secretions compared to controls. Additionally, peak production of pineal melatonin in all exposed groups showed a phase shift delay of approximately one to two hours when compared to controls, and the effect appeared to be an "All or None" response.

In conjunction with the possible effects of EMF exposure on the circadian rhythm of animals, due to the many known functions of the pineal gland, numerous other physiological effects have been hypothesized. Gland dysfunction has been implicated as a possible factor effecting illness. This is owning partially to the alterations in normal biological rhythms. The gland is hypothesized to be involved in the etiology of depressive illness, although its exact role remains unclear. The reduction and phase-shifting of the circadian peaks in melatonin concentrations have been suggested as factors effecting mood changes. Stevens (1987, as cited in Wilson et al. 1990) suggested that reduction in melatonin concentration due to EMF exposure in rats may result in increased circulating estrogen levels. This may stimulate mammary tissue proliferation and thus increase breast cancer risk. Wilson (1988) suggests that pineal dysfunctions may contribute to the onset of depression or may exacerbate existing depressive disorders in humans. It has also been hypothesized that melatonin may have a stimulatory effect on the immune system.

It appears very likely that EMF exposure can alter pineal gland functions by decreasing melatonin synthesis and release. However, given the many possible functions of the gland, it remains to be determined whether EMF effects on the gland's functions represent a health risk to humans.

4.6.3 Other Biological Functions

Along with other observable and measurable parameters, animal reproduction and development can accurately indicate the relative health of a synchronized endocrine system, because the ability of mammalian animals to conceive and carry a pregnancy to term requires a highly coordinated sequence of endocrine-mediated steps.

The majority of studies to date have demonstrated no deleterious effects of exposure to EMF on reproduction and development. Cerretelli et al. (1979) found that long-term (i.e., two months) exposure to an electric field of 100 kV/m had no effect on rats' fertility. Sikov et al. (1984) and Benz et al., 1987 (as cited in OTA, 1989) using identical electric fields prior to and during gestation, found no changes in rat or swine mating performance or fertility. Albert et al., 1984 (as cited in OTA, 1989) was unable to demonstrate any significant differences between exposed and unexposed developing rats. Fam (1980) observed reduced growth in female mice exposed to a 240 kV/m electric field, but not in males. But there were no affects on the number of born and surviving progenies. Several other studies, Sikov et al., 1984, and Konerman and Monig, 1986, (as cited in New York State Powerlines Project Scientific Advisory Panel, 1987) observed no differences in animal weights after prolonged exposure to electric fields. Hilton and Phillips (1981) also observed no effects on growth of rats and mice exposed to an electric field of 100 kV/m. They attributed this to eliminating or minimizing secondary factors (e.g., corona ozone, harmonic distortion, spark discharge) which are associated with certain laboratory exposures.

4.6.4 Immune System Effects

Another theory that has been postulated is that EMF may impact the body's immune system. The immune system is a network of cells and tissues which act as a major surveillance mechanism that protects the host organism from a variety of diseases, including cancer. In vivo research which attempts to assess the integrity of the immune system, examines the reactions of the whole organism to various challenges. Though typically more difficult and time consuming, in vivo testing is a more accurate reflection of the immune systems' capacity for response, than extrapolation from in vitro studies.

The literature on the interaction of EMF with the immune system exhibits a wide variety of conflicting results. Only data from exposure of whole animals to 50 or 60-Hz electric or electric and magnetic fields can be said to show some consistency, and those effects consist of relatively small or no effects. No confirmed repeatable research to date, (as reviewed by Bockman, 1989) has shown that exposure to electric and magnetic fields adversely affects the organism's immune system. Hackman and Graves (1981) showed that transient/minimal rises in blood corticosterone levels in animals initially exposed to an electric field return to normal levels within 15 minutes; subsequent field exposures produced no further effects. Cerretelli et al. (1979) found no differences in mortality for electric field exposed and unexposed groups of mice injected with the bacterium Staphlococcus pyogenes after exposure to 25 kV/m electric fields for up to 42 days. Krueger and Reed (1975) noted no differences in mortality for mice exposed to an electric field of 100 kV/m (75 Hz) for 21 days and injected with influenza virus. Morris and Ragan (1979) and Morris and Phillips (1982, 1983) found no significant differences in serum immunoglobulin (an antibody protein) and cell-mediated response of mice chronically exposed to low-level 60-Hz electric fields. Stopps and Janischewsky (1979, as cited in Word Health Organization, 1984) discerned no differences in the general health or in levels of lymphocytes (white blood cells) and other blood cells of workers maintaining high-voltage equipment and transmission lines in Ontario, Canada. Finally, Morris et al. (1979, 1982, 1983, and 1988) found no observable changes in either mouse T or B lymphocyte cells in response to mitogens (foreign substances) following exposure to 60-Hz EMF for two hr./day for 30 to 60 days or at 100 kV/m for 30 to 150 days. These studies show that exposure of intact animals to EMF greater than those experienced under high-voltage AC powerlines produced no identifiable deficit in immune cell function.

Data from exposure of isolated immune system components (i.e., various animal cell types) to extremely low frequency EMF in vitro have been conflicting. A series of reports have claimed that exposure of human lymphocytes to pulsed EMF stimulates their response to mitogens (substances that induce mitosis-nuclear replication) such as phytohemagglutinin, as measured by DNA synthesis (Hellman et al., 1985; Emilia et al., 1985; Cantini et al., 1986; Franceschi et al., 1986; Cadossi et al., 1986). In contrast, Conti et al., (1983, as cited in Creasey and Goldberg, 1989) using square-wave pulses (not found associated with AC transmission lines) at 1 to 40 microseconds and 200 Hz reported that lectin-stimulated mitogenesis (cell division) of human lymphocytes (white blood cells) was inhibited.

Studies with sinusoidal ELF/EMF have generally shown modest depression of various components of the immune process. Phillips (1986) found that 60-Hz magnetic fields alone, or combined electric and magnetic fields, inhibited natural killer cell-induced cytolysis (cell destruction) of irradiated coliform-bacterial cells (Colo 205) in vitro.

Lyle et al. (1988) reported inhibition of the allogenic cytotoxicity (ability to kill cells) of a normal white blood cell line by 60-Hz sinusoidal electric fields. Winters (1986, as cited in OTA, 1989) in studies on human and dog white blood cells (leukocytes) concluded that extremely low-frequency EMF had no effects on molecular binding sites, immunoglobulins, or the synthesis of DNA, RNA or protein. However, he reported that cultured human colon cancer cells showed a mitogenic response (induced cell division), and resistance to natural killer cells after 24 hours of exposure to a 60-Hz magnetic field. Field-exposed cells also showed an increased ability to multiply, compared to unexposed cancer cells. However, Cohen (1987), in an attempt to duplicate Winter's (1986, as cited in OTA, 1989) results, found no significant effects of the fields on the proliferative ability of the same two cell lines.

Some of the variability reported for in vitro and in vivo experimentation is attributed to possible "window effects" for frequencies and intensities of EMF. Cadossi et al. (1986) reported that inhibition of cellular responses occurred upon exposure to low frequency pulsing electric and magnetic fields, resulting in an induced voltage of 10 mV, in contrast to stimulation seen at other intensities above and below this level.

Franceschi et al. (1986) obtained a bimodol response at low phytohemagglutinin (protein that causes clumping of red blood cells) concentrations in which the effect of EMF was inhibitory rather than stimulatory at specific frequencies and intensities. Additionally, mixed electric/magnetic fields were found to enhance responses not seen under electric or magnetic fields alone.

Based on research evidence presented to date, the Committee finds no clear or consistent evidence that extremely low frequency (ELF) electric and magnetic fields (including 60 Hz) has any physiologically detrimental effects on the blood, immune system, or on their cellular elements. These views are shared by OTA (1989) in it's comprehensive review of immune system studies.

4.6.5 Conclusions

The Committee's summarized conclusions regarding the present state of research of the effects of power frequency EMF on endocrine and immune functions are as follows:

- Researchers have demonstrated no evidence of metabolic disorders in lower animals or humans exposed to EMF at levels generated by high-voltage AC transmission lines.

- Studies have shown that integrated functioning of the endocrine systems' components governing complex biologic functions such as conception, growth and development, appear to perform normally in the presence of electric and magnetic fields such as those experienced under high-voltage AC power lines.

- Research evidence presented to date appears to reject the hypothesis that acute or prolonged exposure to EMF equivalent to or up to several times stronger than fields experienced under high-voltage AC transmission lines results in biologic disruption of endocrine or immunologic systems.

4.7 Biological Mechanisms

4.7.1 EMF - Cellular Interaction

Although certain epidemiologic studies show a possible weak association between EMF and certain diseases, and certain experimental laboratory studies report biological effects, the scientific community generally believed until recently that power-frequency fields (i.e., 50 and 60 Hz) could not transfer enough energy to biological systems to induce any changes. Unlike other energy sources (e.g, x-rays, microwaves) power-frequency fields do not have enough energy to break chemical bonds or warm tissues. Ionization and warming of tissue are two well established physical mechanisms known to cause biological damage. However, recent studies have demonstrated that under certain conditions power-frequency fields can induce changes at the cellular level. Thus, certain mechanisms (i.e., biological models) have been postulated to explain these observed changes. An excellent summary of these possible mechanisms is presented by Creasey and Goldberg (1989).

4.7.2 Cell Membrane Models

The cell membrane is the boundary of the cell, maintaining the cell's structural integrity and controlling flows of materials and energy signals into and out of the cell. Under normal conditions, this membrane transmits information from the cell surface to the cell interior, mediating cellular reactions, and also acts as a highly selective filter, maintaining an unequal concentration of ions on either side of the cell membrane. This mechanism allows nutrients to enter and waste products to exit the cell as required to support life functions.

The cell membrane also uses unequal ion concentrations to transmit external signals to the cell's interior by regulating selective entry of molecules and ions. The most important of these ions are Calcium (Ca^{++}), Sodium (Na^{+}), Chloride (Cl^{-}), Hydrogen (H^{+}), and Potassium (K^{+}). Entrance and exit of these ions occurs through ion channels in the cell membrane, which open and close in response to ionic concentrations and the binding of molecules such as hormones. Additionally, certain membrane-bound enzymes (attached to the cell membrane) take part in the synthesis of molecules and control initial actions of some drugs.

Most postulated models point to the cell membrane as the specific site of interaction between EMF and the cell. Adey (1986) suggests that EMF interacts with the glycoprotein receptor sites on the cell membrane, which are involved in transduction of signals to the cell's interior. However, the effect studied most frequently has been the apparent nonlinear pattern of Calcium (Ca^{++}) ion released from cells, which results following ELF exposure. Normally, Ca^{++} flow governs a number of bodily processes such as muscle contraction, egg fertilization, and cell division. Ca^{++} ions flow across cell membranes in response to signals from outside the cell, acting as a messenger in response to specific electrochemical signals of specific intensity and frequency. However, in vitro EMF exposure studies have shown unusual rates of Ca^{++} efflux (outward flow). Liboff (1983, 1985, and 1987 as cited in Creasey and Goldberg) postulated a mechanistic theory based on cyclotron resonance to explain this effect, i.e., EMF of the proper frequency and intensity, in combination with the earth's D.C. magnetic field, can affect the movement of Ca^{++} ions through channels in the cell membrane. Bawin and Adey (1976, as cited in OTA, 1989) observed a decrease in efflux of calcium from chick brain tissue exposed at frequency and amplitude windows around 6 Hz and 16 Hz and at 20 V/m, while Blackman et al. (1982, 1985a, 1985b) reported an increase in calcium efflux in chick brain tissue exposed to a complex series of frequency/amplitude windows. Bellossi (1986) observed no difference in Ca^{++} efflux in neonatal chick brains exposed in vitro to uniform or non-uniform static magnetic fields ranging in intensity from 2,000 to 9,000 gauss. Blackwell and Reed (1985) failed to find any signs of change in exploratory activity and of barbiturate-induced sleeping time in male mice exposed to 50 to 400 V/m at 15, 30, and 50 Hz. Both of these parameters can be affected by changes in the central nervous system (CNS) associated with calcium changes. It is possible the strength and relative orientation of the earth's natural static magnetic field (i.e., 0 Hz) in the laboratory superimposed on the induced AC field contributes to the inconsistency of the data.

4.7.3. Conclusions

In regard to the mechanism theories evaluated by researchers to date, the Committee has reached a number of conclusions. These conclusions are supported in general by the Office of Technology Assessment (1989) in their background paper on the biological effects of power-frequency electric and magnetic fields:

- In the case of EMF exposure, it is possible that the "window effect" replaces the concept of larger (more intense) fields resulting in a greater effect than that caused by a less intense field. If such a "window effect" relationship between EMF frequency/amplitude and biological reactions should be substantiated, regulations of EMF exposure by setting standards based on "more is worse" approach may not be an effective approach.

- Observed effects apparently induced by application of EMF may be influenced by the positioning of the field relative to the earth's natural static magnetic field. Also, the apparent "window" nature of observed effects requires the evaluation of a wide range of frequency/amplitude settings during experimentation.

- All of these mechanisms are speculative at best. More research is needed before these theories can be proven or disproven. Although very speculative at this time, this type of research is very important. If a mechanism is established at the cellular level, then this may support the results from the positive epidemiologic and in vivo laboratory studies, and aid in the design of new studies.

Table - 4.1 - Summary of Observations/Conclusions of Experiments to Determine Behavioral Effects of EMF Exposure, as Detailed in Section 4.3

Researcher	Experiment	Observations/Conclusions
LOWER ANIMALS		
Stern et al (1983) & Stern and Laties (1985)	Detection of electric fields by rats.	Rats detected electric fields as low as 3.0 kV/m and as high as 10 kV/m.
Kato et al (1989)	Exposure of rodents to electric fields to determine animals ability to detect field.	Body hair and whiskers of rodents vibrated when rodents were exposed to electric fields.
Stell and Adey (1988)	Detection of 60-HZ electric fields by rodents as a function of circadian rhythm activity.	Rats exhibited no differences in detection performance during high/low activity periods, up to 25 kV/m exposure.
Smith et al (1979)	Exposure to power-frequency electric fields to determine effects on general activity of animals.	No observed effect of power frequency electric fields on general activity of animals tested.
Graves et al (1985)	Exposure to power frequency electric fields to determine effects on general activity of chicks.	General activity not affected by power frequency electric fields.
Smith and Justesen(1977)	Exposure of mice to 60-HZ magnetic fields to determine effects on motor behavior.	Reported a slight increase in mouse motor behavior (movement) in the presence of 60-HZ magnetic fields; however, increased activity was not sustained, and was observed only at the onset of field charge.
Hjeresen et al (1982)	Determination of avoidance of electric fields by pigs.	Female pigs avoided electric fields of 30 kV/m during their sleep/rest period.
Creim et al (1982)	Avoidance of electric fields by rodents.	No avoidance in rat exposed to 100 kV/m.
Creim et al (1984)	Avoidance of 60-HZ electric fields by rodents.	Exposure of moderate duration to 60-HZ electric fields (133 kv/m or less) did not produce taste aversion in rats.
Stern and Laties (1987)	Exposure to 60-HZ electric fields to determine avoidance behavior by rodents.	Under many conditions, fields as high as 100 kV/m were not a very aversive stimuli for rats.
Hackman and Graves (1981) Rosenberg et al (1981)	Exposure of rodents to electric fields to determine avoidance behavior.	Reactions to electric fields, sometimes lasting only a few minutes; response attributed to recognition of environmental change, to which the animal quickly adjusts.

Table 4.1 (Continued)

Researcher	Experiment	Observations/Conclusions
Davis et al (1984)	Effect on general activity level of rodents.	No changes in mice activity levels in the presence of DC or AC magnetic fields.
Groh et al (1988)	Effect on general activity level of rodents as controlled by circadian rhythms and physiochemical regulators.	Observed phase shifts in light/dark-induced circadian rhythms depended on field strengths (greater than 25 kV/m) seasonal light/dark effect sensitivity, and exposure during susceptible phases of the circadian cycle. Below 25 to 35kV/m, majority of mice showed no consistent measurable response, and maximized effect at greater than 100 kV/m. No evidence of a simple dose-dependent response for activity or respiration. All known potential long-term health risks of high intensity electric fields attributed to actions as circadian regulators.
Rogers et al (1988)	Activity/behavior patterns of baboons usually exposed to 60-HZ fields.	Exposure caused baboons to huddle together, at the onset of field charge. Animals may have huddled to reduce field strength and increase shielding, all protective responses to perceived stimuli. Reactions not consistent, and temporary, huddling dependent on field strength. Baboons reacted to field as a threat by huddling at beginning of exposure, "learning" after some time that there was no danger, and returning to normal patterns. Re-exposure produced no effects.
Orr et al (1987)	Performance patterns of baboons exposed to 30 kV/m and 60 kV/m electric fields.	Responses to food reward affected by electric fields upon initial exposure; responses returned to normal within a few days.
Salzinger et al (1987)	Performance of rats exposed to electric and magnetic fields.	No effects on performance of a memory task was observed in adult male rats exposed for 72 hours to a magnetic field of 1.0 gauss and an electric field of 30 kv/m. However, when pregnant female rats were exposed, a trend toward a reduction in response rate was evident in the offspring.
HUMANS		
Stern et al (1983)	Detection of electric fields.	Humans were able to detect electric fields between 5 kV/m and 15 kV/m.
Graham and Cohen (1985)	Detection of magnetic and electric fields.	Determined that 90% of seated humans could detect an electric field of 9 kV/m, but none could detect magnetic field up to 0.4 gauss.
Tucker and Schmitt (1978)	Detection of magnetic fields.	Out of 200 humans, none could detect a magnetic field of 7.5 to 15 gauss.
Gamberale et al (1987)	Performance of 26 utility linemen exposed to 60-HZ EMF in the laboratory over two days.	Measurements of behavioral performance, EEG, mood scales, subjective symptoms and various blood chemistry parameters revealed no statistical differences in exposed vs. control groups.
Graham et al (1988)	Double-blind experiments exposing male humans to an electric field of 9 kV/m and a magnetic field of 200 mG. Subsequent exposure to 12 kV/m, 300 mG.	Results showed slowing of heart rate, and changes in central nervous system occurring soon after field onset or offset, suggesting exposure changes more important than exposure duration. Exposure to higher levels showed no consistent differences between controls and exposed. Exposure may interact with biological systems only in limited "windows" of stimulation, i.e., for a particular frequency, some field intensities produce effects, and those intensities above/below the "window" don't.

Table 4.2 - Summary of Observations/Conclusions of Experiments to Determine Effects of EMF Exposure on Cancer Initiation and Promotion, as Detailed in Section 4.4

Researcher	Experiment	Observations/Conclusions
CANCER INITIATION		
Cohen (1986); Cohen et al, (1986 a&b);Livingston et al (1986)	Exposure of human lymphocytes (white blood cells) to 60-HZ EMF fields.	Exposed cells did not show any change or mutation in the DNA material, i.e., no evidence of cancer initiation.
Carstensen (1987	Exposure of mouse bone-marrow cells to 60-HZ fields.	Exposed cells did not exhibit any change or mutation in the DNA material.
Reese et al (1988)	Exposure of Chinese hamster ovary cells to 60-HZ fields.	No changes or mutations in DNA material were observed.
Nordenson & Hansson (1987)	Examination of human amniotic cells, exposed to sinusoidal and sawtooth magnetic fields.	Researchers reported chromosome damage due to magnetic exposure.
Bauchinger et al (1981)	Examination of switchyard workers exposed occupationally to EMF.	Researchers reported no chromosome damage due to EMF exposure.
d'Ambrosio et al (1985)	Exposure of bovine white blood cells to 50-HZ fields.	Increased percentage of chromosome aberrations in bovine peripheral blood lymphocytes exposed for 72 hours.
El Nahas & Oraby (1989)	Exposure of Swiss male mice to 100,170, 220, and 290 kV/m 50-HZ electric fields for 24 hours (high exposure used to scale up to humans).	No increase in micro nuclear polychromatic erythrocytes (red blood cells) in the bone marrow of mice exposed to 100 kV/m, but significant increases in mice exposed to higher fields.
CANCER PROMOTION IN VITRO		
Byus and Adey (1988)	Exposure of cells in-vitro to EMF, to examine changes in hormone production.	EMF exposure increased production of the growth hormone ornithine decarboxylase (ODC), depending on amplitude, frequency and exposure duration (increase in ODC production serves as indirect marker to support cancer promotion theory) Note: increase in ODC production doesn't necessarily mean that exposed cells will become tumors and EMF are cancer promoters, since a variety of stimuli, which do not play a role in carcinogenesis, can induce ODC activity. In addition, the enhancement of ODC activity by EMF was much less than for known promoters, such as phorbol esters.
Frazier et al (1989)	Tested the hypothesis that magnetic fields can promote transformation of initiated cells.	Exposure to the magnetic fields did not significantly alter transformation frequencies of either initiated or promoted cells as compared to sham-exposed cells, an indication that magnetic fields are not carcinogenic promoters.
Cain et al (1987)	Exposure of cells in-vitro to EMF to determine changes in enzyme activity.	Cells exposed to EMF were observed to undergo changes in enzyme activity (changes similar to those caused by known cancer promoters, (e.g., phorbol esters)).
Fletcher et al (1987)	Exposure of cells in-vitro to EMF to detect changes in cell-to-cell communication.	Cells exposed to EMF were observed to undergo changes in cell-to-cell communication (changes that are similar to those caused by known cancer promoters, (e.g., phorbol esters)).
Phillips et al (1986)	Exposure of malignant human colon cancer cells to EMF.	Observed enhanced growth rates in malignant human colon cancer cells.
Cohen (1987)	Exposure of malignant human colon cancer cells to EMF.	Cohen (1987) could not duplicate Phillips (1986) results.
Adolphe et al (1987)	Exposure of malignant human uterine cervical cancer cells in culture to 50-HZ EMF to determine effects on growth.	Observed no effect on growth of malignant human uterine cervical cancer cells in-vitro.
Goodman et al (1989)	Exposed human cells to sinusoidal with repetition rates of 60 HZ and 72 HZ.	Observed induced quantitative changes in messenger RNA and proteins.
CANCER PROMOTION IN VIVO		
Leung et al (1988b)	Exposure of rats to 7, 12-dimethyl benzene (a) anthracene and 60 HZ, 40 kV/m electric field compared to rats exposed to the chemical only.	Observed no significant difference between exposed and unexposed rats in the number of rats that developed mammary tumors, but did find an increase in the number of tumors per tumor-bearing rats.

Table 4.2 (Continued)

Researcher	Experiment	Observations/Conclusions
Chandra and Stefano (1978)	Exposure of mouse mammary tumors to magnetic fields, and transplanted into healthy mice to examine changes in growth characteristics.	No effect on the growth characteristics of mouse mammary tumors exposed to magnetic fields before or after being transplanted into healthy mice.
Thomson et al (1988)	Implantation of P388 leukemia cells in mice exposed to 60-HZ magnetic fields to detect effects on the incidence or progression of these cancer cells.	Observed no effect on the incidence or progression of P388 leukemia cells implanted in mice exposed to 60-HZ magnetic fields.
Batkin and Tabrah (1977)	Exposure of mouse tumors (in vivo) to 60-HZ magnetic fields to detect changes in growth.	A reported decrease in mouse tumor growth in response to 60-HZ magnetic field exposure.

Table 4.3 - Summary of Observations/Conclusions of Experiments to Determine Effects of EMF Exposure on Development and Growth, as Detailed in Section 4.5

Researcher	Experiment	Observations/Conclusions
TERATOGENIC EFFECTS		
Graves et al (1985)	Exposure of more than 20,000 chick embryos to 60-HZ electric fields from .1 to 100 kV/m to detect effects on incubation and development at and after hatching.	No observed significant change in growth, development, or overall health of the exposed chick embryos.
Sikov et al (1987)	Exposed Hanford miniature swine to EMF.	Observed malformations in offspring of sows exposed to EMF.
Durfee et al (1975)	Exposure of chick embryos to .001-3.6 kV/m electric fields at 45 HZ to 75 HZ during and after incubation to detect effects on fertility, hatchability, survivability, weight gain, and behavior.	No observed effects on chicken fertility, hatchability, survivability, weight gain, and behavior.
Sandstrom et al (1987)	Exposed fertilized hen eggs to magnetic fields with an asymmetrical saw-tooth waveform.	No significant increases in abnormalities were observed in fertilized hen eggs, which were exposed during their first two days of development.
Delgado et al (1982)	Exposure of chick embryos to low-frequency pulsed magnetic fields during early development.	Abnormalities reported in chicken embryos exposed to low-frequency pulsed magnetic fields. (Note: pulsed magnetic fields are not normally associated with transmission lines).
Ubeda et al (1983)	Exposed fertilized chick embryos to pulsed electric and magnetic fields.	Observed effects in chick embryos exposed during the first 48 hours of development.
Sisken et al (1986) Maffeo et al (1984)	Exposure of chicken embryos to low-frequency pulsed magnetic fields during early development.	Neither researcher was able to replicate the teratogenic effects reported by Delgado et al(1982) and Ubeda et al (1983).
Berman et al (1988a 1988b)	"Henhouse Project" replicating same experiment at six independent laboratories, exposing chick eggs to extremely weak pulsed magnetic fields under same set of characteristics and evaluated for same set of parameters: egg fertility, embryo abnormalities fertility, in development and growth.	Based on data combined for all six labs, results showed overall increase in proportion of abnormal chick embryos in groups exposed to pulsed magnetic fields. Exact proportion of abnormalities varied among labs: two labs reported increased abnormalities, four labs reported no differences. (Note: pulsed magnetic fields are not normally associated with transmission lines; extrapolating results to 60-HZ effects on humans is highly uncertain.
Martin (1988)	Exposure of chick embryos to pulsed EMF to detect effects during early development.	Effects observed when exposure occurred during the first 24 hours of incubation, but no effects if embryos exposed later in their development.
Martin (1989)	Exposure of two different chicken strains to pulsed fields.	Effects were observed in the White Leghorn strain, but not in the Arbor Acre strain.

Table 4.3 (Continued)

Researcher	Experiment	Observations/Conclusions
REPRODUCTIVE EFFECTS		
Seto et al (1983)	Exposure of rats to electric fields for three generations to detect malformations and changes in growth/development.	No effect on food and water uptake, but effects on growth patterns were observed from four to eight weeks of age, but not beyond eight weeks.
Stuchly et al (1987)	Exposure of rats to unsymmetrical sawtooth magnetic fields to detect reproductive effects.	No statistical differences between rats exposed and those not exposed.
Sikov et al (1978; 1984)	Exposure of rats prior to mating; exposure of pregnant female rats to detect effects on fetal development, birth rates, etc.	No effects on fetal length and weight or on internal/external malformations; more stillbirths in one of the exposed groups.
Rommereim et al (1984)	Exposure of rats to an electric field to detect changes in incidence of malformed offspring.	No differences observed between the exposed group and the unexposed (sham) group in the first generation. When first generation rebred, a significant increase in malformed fetuses observed in exposed group. No such malformations found in subsequent replication.
Lotz and Saxon (1984)	Exposure of Rhesus monkeys to EMF.	Observed reduced weight loss in males chronically exposed to EMF, but not in females.
Smith et al (1981)	Exposure of mice to very low electric fields to detect changes in growth and development of over 1,400 mice in 128 litters.	Neither fertility, litter size, stillborn/live born ratios, nor sex ratio were affected.
Benz et al (1987)	Exposure of 3,000 mice to EMF over 3 generations to detect reproductive/developmental effects.	No effects observed.

Table 4.4 - Summary of Observations/Conclusions of Experiments to Determine Effects of EMF Exposure on Endocrine Ststem Function and Immunity, as Detailed in Section 4.6

Researcher	Experiment	Observations/Conclusions
HORMONE EFFECTS		
Carmaciu et al (1977)	Exposure of rats to 200-kV/m electric field for six to 72 hours to detect changes in hormone levels.	Initial increases in adrenal hormones epinephrine and norepinephrine (apparently caused by exposure) stabilized quickly. No further increases were noted during a subsequent 12-day chronic exposure period. No detectable neurological or neuro endocrine changes correlated with increased hormonal secretions. Elevated neuroendocrine secretions induced by exposure were within normal response experience for test animals.
Free et al (1981)	Prolonged exposure of rats to strong 60-HZ electric fields to determine effect(s) on hormone levels.	Observed slightly lowered plasma corticosterone levels, together with slightly lower testosterone and prolactin levels. Changes which may be related to alterations in episodic rhythms.
Udintsev et al (1986)	Exposure of rats to an alternating magnetic field (50 HZ; 200 gauss) to determine effects on hormonal balance.	Exposure activated hypothalamo-hypophyseal adrenal system (affecting behavior, metabolism, body temperature, etc.). Steroid and adreno corticotrophic hormone (ACTH) were elevated as well as plasma and tissue-free fatty acids and phospholipids, but prolonged repeated exposures inhibited activity of endocrine system.
Lymangrover et al (1987)	Exposure of rat adrenal cells to 60-HZ fields to detect changes in cellular response.	EMF exposure apparently stimulated cellular response to ACTH.
Kartashev & Ivanova (1988)	Exposure of mice to 60-HZ fields to determine effects on adrenal and thyroid systems.	Activation of the adrenal and thyroid system observed.
Quinlan et al (1985)	Exposure of rats to 60-HZ fields to detect changes in adrenal system function.	Failed to show any generalized activation of the hypothalamo-hypophyseal-adrenal system, but an increase in growth hormone production was observed.

Table 4.4 (Continued)

Researcher	Experiment	Observations/Conclusions
Michaelson & Lu (1988)	Exposure of rats to an electric field of 80 kV/m for four hour at 71-hour intervals to detect changes in adrenal gland function.	Rats exhibited no persistent changes in adrenal gland function, and no indication of physiologic or neuroendocrine stress.
Leung et al (1988a)	Exposure of rats to electric fields to detect indications of stress.	Rats exhibited a statistically significant increase in the incidence and severity of chromodacryorrhea, suggesting rats exposed to electric fields are subjected to a chronic low-level stress.
Michaelson (1987)	Exposure of acclimatized and non-acclimatized rats to 50, 80, or 100 kV/m sustained or interrupted electric fields (60 HZ) for up to five hours and daily exposure repetition for five successive days, or at 48-72 hour intervals, to detect changes in hormone balance.	Sustained and intermittent 80 kV/m exposure may elicit subtle regulatory adjustments of endocrine levels, but levels were within the threshold for a recognized physiological stressor. Within design constraints, no perturbation of rat endocrine system. Doubtful that prolonged exposure would cause further detrimental effects since adaptation and variability would help moderate any influences on endocrine balance.
CIRCADIAN RHYTHMS		
Reiter et al (1988)	Exposure of rats to electric fields of 10, 65, or 130 kV/m from conception to 23 days of age to detect changes in circadian rhythms.	Reduced peak nighttime pineal melatonin levels and shifts in circadian rhythms. No dose-dependent relationships was observed.
Anderson et al (1987)	Exposure of rats to 0, 10, 65 or 130 kV/m 60-HZ electric fields from conception to 22 days to detect changes in circadian rhythms as indicated by changes in hormone levels.	Stable but significantly suppressed melatonin secretions in exposed animals. Peak production of pineal melatonin in all exposed groups showed a phase shift delay of approximately one to two hours, compared to controls. Effect appeared be an "All or None" response. Changes also noted in pineal serotonin and N-acetel serotonin.
Groh et al (1987)	Exposure of rodents to 60-HZ electric fields to detect changes in circadian rhythms as evidenced by changes in hormonal production.	Can upset the pineal gland's circadian rhythms for the synthesis and secretion of melatonin, with recovery observed in less than three days after cessation of field exposure in Wilson's et al, (1986) study.
Wilson et al (1981; 1986)	Prolonged exposure of rats to electric fields to detect field-induced changes in circadian rhythms.	Significantly reduced the nighttime rise in melatoin with recovery observed in less than three days after exposure cessation.
OTHER BIOLOGICAL FUNCTIONS		
Cerretelli et al (1979)	Long-term exposure (i.e., two months) to an electric field of 100 kV/m to detect changes in fertility.	No effects on rat fertility.
Sikov et al (1984); Benz et al (1987)	Exposure of rats and swine to identical electric fields prior to and during gestation to detect field-induced changes in mating and fertility.	No changes in rat or swine mating performance or fertility.
Albert et al (1984)	Exposure of developing rats to EMF to determine effects, if any, on growth and development.	Unable to demonstrate any differences between exposed and unexposed developing rats.
Fam (1980)	Exposure of mice to an electric field of 240 kV/m to determine field-induced effects on development.	Observed reduced growth in female mice, but not in males, no effect on number of offspring or surviving progenies.
Sikov et al (1984); Konerman and Monig (1986); Hilton and Phillips (1981)	Prolonged exposure of various laboratory animals to electric fields to detect field-induced effects on development.	No differences in animal weights between exposed and control groups. Hilton and Phillips (1981) attribute no effects observed due to eliminating or minimizing secondary laboratory effects (e.g., harmonic distortion, spark discharge).
IMMUNE SYSTEM EFFECTS		
Hackman and Graves (1981)	Exposure of test animals to electric fields to detect changes in blood hormone levels.	Transient/minimal rises in blood corticosterone levels in animals initially exposed to an electric field returned to normal levels within 15 minutes; subsequent field exposure produced no further effects.

Table 4.4 (Continued)

Researcher	Experiment	Observations/Conclusions
Cerretelli et al (1979)	Exposure of mice to 25 kV/m electric fields for up to 42 days, followed by injection with the bacterium Staphlo-coccus pyogenes to determine field-induced effects on immune system.	No differences in mortality for exposed and unexposed groups of mice.
Krueger & Reed (1975)	Exposure of mice to 100 kV/m electric field for 21 days, and injected with influenza virus to detect effects on mouse immune defenses.	No differences in mortality between control and exposed mice.
Morris and Ragan (1979); Morris and Phillips (1982, 1983)	Chronic exposure of mice to low-level 60-HZ electric fields to detect field-induced changes in antibody production and cell-mediated response to infection.	No changes in serum immunoglobulin and cell-mediated responses.
Stopps and Janischewsky (1979)	Examination of general health and blood chemistry of workers maintaining high-voltage equipment and transmission lines to detect field-induced effects.	No differences in the general health or in levels of lymphocytes (white blood cells) and other blood cells.
Morris et al (1979, 1982, 1983, and 1988)	Exposure of mice to 60-HZ EMF for two hour/day for 30-60 days or at 100 kV/m for 30 to 150 days, followed by exposure to mitogens, to detect changes in immune responses.	No observable changes in either mouse T or B lymphocyte cells.
Hellman et al (1985); Emilia et al (1985); Cantini et al (1986); Franceschi et al (1986); Cadossi et al (1986)	Exposure of human lymphocytes to pulsed EMF to determine any field-induced changes in cellular response to mitogens.	Exposure to pulsed EMF stimulated lymphocyte response to mitogens such as phytohemagglutanin,as measured by DNA synthesis.
Conti et al (1983)	Exposure of human lymphocytes to square-wave pulsed electric fields (not found associated with transmission lines) to evaluate field-induced effects.	Lectin-stimulated mitogenesis (cell division) of human lymphocytes was inhibited.
Phillips (1986)	Exposure of irradiated bacterial cells to 60-HZ magnetic or combined electric/magnetic fields to determine cellular immune response.	60-Hz magnetic fields alone, or combined EMF inhibited natural killer cell-induced cytolysis of irradiated coliform bacteria in vitro.
Lyle et al (1988)	Exposure of white blood cells to 60-HZ sinusoidal electric fields to detect inhibition of the allogenic cytotoxicity of the cells.	Inhibition of the allogenic cytotoxicity of a normal white blood cell line was observed in the exposed cells.
Winters (1986)	Exposure of human and dog blood cells to extremely low-frequency EMF to determine effects on molecular binding, immune responses or protein synthesis.	Extremely low EMF had no effects on molecular binding sites, immunoglobulins, or the synthesis of DNA, RNA, or protein. Cultured human colon cancer cells showed a mitogenic response, and resistance to natural killer cells after exposure. DNA synthesis in human skin fibroblasts was evaluated after exposure to a 60-Hz magnetic field.
Cohen (1987)	Duplication of Winters (1986) experiment.	Observed no significant effects.
Cadossi et al (1986)	Exposure of cells to low-frequency pulsing EMF to examine for inhibition/stimulation of cellular responses.	Inhibition of cellular responses occurred at an induced voltage of 10 mV, in contrast to stimulation observed at other intensities above and below this level; possible "window effect" for specific intensities of EMF.
Franceschi et al (1986)	Exposure of red blood cells to pure and combined electric and magnetic fields to examine stimulative/inhibitory cellular responses.	A bimodal response at low phytohemagglutinin concentrations in which EMF effect was inhibitory rather than stimulative at specific frequencies and intensities. Mixed EMF fields enhanced responses not seen under electric or magnetic fields alone.

Table 4.5 - Summary of Observations/Conclusions of Experiments to Determine Effects of EMF Exposure on Biological Mechanisms, as Detailed in Section 4.7

Researcher	Experiment	Observations/Conclusions
EMF-CELLULAR INTERACTION		
Bawin and Adey (1976)	Exposure of chick brain tissue to EMF at varying frequencies and amplitudes to detect changes in cellular calcium metabolism.	A decrease in efflux of calcium from chick brain tissue at frequency/amplitude windows around 6 HZ and 16 HZ, and at 20 V/m.
Blackman et al (1982, 1985a, 1985b)	Exposure of chick brain tissue to EMF at varying frequencies and amplitudes to detect changes in cellular calcium metabolism.	An increase in calcium efflux at a complex series of frequency/amplitude windows.
Bellossi (1986)	Exposure of chick brain tissue to static magnetic fields in an attempt to replicate efflux experiments.	No observed effect on calcium efflux in chick brains exposed in vitro to uniform and nonuniform static magnetic fields ranging from 2,000 to 9,000 gauss.

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5.0 JUDICIAL ISSUES

5.1 Purpose

The sole purpose of this section of the Report is to provide the Public Utility Commission with information relative to the growing level of activity in regulatory and judicial arenas dealing with the electric and magnetic fields (EMF) health effects issue as it pertains to siting and constructing high voltage transmission lines. Conclusions, if any, as to whether or not EMF poses a health risk should be drawn from the scientific evidence presented elsewhere in this report.

5.2 Introduction

The electric and magnetic fields (EMF) health effects issue is complicated and surrounded by controversy. Further, it is an issue that both the scientific community and society as a whole must address. Answers to some questions concerning EMF and health may, in time, come from research, but until the questions have been resolved, the EMF issue will be addressed in courtrooms, regulatory arenas, and before legislative bodies. As a result, electric utilities can expect to face the EMF health effects issue each time they seek the necessary approvals for siting and constructing high-voltage power lines.

One of the earliest reported public concerns over the possible health effects of EMF from high voltage transmission lines was expressed in the mid 1970s during hearings before the New York State Public Service Commission over a 765-kV transmission line proposed by New York utilities to import hydro-electric power from Canada. Earlier environmental concerns raised about high-voltage transmission lines were related to visual impact or aesthetic issues, corona effect, and audible noise. Also, there were earlier concerns of safety such as electric shock and conductors falling. Some of these earlier issues along with the health effects issue were brought up during the New York hearings.

5.3 EMF Proceedings

5.3.1 General Considerations

The Edison Electric Institute (EEI) has been collecting and disseminating information on proceedings involving EMF health effects since 1984. In the most recent EEI survey "Electric and Magnetic Field Cases" Summary Report, February 1989, there were 86 "reported EMF proceedings" involving electric utilities throughout the United States. "Reported proceedings" are only those proceedings reported in response to a survey of EEI member companies, American Public Power Association (APPA) members, and the National Rural Electric Cooperative Association (NRECA) members.

Since the February 1989 EEI survey, an additional 115 proceedings have been identified, bringing the total number of reported proceedings involving EMF to 201. This report does not suppose that all proceedings have been reported or identified but does include data from:

A. Utilities that previously have identified an EMF health effects proceeding in response to industry surveys;

B. All investor-owned utilities in the State of Texas as well as all but one of the municipal utility systems in the State of Texas having more than 10,000 residential customers;

C. A random sampling of other utilities including investor owned, municipal, and rural utilities.

The reported proceedings are tabulated in Appendix C.

5.3.2 Types of Proceedings

Each reported proceeding has been categorized by type as either (a) siting, (b) zoning, (c) condemnation, (d) tort, or (e) other. A brief description of each proceeding type follows:

a. Siting Proceedings. Siting proceedings are normally held before State Public Utility Commissions, Public Service Commissions and other state agencies where utilities are seeking Certificates of Public Convenience and Necessity (CCN) or other similar types of approvals for proposed transmission line projects. The agency having jurisdiction generally must assess (a) the need for the project, (b) alternatives to the proposal, and (c) the environmental and/or other considerations of the proposed project to minimize adverse impacts.

In the State of Texas, projects requiring CCN certification must meet the requirements of Section 54(c) of the Public Utility Regulatory Act (PURA). (Certificates of Convenience and Necessity shall be granted on a non-discriminatory basis after consideration by the Commission of the need . . . and on such factors as community values, recreational and park areas, historical and aesthetic values, environmental integrity and . . .).

Utilities, in siting proceedings, normally bear the burden of proving the need for the project and that the project will not have unacceptable environmental impacts.

b. Zoning Proceedings. Zoning proceedings are similar in many respects to siting proceedings. Zoning proceedings are normally held before local zoning boards and other local governmental bodies, and, like siting proceedings, the utility generally bears the burden of proof.

A major difference between siting and zoning proceedings is the type of hearing procedure that is employed. In siting proceedings, state agencies normally convene full evidentiary hearings, with expert witnesses, and generally follow established rules of evidence. Zoning proceedings frequently involve public hearings, lay witnesses, limited cross examination of witnesses, and loosely applied rules of evidence. Also, local politics may play a significant role in the proceedings.

c. Condemnation Proceedings. The major issue in a condemnation proceeding is the amount of compensation owed to a landowner as a result of a utility exercising its right of eminent domain and taking the landowner's property for a project. In condemnation proceedings the landowner is entitled to "just compensation" which usually means full compensation for the property taken, plus damages, if any, to the remainder caused by the taking.

d. Tort Proceedings. Tort proceedings are those whereby the plaintiff alleges that the defendant has committed a wrongful act which resulted in either personal injury or other damage suffered by the plaintiff.

e. Other Proceedings This category encompasses various proceedings which cannot be easily categorized as any one of the above.

Of the 201 EMF proceedings reported in the most recent updates to the survey, 75% were either siting or condemnation related. The breakdown by type is shown in Table 5.1.

Table 5.1 - Breakdown of EMF related Proceedings

Type	Number	Final	Pending	% of Total Proceedings
Siting	72	64	8	36
Zoning	17	11	6	8
Condemnation	78	67	11	39
Tort	12	7	5	6
Other	22	19	3	11
Total	201	168	33	100

Of the five categories of proceedings outlined in Table 5.1, the Public Utility Commission of Texas will be involved primarily with siting issues and may expect the EMF health effects issue to be raised in proceedings involving the CCN process for siting of transmission lines.

5.3.3 Results of the Reported EMF Proceedings

a. Siting Proceedings. Of the 72 reported siting proceedings identified in which EMF health effects were raised, 64 are final with eight pending.

In 40 of the reported final proceedings, the authorizing bodies either did not address the EMF issues, determined the field levels to be acceptable, or found that the risk of EMF health effects was unproven or of insufficient magnitude to prohibit authorization of the facility.

In seven of the proceedings the facilities were approved with various stipulations by the authorizing bodies that field measurements were to be taken before and after construction, EMF research would be monitored and reported back on an annual or semi-annual basis, or magnetic fields were to be minimized. (Appendix C; Siting #s 48, 53, 54, 66, 67, 71, & 72)

In one proceeding the utility made application to construct and operate a 230-kV transmission line and related substation. The landowners raised the EMF health effects issue; the utility submitted reports on the EMF health effects issue; the landowners dropped all EMF claims and the 230-kV line was approved when a new route was agreed upon. (Appendix C; Siting #6).

In one proceeding involving a 230-kV line, the EMF health effects issue was raised but there were no specific findings related to EMF. An alternate route was proposed. (Appendix C; Siting #9)

In one proceeding involving a 138-kV line, siting was approved and intervenors' request that the utility provide indemnification was denied. (Appendix C; Siting #10).

In one proceeding, the utility filed a written report on the EMF issue and the line was approved and subsequently built. (Appendix C; Siting #11)

In one proceeding the opponents to a transmission line presented EMF testimony by an engineer. The utility produced a company engineer. The line was approved and upheld by the State court. (Appendix C; Siting #15)

In one proceeding EMF testimony was presented. The authorizing body made no finding regarding EMF but denied certificate on other grounds. An amended application was filed by the utility and the Certificate was granted. (Appendix C; Siting #16)

In one proceeding an application for a transmission line was withdrawn by the utility after a reassessment of the need for the line. (Appendix C; Siting #27)

In two proceedings, the applications were approved but the utility decided not to build the lines. (Appendix C; Siting #s 35 & 36)

In one proceeding, the authorizing body found that health hazards were conjecture and had not been established. The Supreme Judicial Court affirmed this finding and remanded the proceeding on other issues not related to EMF. (Appendix C; Siting #38)

In one proceeding involving a high-voltage direct current (DC) transmission line, the hearing examiner recommended denial of a certificate based on purported health effects from air-ions. EMF was not an issue. The utility withdrew the application. (Appendix C; Siting #12)

In one proceeding, a State Corporation Committee granted a Certificate of Environmental Compatibility for a 500-kV transmission line, but did not make a direct ruling on the EMF issue. (Appendix C; Siting #4)

In one proceeding involving a 500-kV line the application was approved. Prior to construction, an intervenor group (COPE) raised the EMF issue and was successful in modifying the proposed route. The utility applied for site certificate amendments for four route changes and these amendments have been approved. In addition, the utility modified the circuit configuration from a flat arrangement to a delta arrangement to reduce the magnetic field levels. (Appendix C; Siting #45)

In one proceeding involving a 500-kV line the siting board denied certification on the basis of the unavailability of formal EMF standards. EMF regulations were adopted and the line was approved on remand. (Appendix C; Siting #21)

In one transmission line siting proceeding, the EMF issue was raised, witnesses testified, and approval for the line was granted. The intervenors appealed to the County Planning Commission and the approval for certification was rescinded. The utility rerouted the line. (Appendix C; Siting #37)

In a 1984 siting proceeding, Salt River Project, Phoenix, AZ was denied a Certificate of Environmental Compatibility by the Arizona Corporation Committee. The denial was based, in part, on EMF health effects raised during the proceedings. The main health effect raised was cancer, particularly leukemia and brain tumors. (Appendix C; Siting #52)

b. Zoning Proceedings. Of the 17 zoning proceedings reported, 11 have been finalized or settled, six are pending.

In two proceedings the zoning councils imposed, either directly or indirectly, magnetic field limits. (Appendix C; Zoning #s 6 & 9)

In two proceedings the zoning councils approved transmission lines after the utilities voluntarily modified the routes. (Appendix C; Zoning #s 7 & 14)

In four proceedings EMF health effects testimony was presented and the requested facilities were approved. (Appendix C; Zoning #s 5, 11, 12, & 16)

In one proceeding an application to construct a substation was withdrawn without prejudice after hearings were held on the EMF health effects issue. (Appendix C; Zoning #10)

In one proceeding it was determined that county boards are preempted from setting EMF standards once the State Public Service Commission has authorized the facility. (Appendix C; Zoning #13)

In one proceeding, the utility, Tri-State Generation and Transmission Association, Denver, Colorado, withdrew its application for a high voltage transmission line after the proceeding was remanded to the Grand County Colorado Planning and Zoning Commission to reconsider cancer promotion and other EMF health effects raised during the application proceeding. Mountain Parks Electric, Tri-State's local distribution customer, built distribution lines to serve the load. (Appendix C; Zoning #17)

c. Condemnation Proceedings. Of the 78 condemnation proceedings reported, 67 are final with 11 pending. In 19 of the proceedings it was not possible to determine from the reports whether the EMF issue affected the awards. However, in 13 of the proceedings the court either refused to decided the EMF issue or excluded all testimony on EMF health effects. In addition, there were nine reported condemnation actions in which the judge or jury made specific findings that the landowner was not entitled to additional damages based on the EMF issue. In 24 proceedings, settlements were reached which were apparently agreeable to the parties involved.

In one proceeding, Houston Lighting & Power Company (HL&P) v. Klein Independent School District (Klein) (No. 395-755, Civil Court at Law No. 1, Harris County, TX), Klein was awarded $104,275 in damages. HL&P relocated the line off school property. (Appendix C, Condemnation #24)

In another proceeding, Louisiana Power & Light Company (LP&L) v. Mobley (1986), the Court of Appeals of Louisiana held it was permissible for the trial judge to force LP&L to pay for damages to land if damages were caused by fear of adverse EMF health effects. (Appendix C; Condemnation #32).

d. Tort Proceedings. Of the 12 reported Tort proceedings, seven are final and five are pending.

In four of the finalized proceedings, the cases were dismissed. (Appendix C, Tort #s 1, 4, 5, & 10)

In one proceeding, the court found that the utility could not be held for the tort of trespass since it (the utility) was in rightful possession of the property under the state condemnation law. (Appendix C; Tort #6)

In one proceeding, the landowner claimed trespass and nuisance as a result of EMF. A trial court dismissed the complaint stating that the Public Utility Commission was the proper forum to resolve such issues. On appeal, the landowner succeeded in having the nuisance and trespass claims reinstated. The case settled with no final ruling on the EMF issue. (Appendix C; Tort #9).

In one proceeding the utility found a new site for a proposed substation after local residents expressed concern over the proximity of the proposed substation to a local high school. (Appendix C; Tort # 11)

e. Other Proceedings. Of the 22 reported "other" proceedings, 19 are final and three are pending.

There appears to be little commonality among the proceedings classified as "Other". However, in at least eight of the proceedings, hearings of various types were held, the EMF issues were presented, and a variety of facilities were approved. In three of the proceedings, resolutions, ordinances, and/or initiatives were passed to prohibit construction of transmission lines above certain voltage levels. Brief details of these and the remainder of the proceedings are found in Appendix C--Other.

5.3.4 Texas Proceedings

Nine utilities operating wholly or partially within the State of Texas reported one or more proceedings where EMF or other health effects issues were raised. These proceedings are briefly summarized below.

In Docket 5023 (1984) before the Texas Public Utility Commission, the hearing examiner recommended denial of a CCN request by Central Power & Light Company (CP&L), a subsidiary of Central & Southwest Services Corporation, for a 400-kV direct current (DC) transmission line in southeast Texas. The examiner determined the applicants had not met the burden of proof to show that the line would not adversely affect the health of individuals who live and work adjacent to the line. It should be noted that the issue in this proceeding was air-ions, not EMF. CP&L withdrew the application.

Central Power & Light Company (CP&L) filed an application for a 345-kV transmission line between their Lon Hill and Coleto Creek stations (Docket #9305) EMF testimony was filed by CP&L. Regional hearings were held and environmental issues, other than EMF, surfaced during these regional hearings. The proceeding is pending while CP&L investigates reroutes to avoid the environmentally sensitive areas.

Houston Lighting & Power Company (HL&P) was sued by Klein Independent School District in a condemnation action. The School District was awarded $104,275 in actual damages. During the pendency of the appeal of this case, the transmission line could not be used due to an injunction issued by the trial court. For its operational needs, the Company relocated this line. An award of $25 million in punitive damages was overturned on appeal by the Texas Court of Appeals on grounds that HL&P was rightfully in possession of the property under Texas Condemnation Law. The Texas Supreme Court in essence upheld the Appeals Court decision by refusing to hear the proceeding. A motion for reconsideration was filed by the School District and this motion was denied by the Texas Supreme Court.

Scott, et al v. Houston Lighting & Power Company (No. 87-058967, District Court for Harris County, Texas) is a personal injury lawsuit filed against HL&P on December 14, 1987. Mr. Scott's home is located adjacent to the right-of-way of a double circuit 345 kV transmission line (Singleton-Tomball-King). Mr. Scott suffered from a brain tumor diagnosed in 1987, and it is alleged that the tumor was either caused or aggravated by the electric and magnetic fields emanating from the transmission line. Mr. Scott, et al, further alleges that HL&P is liable for his terminal health condition because the Company (HL&P) knew of potential health hazards resulting from EMF since 1975. This case has been dismissed.

Rainwater v. Houston Lighting & Power Company (No. 87-058968, District Court for Harris County, Texas) was filed on December 14, 1987 by Mr. Scott's sister, Beverly Scott Rainwater. Ms. Rainwater sold HL&P an easement for the Singleton-Tomball-King Transmission Line Corridor, and charged HL&P with real estate fraud. Ms. Rainwater alleged that HL&P knew of potential health effects resulting from transmission line electric and magnetic fields and that had HL&P revealed that information to her, or had she known about it, she would not have sold the easement rights. This case has been dismissed.

Texas Electric Service Company[1] v. Robert Carl Berger, et al (Cause No. 85A-216, 97th Texas Judicial District), May 1987, involved a condemnation proceeding for a right-of-way/easement to construct a 345-kV high-voltage transmission line across Berger's property. The primary issues were land values relative to the actual land taken and land values before and after the taking of the land and compensation due Berger, et al.

Berger's attorney failed in his attempt to introduce EMF health effects testimony into evidence. The jury ruled against Berger and awarded an amount less than the value of the land set in the original condemnation hearing.

Matador Cattle Company v. Southwestern Public Service Company (No. 1981 110th Judicial District Court, Motley County, Texas) May 1, 1987. The EMF issue in this condemnation proceeding involving the TUCO-Oklaunion 345-kV line was whether or not the electric and/or magnetic fields extended beyond the limits of an easement onto adjacent lands. The jury found that the fields do extend beyond the easement limits. The Court found the line to be constructed in accordance with all applicable state and federal regulations and declined to award damages for EMF trespass or grant an injunction against operation of the line.

The City of Austin and the Lower Colorado River Authority (LCRA) engaged in a study to determine new configurations for a proposed 345-kV loop around the City of Austin. The original plan for a 345-kV loop was vetoed by the Austin City Council. A second plan utilizing 138-kV lines was incompatible with LCRA's system requirements. The involved utilities have been directed by the Austin City Council to determine methods of insuring system reliability to the Austin area while minimizing human exposure to EMF.

In 1979, LCRA applied for and obtained a CCN for a 345-kV line and associated substation. The Public Utility Commission adopted a hearing examiner's ruling that there were no proven health effects and added a provision that the Commission could amend or revoke the Certificate if future research shows that exposure to electric fields causes adverse health effects.

In addition, LCRA has had a total of 11 right-of-way (ROW) condemnation proceedings involving EMF. Eight of the cases settled out of court and three went to trial. LCRA prevailed in all three court actions. During the proceedings much EMF testimony was presented by both sides, however, there was no mention of EMF in any of the final rulings.

In the early 1980s, City Public Service (CPS) of San Antonio was involved in condemnation proceedings involving a 345-kV line in the Stone Oak area. After the landowners raised the EMF issue and presented expert testimony, the landowners were awarded an amount slightly less than the initial valuation of the condemned property. CPS has had seven other ROW condemnation cases involving EMF settled out of court.

Brazos Electric Power Cooperative, Inc. (BEPC) reported three condemnation proceedings involving 138-kV transmission lines. In one proceeding (Brazos Electric v. Thelma Ray), the utility offered $42,000 for a 4.2 acre parcel out of a 100 acre tract of land. The landowner claimed that the total 100 acres was damaged and asked for $1,000,000. Testimony on EMF issues was presented. The jury set the value of the 4.2 acres at $77,000. In the final order, there was no mention of EMF by either the jury or the judge. In the other two proceedings (BEPC v. Maddle and BEPC v. McAllum) trial juries awarded the landowners slightly less than originally awarded by the special commissioners courts. No mention of EMF was made in either of the final orders.

Bluebonnet Electric Cooperative (BBEC) reported one condemnation proceeding involving right-of-way for a 138-kV transmission line (BBEC v. Colhoun). Discovery is in progress with no trial date set.

5.4 Conclusions

The EMF issue is a complex issue that is being studied by electric utilities, scientists, regulatory agencies, and public health officials. To date, the research has not demonstrated any adverse health effects associated with exposure to EMF. Because of its complexity, the EMF

1 Now a division of Texas Utilities Electric Company.

issue will continue to be raised in future legal proceedings. This is particularly true in siting and zoning proceedings where regulatory and/or local governmental bodies are required to consider impacts on public health and welfare.

In future condemnation proceedings it is expected that opponents of high voltage powerlines will continue to emphasize the public fear issue. This issue evolved based on the contention that the electric and magnetic fields extend beyond the edge of the right-of-way and pose health risks or that the public's fear of health risks associated with EMF affects the market value of the property.

Since few tort actions with EMF implications have been filed to date, it is difficult to predict whether tort litigation will increase in the future. Tort litigation has the potential to expose utilities to the greatest liability since tort proceedings need not be restricted to proposed or newly constructed high-voltage powerline projects, but may involve potential EMF health effects related to distribution facilities.

Because of the EMF health effects issue, utilities face the future with uncertainty, and can only attempt to minimize EMF litigation. Utilities, by necessity, need to:

- Stay abreast of current and emerging research;
- Continue to plan and site facilities in accordance with the rules set forth by the Public Utility Commission of Texas;
- Develop an awareness of the public's curiosity about EMF health effects;
- Develop public education and information programs; and
- Continue funding EMF health effects research projects either through organizations like the Electric Power Research Institute (EPRI) or through other nationally recognized research organizations.

Regulatory and governmental agencies also need to stay abreast of the emerging research in order to make fair and prudent decisions in siting and zoning proceedings where the EMF health effects issue is raised. Likewise, public health officials must develop an awareness of the issue such that fact can be separated from fiction in deciding if EMF poses a risk to public health.

6.0 REGULATORY ISSUES

6.1 Introduction and Background

The increase in demand for electricity and the need to establish new corridors for transmission lines was faced by opposition in the 1970's who alleged that high-voltage lines might have an effect on the health of near-by residents. A notable example was the New York Power Authority experience, which resulted in heightened interest and expanded research into possible health effects due to electric and magnetic fields (EMF) caused by transmission lines. These activities and cases involving controversies, contested lines, and litigation led to consideration of establishing environmental exposure standards or limits. Electric field standards were also set as early as 1976 in Minnesota.

In this chapter, the Committee examines actions that have been taken in response to the call by some for standards to protect the public health. These efforts at regulating the electric and magnetic fields will be reviewed to determine if they are related to health effects.

6.2 Standards and Limits

It is important here to define terms that are used in regulatory language. The use of terms may vary in different jurisdictions; statutes and regulations may contain specific definitions for certain terms and should be referenced. A standard is an acknowledged measure for comparison; it may be qualitative or quantitative. Examples of qualitative standards are design specifications (such as steel construction), requirements for training, or credentials of personnel. Quantitative standards include distances, concentrations, or time periods. Standards may be included as part of a quality assurance or performance program and may be adopted voluntarily. When standards are adopted by a governmental body, they become mandatory and restrictive and may result in penalties as a consequence of government enforcement authority.

Standards are derived in a variety of ways. A pioneering group or industry may choose a design or protocol that others follow. Standards may be generated by consensus; i.e., representatives of interested groups (such as scientists or engineers) convene to analyze the facts, discuss, and debate until agreement is reached. Such groups include the American National Standards Institute (ANSI) and the National Council on Radiation Protection and Measurements (NCRP).

The term "limit" is a narrower term and refers to the level which is restrictive, e.g. speed limit. A limit is precise and can be measured, such as an electric field limit in kilovolts per meter. If a standard or limit is recommended or optional, this is usually called a guideline or guidance level. Guidelines are not developed in a formal rulemaking procedure. There is usually no authority for restriction or penalty if the guideline is not used and other approaches are taken.

Criteria or criteria documents may refer to collections of information, data, or evidence which can be used to make decisions or informed judgements about standards, guidance, or limits. Criteria documents have been compiled by groups such as World Health Organization (WHO) and National Institute for Occupational Safety and Health (NIOSH).

In the EMF context, a standard can be established which specifies restrictions on transmission lines. These may include additional siting criteria, specifications for corridors, height and other design features, and levels of calculated or measured electric and magnetic field strengths. Those field strength levels are often referred to as the limits.

6.3 General Rationale for Health-Based Exposure Standards

A health-based chronic exposure standard restricts exposure to environmental agents which may cause adverse health effects in some or all populations. Efforts at setting this type of EMF standard have been made in recent years to alleviate concern about the possible health effects from chronic exposure to EMF. The basis for these standards is of particular importance when considering regulatory implications. The Committee examined the existing and developing standards to see if such an effort is applicable. The objective was to determine if a health-based exposure standard has been established, or can be justified, as a possible consideration by the PUC.

Health-based exposure standards can only be generated after health risk assessments occur. (See previous sections regarding health effects, risk and epidemiology.) A risk assessment compiles and analyzes available knowledge, scientific findings and clinical results, and other evidence to make a conclusion about the health outcomes or deleterious effects from an agent or occurrence. Consideration is then given to possible benefits which may outweigh the negative outcome or risk, and the realization that "zero risk" cannot be the goal for environmental agents. Attention is also directed at methods and technology available to achieve a desired level or condition, practical restrictions, and financial constraints on the management of the risk. This process is inherent in public health policy and regulations; such as chlorination of public drinking water supplies to reduce the risk from waterborne diseases, or the establishment of programs to immunize children and adults.

The decision for how to manage a risk may involve setting a standard for exposure. This standard can be derived by applying a margin of safety or utilizing thresholds to generate limits with acceptable risks. If the standard is used in the regulatory manner, it is formally proposed, offered for scrutiny and public comment, and adopted. This formal rulemaking process is specified in administrative codes for the political jurisdiction at federal, state, or local levels.

6.4 Scientific Basis for EMF Standards

There are some complicating factors in the present state of knowledge about 60 Hz EMF which preclude setting health-based standards at this time. The usual assumptions used to set limits (both occupational and population standards) are not valid in this case. There are insufficient and inconsistent data on which to establish a health risk. These are detailed in preceding sections of this report and in several literature review papers.

The basic assumption in protection from exposure to most environmental hazards, such as chemicals (benzene, pesticides), or physical agents, (ionizing radiation or ultraviolet radiation) is that increased exposure, either to higher levels or for longer duration, increases the risk and severity of deleterious effects. More exposure is worse; less exposure is better. This may not be the case in EMF effects based on present scientific evidence. It has been hypothesized that there could be "window effects" for different frequencies and different amplitudes. These have been demonstrated in human exposures as well as in vitro experiments in which a result was observed at one level and disappeared at others, often higher or stronger than the reactive one. It therefore becomes possible to select a standard which could be lower, but is in the response "window" and could result in different exposure groups. A possible implication for the regulatory issue is that prohibition of higher-kV lines may force construction of additional lower voltage lines for the load demand reliability. Those additional lines may "expose" a greater number of people.

Another limitation in using current data to generate a health-based standard is that no dose has been derived. There is no consistent response relating a metric of the fields with a health outcome, and no decision can be made about safe or unsafe levels or fields.

One cannot employ the methodology used for other environmental pollutants nor justify models similar to those used for ionizing radiation, microwave and radio frequency radiation, or chemical exposures. For example, it would be very convenient if the same approach used in setting standards for lead could be used. Lead is a heavy metal, commonly found in the environment of an industrialized society. Various standards for exposure to lead have been set which have been derived from clinical tests and observations of patients exposed to lead. There are occupational exposure limits for many different lead compounds. There are limits on the lead content in drinking water. There are blood concentration levels of lead which are used to trigger decisions in the work place, or to signal investigation of children exposed to agents such as lead-based paint. It is not clear whether additional EMF research will complete the missing information, find another cause, or if new mechanisms will generate a different framework of standard setting. The 60-Hz data cannot at this time be adapted to this framework because the risk is niether known nor quantifiable, and no dose response has been found.

6.4.1 Occupational Standards

The rationale and justification for occupational standards can be based on assumptions and the use of biological models that have been derived from the scientific experiments. These models may be used to calculate a dose and dose response, i.e., a biological result, usually in average-sized adults with normal ranges of physiological functions, such as breathing rates or excretion rates. This so-called "healthy worker" is usually assumed to be working an 8-hour day and away from the work place for the remaining 16 hours in a day. This latter portion of the day allows the body to recuperate and repair biological damage or insult that may have been caused by the chemical or physical agent.

In the case of chemicals in the work place for which deleterious or lethal concentrations are well-documented, the exposure to a worker is limited to a specified concentration which may include a time duration for the exposure to the chemical or carcinogen. In industrial hygiene, this is called a time-weighted-average. Good examples in the literature are found for lead, benzene, and many others.

Indication of the complexities in 60-Hz standard setting should be noted when one compares the metrics and field characteristics detailed in the literature. Some researchers use a single measure of field strength or flux density; others attempt an averaging; others apply more elaborate engineering approaches. No data as yet indicates what "number" best defines the field for purposes of establishing health effects. The advances in exposure assessment and characterization of the fields has been noted in recent years and may contribute to a greater understanding of the science.

Another technique in setting occupational standards is to establish a ceiling or upper limit. Of importance in this context is the standard recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) in "Threshold Limit Values (TLV) and Biological Exposure Indices for 1989-1990." ACGIH added a section on "Extremely Low Frequency (ELF) Electric Fields" up to 30 kHz, and recommend 25 kV/m for a routine occupational limit. They also have an existing "Static Magnetic Fields" limit of 600 gauss, whole body exposure. These field levels are levels to "which it is believed that most workers may be exposed repeatedly without permanent biological effects..." They are not to be used as a demarcation between safe and dangerous levels.

The ACGIH stated in 1989 that they had "not found sufficient information to propose a TLV," but will continue to study "Low Frequency Magnetic Fields" and "Static Electric Fields." Subsequently, the ACGIH Physical Agents Committee prepared a Notice of Intended Change for 1990-91, concerning "Sub-Radio frequency (30 kHz and below) Magnetic Fields, and Sub-Radio frequency (30 kHz and below) and Static Electric Fields." That proposed exposure value was adopted in the 1991-92 edition. It limits worker exposure to a permissable magnetic flux density of 1 mT at 60 Hz.

6.4.2. Environmental Standards for the General Public

Population-based standards for the general public have been used for various kinds of exposures. Examples of these kinds of standards include limits set on chemical constituents in drinking water, air pollution indices including emission levels from industries and automobiles, asbestos, radon gas in homes, and contamination levels in food and produce. These standards may take into account the individuals in the population who are more sensitive to the environmental agents. The most sensitive are usually fetuses, young children, the aged, ill, or handicapped. Such standards may assume that the exposure is continuous (24 hours per day, 7 days per week) and chronic (will occur over the next 50 years or a lifetime). The standards must rely on biological evidence, quantification of dose, extrapolation to the populations at risk, laboratory results, and measurement of what is in the environment. Evidence of this type is incomplete and insufficient at this time to support EMF standards. Setting a standard based on concern about a rare condition, such as childhood cancer, in the absence of a biological mechanism and dosimetric response, does not provide any real protection to the public.

6.5 Existing Standards

6.5.1. International Standards

(See Table 6.1 for a summary.)

This discussion of international work will focus on the selected countries because of the long-standing parallels with the United States in the areas of environmental policies. Although there has been some interesting effort in the Soviet countries, it is difficult to relate to western circumstances or extrapolate how the standards are implemented and enforced. It is possible with the dramatic political changes that in a few years much

Table 6.1 - Recent International Standards for 60-Hz Fields

Standard	Electric Field	Magnetic Field
IRPA (public)	5 kV/m	1000 mG
IRPA (occupational)	10 kV/m	5000 mG
United Kingdom (all)	10.233 kV/m	1630 A/m (20 G *)
Australia (public—all day)	5 kV/m	0.1 mT
Australia (public–limited day)	10 kV/m	1 mT
Australia (occupational—all day)	10 kV/m	0.5 mT
Australia (occupational limited day)	30 kV/m	5 mT**

* Flux density in tissue
** Maximum 2 hours per day

more open dialogue will occur about their work.

a. The International Radiation Protection Association (IRPA) issued "Interim Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields" in 1990 which are based on protection from induced currents and "established effects of exposure." IRPA stated that an association with cancer was not considered because present data does not provide "any basis for health risk assessment useful for the development of exposure limits." (IRPA, 1990)

b. The United Kingdom approved a guidance standard in 1988. The National Radiological Protection Board (NRPB) chose not to differentiate between occupational versus the public exposure at low frequencies because of the absence of a "scientific justification." The NRPB guidelines cover the frequency range up to 300 GHz and are based on the specific energy absorption rate and thermal effects for the higher frequencies. At frequencies below 30 MHz, induced current is considered; the electric and magnetic fields are derived separately in root-mean-square values. The electric field strength is specified in V/m and magnetic field strength in A/m. For 60 Hz, the levels are 10233 V/m (10.2 kV/m) and for 50 Hz, 12280 V/m (12.3 kV/m). These are similar to the 9 to 10 kV limits in Table 6.2 for states in the United States.

The magnetic field strength is limited to 1630 A/m. The magnetic flux density in tissue is also given as an alternative to the equivalent magnetic field strength; that limit is 2mT or 20 G.

The NRPB stated that they agree with the International Nonionizing Radiation Committee (INIRC) of the IRPA in its conclusions, that:

> "there is at present insufficient biological and epidemiological data to make a health risk assessment or even to determine whether there is a potential hazard to health with regard to athermal effects of electromagnetic fields."

They further explain that "the experimental evidence for biological studies is often statistically weak and proves difficult to reproduce." Regarding the population-based and occupational epidemiologic studies, they conclude that if the risks are real, they are within the range regarded as "tolerable" and "should not unduly concern individuals." (NRPB, 1989)

c. The World Health Organization (WHO) published Environmental Health Criteria 35: Extremely Low Frequency (ELF) Fields in 1984. The document reviewed the existing worldwide research and reached conclusions on the existing studies. For intermittent exposures to electric fields below 10 kV/m, no restrictive considerations appear necessary. In the absence of adequate data and in lieu of conclusions about possible long-term effects, precautionary measures are suggested, i.e., keeping exposures ALARA (As Low As Reasonably Achievable). A subsequent Environmental Health Criteria 69: Magnetic Fields (1987) expanded the discussion, but was unable to make conclusions about chronic exposure; it was completed prior to the more recent studies of magnetic fields. These criteria detail the scientific data base and rationale for recommendations, and may contribute to evidence for possible recommendations or standards for the IRPA, NRPB, or NCRP.

d. Australia established "Interim Guidelines on Limits of Exposure to 50/60 Hz Electric and Magnetic Fields (1989)" expanding groups but following the rationale stated in the other examples noted. (Commonwealth of Australia, 1989)

6.5.2. United States

No national standards exist for the regulation of long-term health effects from 60-Hz electric and magnetic fields, nor does a federal agency have a clear mandate or specific authority to regulate or take the initiative. In the absence of federal direction, the states have reacted in various ways to the issue.

Interest at the Congressional level has been evidenced by hearings in Washington to receive testimony from the federal agencies, research scientists, industry representatives, and concerned citizens. Those hearings include the House Subcommittee on Natural Resources, Agriculture Research and Environment Hearing on EMF Research Bill HR 4801 (July 25, 1990); House Interior General Oversight and Investigation Subcommittee (March 8, 1990); House Subcommittee on Water and Power Resources (October 6, 1987). The hearings have involved extensive argument on the research needs, the limited federal support and the role of the federal agencies.

Environmental Protection Agency (EPA) is the federal agency with authority to establish national environmental standards for water and air pollution, toxics, and hazardous wastes. The Agency does not currently have a legislative or judicial mandate regarding exposures to EMF as it has for regulating other environmental areas, such as air standards under the aegis of the Clean Air Act, or to set other standards for hazardous waste or water contamination. Nor has the Agency been placed under court order, as in the chemical carcinogen cases, to set standards based on health risks, and scientific health-risk assessment. On September 29, 1988, EPA announced the phasing out of its activities in nonionizing radiation because of agency priorities and limited resources. However, the staff more recently undertook a review of the scientific literature and consideration of policy implications that may lead to more federal involvement, and funding allocations.

The Department of Energy (DOE) has been the only federal agency to play a consistent role in the EMF issue for the many years since interest heightened. DOE has a compelling role because EMF concerns involve the energy distribution and use in this country. The DOE has made significant contributions by maintaining funding of basic research and monitoring the science.

Other federal agencies have potential roles if certain health effects should be demonstrated for EMF. The Department of Transportation is evaluating "maglev" trains which travel via high-speed magnetic levitation. The Food and Drug Administration has been a lead agency in matters involving radiation and in regulating consumer products, both ionizing and nonionizing radiation with potential exposure to the public, such as televisions, microwave ovens, and lasers under Public Law 90-602, and subsequent Public Law 101-629, Safe Medical Devices Act of 1990. Should additional studies with occupational exposures indicate a need for action, the Occupational Safety and Health Administration may become more involved. Other agencies with potentially expanded roles are those with interests and responsibilities for worker and public health: National Institute of Health, National Institute of Occupational Health and Safety, National Cancer Institute, and the Centers for Disease Control.

Outside the federal agencies, there has been preliminary work by the National Council on Radiation Protection and Measurements (NCRP), by the American National Standards Institute (ANSI), the American Conference of Governmental Industrial Hygienists (ACGIH) and the Institute of Electrical and Electronics Engineers, Inc. (IEEE). These groups are noted for developing scientific guidance documents describing measurements, exposures, and protection practices. Developing consensus standards is done by committees of scientists, engineers, and other experts in the specialized area. These recommended standards often lead to an industry or regulatory standard. The regulatory community considers this expertise in adopting its own standards, even to the adoption verbatim of some portions. With the exception of ACGIH as noted in the above section on occupational standards, these groups have not pursued the issue to the rigorous level they employ to make formal recommendations. Until the science becomes less speculative and scientific consenses can be approached, they may not accelerate the effort.

Some national associations have also expressed concern about the EMF issue and urged a greater federal role. Others have commissioned study groups or committees, have proposed policy statements, or passed resolutions on the issue. These groups include the National Association of Regulatory Utility Commissioners, the Association of the State and Territorial Health Officers, National School Boards Association, the Conference of Radiation Control Program Directors, Inc. and others. Much of the concern arises because of the diversity of responses in the states and potential problems with conflicting overlap, or incompatible recommendations or standards.

The National Electric Safety Code (NESC) has been employed for many years by the industry and many state regulatory agencies as a standard for reducing potential shock hazards from transmission lines. The NESC is used in design criteria for lines by placing limits on induced current levels of 5.0 milliamperes RMS (root mean square), in objects in proximity of the lines. Assumptions must be made to estimate the largest vehicle or equipment anticipated to be present under the lines. The code in practice is used in the determination of right-of-way and clearance distances for specifications of line construction and placement, and to limit the maximum level of the electric field on the right-of-way. (BPA, 1989)

The NESC is established for the prevention of electric shock and is based on safety concerns from a single acute exposure. It is not intended to protect from possible long term health effects due to chronic exposure.

6.5.3 Other States

In response to the EMF health effects issue, and this lack of national-level initiative, the individual states have exercised a variety of options; some leading to a regulatory response; however most states have found no basis for regulation. The few regulatory responses are a hodge-podge of restrictions with differing rationales and incentives. This continues since the 1970's when the concern was for electric field exposures, until recent interest turned to magnetic fields. The states' responses can be described in four groups: (1) take no special action, (2) study and report on the issue, (3) undertake and fund research, and (4) use regulatory authority and establish standards.

In the first group, many states have chosen not to take additional action, but continue to review each siting issue on a case-by-case basis.

States in the second group have directed a formal review of the scientific literature by a state agency or an ad hoc committee of experts. The states usually request a recommendation or report for the legislature or regulatory authority. Virginia has an on-going review with periodic reporting; annual updates have followed the initial report. Other states requested a single written report such as Washington and Oregon. Montana used this approach for the electric field question and subsequently adopted electric field limits based on the recommendations. These various state reviews are usually undertaken for political concerns, have little funding or support and have made limited contribution to understanding of the issue. There appears to be a need instead for collaborative effort on a national level, rather than 50 separate studies, since the scope of the problem is national and international (notably Canada and the northern U.S.).

The third type of state response is represented by New York and California. Both states implemented research programs funded by the utilities and administered by state agencies. Maine's legislature considered this option in 1989, but decided to collect and evaluate existing data and research findings. Maryland has also undertaken a research program.

The fourth response option that a few states have taken is the adoption of regulatory standards imposing limits on the electric and/or magnetic fields. A tabulation of the existing limits for transmission lines for the seven states is shown in Table 6.2. The electric field limit was set based on the consideration in the early 1970's that if a biological effect exists, it is due to the electric field component interacting with, or influencing, the chemical and electrical nature of human physiology. Later research implicating magnetic fields is evidenced in the Florida rule in 1989 and the preliminary rulemaking activities in New York and New Jersey. The rationale and the development of these limits is important for us to consider.[1]

The difficulty in examining the standards is finding any method to evaluate their benefit. The electric field limits have been in use for several years: for the NESC-based limits for induced current, the protection against shock is a benefit. For the limits set on the fields for presumed protection from chronic exposure, no quantifiable outcome is estimated, therefore no benefit has been offered or substantiated. Even more difficult to evaluate is the presumed link to magnetic field limits and childhood cancer. At what level is the outcome of cancer expected and at what level will it be reduced? Since no dose response has been demonstrated, no protection or prevention can be measured. Table 6.2 shows the standards for transmission lines that have been in place in the specified states.

1. Minnesota's standard for electric fields dates back to 1976 as a result of the hearing for the Winnipeg-Twin Cities Transmission Project. The Environmental Quality Board set the 8-kV/m limit in the right-of-way based on suggestive evidence at the time that 10 kV/m is a level which protects the public health and welfare. They reduced that level based on the fact that lower fields could be achieved using available technology. This limit is used for new transmission lines of 200 kV or higher.

2. North Dakota Public Service Commission employs a 9-kV/m electric field limit which was selected after the issue of biological effects arose in some of their siting cases. In lieu of a scientific rationale, the level was chosen to respond to potential concern for health effects.

3. Oregon like Montana has a codified rule for electric field limits for transmission lines. The 1980 rule requires the Oregon Energy Facility Siting Council to use the 9-kV/m limit in the right-of-way, i.e., in areas accessible to the public. They adopt the NESC, but encourage an effort to keep the induced current level to be as low as reasonably achievable. The intent of the standard is to protect the public health. In 1990, a study was commissioned to review the literature. (Oregon, 1991)

4. Montana set electric field limits as a prudent approach toward a public health-based standard. The standard was recommended in an extensive review of the available evidence on electric fields. They commissioned a scientist in bioelectromagnetics research to evaluate the scientific work and suggest action if warranted. (Sheppard, 1983) Concluding no serious hazards had been proven, the report did offer a limit as a precautionary level to provide protection from any potential health effects due to chronic exposure. In adopting the rules, the Montana Board of Natural Resources and Conservation included the 1-kV/m limit at edge-of-right of way, but specified it for residential areas, and provided the landowner

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1 Banks (1989a, 1989b, 1990) has researched the regulatory process and evidentiary record for the states in great detail and can be consulted for further reference. Slesin (Microvave News) also reports political and scientific events regarding regulatory issues.

an option to waive that limit and thereby reduce the width of the right-of-way. They also added a 7-kV/m peak limit at road crossings. The provisions include a welfare-based standard as well to reduce the annoyance characteristic from audible noise, further extending the width of the right-of-way.

5. New Jersey has a nominal 3-kV/m limit at the edge of right-of-way which has been used since 1981 as a basis for response to complaints concerning existing lines. The basis was the status quo condition at the time and the lack of any evidence on adverse human health effects at that level. Consideration was given to annoyance from transient spark discharge at 6 kV/m, so a margin of two was used to set the 3 kV/m. They are currently involved in rulemaking to set a magnetic field limit following a directive from the Commission on Radiation Protection.

6. New York set an interim standard of 1.6 kV/m edge of right-of-way limit (350-foot width) in 1978 at the commencement of the Power Lines Project. The intent was to set the width of the right-of-way to status quo, the field levels generated by existing 345-kV lines. The limit is used in determining width of right-of-way. An added limit for electric fields in the right-of-way on public roads is 7 kV/m; 11 for private roads and 11.8 for other terrain. This limit is similar to the National Electric Safety Code, but restricts induced current to 4.5 mA instead of 5.0 mA. In recent years following the extensive research program, considerable activity occurred toward setting a magnetic field limit. An evaluation of the existing 345-kV lines in the state has been performed to suggest a limit that would be equity-based, i.e., they would not permit additional lines which would cause fields higher than have already existed. (That level is approximately 200 mG.)

7. Florida's legislature empowered the Department of Environmental Regulation to adopt rules for transmission lines in 1983 which would restrict the electric and magnetic fields. Upon the advice of a scientific advisory group of experts, the Department did not exercise that prerogative. Following legal proceedings and a second scientific advisory group, limits were recommended. Rulemaking and adoption of magnetic and electric field limits followed, setting limits for

Table 6.2 - State EMF Standards for Transmission Lines*

State	Electric Field (kV/m)	Magnetic Field (mG)	Location	Application
Minnesota	8		in ROW	> 200 kV
North Dakota	9		in ROW	Informal
Oregon (codified)	9		in ROW	230 kV, > 10 miles
Montana (codified)	1		edge of ROW	> 69 kV
	7		in ROW	road crossings
New Jersey	3	**	edge of ROW	Guideline for complaints
New York	1.6	200mG***	edge of ROW	>125 kV, >1 mile
	7		in ROW	public roads
	11		in ROW	private roads
	11.8		in ROW	other terrain
Florida (codified)				500 kV lines
	10		in ROW	Single Circuit
	2	200	edge of ROW	Single Circuit
	2	250	edge of ROW	Double circuit
				230 kV or less
	8		in ROW	
	2	150	edge of ROW	

*Compiled from Banks(1989), OTA(1989), MWN(8/89), FL Statute
** Under consideration
*** Final 9/11/90 PUC "Interim Standards"

lines of 69 kV and above, and includes substations. The electric field limit at the edge of the right-of-way is 2 kV/m; in the right-of-way, it is 10 kV/m for 500-kV lines and 8 kV/m for 230-kV lines or lower. The magnetic field limit is specified only for the edge of the right-of-way: 150 mG for 230-kV lines or lower, 200 mG for single circuit 500-kV lines and 250 mG for double circuit 500-kV lines.

The standards were set in response to concerns and political motivations regarding the possibility, not evidence, of adverse health effects. The standard has therefore been categorized as a welfare-based, not health-based standard. The standard is subject to review during 1991.

6.6 The Situation in Texas

The EMF issue in Texas is similar to the experience in other states. When attempting upgrades or selecting new corridors, the utilities are faced with a potentially lengthy and expensive legal situation. Historically, there have been challenges to their siting proposals; however, they were often based on monetary and contractual arguments and were settled by negotiating the price and arrangements for land acquisition. The decision making did not greatly involve tort claims and legal battles alleging health claims.

Some more recent siting cases have been in the courts and appellate courts for years. Should standards be established, the siting process might be simplified. Once a standard is set, a utility can use design criteria and practice to achieve compliance. The standard would ostensibly remove the argument for health effects or greatly reduce the chances for appeal. Barring the complication, for a moment, that there is no clear or conclusive evidence on which to develop a health-based standard, what options exist in Texas?

In Article III, Sec. 16, (a), the PURA gives to the PUC "..the general power to regulate and supervise the business of every public utility within its jurisdiction.." Additionally the PUC "... shall make and enforce rules reasonably required in the exercise of its powers and jurisdiction, ..."

The substantive rules promulgated under this authority currently contain a provision which is associated with the EMF issue. It is addressed in the reference to the construction of new service, Section 23.44(a), New Construction:

Standards of construction. In determining standard practice, the commission will be guided by the provisions of the American National Standards Institute, Incorporated, the National Electric Safety Code, and any such other codes and standards that are generally accepted by the industry, except as modified by this commission or by municipal regulations within their jurisdiction. Each utility shall construct, install, operate, and maintain its plant, structures, equipment, and lines in accordance with these standards, and in such manner to best accommodate the public, and to prevent interferences with service furnished by other public utilities insofar as practical.

It appears that if electric and magnetic field exposure standards are adopted by the ANSI, NESC or another group that the industry accepts, the PUC can readily adopt them as guides. If they are to be implemented as limits for all siting cases, this may require rulemaking and inclusion in the substantive rules.

In examining the rule for the standards of construction, a question arises if one considers the possibility that municipal regulations may be adopted. Can any or all cities adopt exposure limits for EMF and thereby restrict a PUC permitted line? How serious would be the effects of several different limits for one service area? The ramifications may be important in future cases, such as the case in which an Austin city ordinance restricted lines which were necessary for land development ostensibly referencing possible public health concerns. The ordinance was rescinded in 1989.

The PUC also has the option of deferring arguments and potential health effects issues to the Texas Department of Health (TDH). In effect, the PUC could rely on TDH's expertise and authority to identify the presence of health risks to the public, advise other appropriate authorities, and participate in the development of health-based standards if they become justified. Should future evidence suggest personal life-style changes, for pregnant mothers, children with genetic or other traits which alter their risk for childhood leukemia, or occupational health considerations, health agencies have the needed expertise and experience.

6.7 Conclusions

In the area of regulatory issues, a wide variety of actions has been taken by legislative and administrative bodies in response to public and media concerns about potential health effects. The range of response is great and the rationale and reasons vary. There has been some formal and some informal use of standards, although standard setting has been controversial and of unknown benefit. The majority of states have determined after their own research, or based on reports from experts, that the most appropriate response at this time is to defer any standard-setting activity until scientific evidence is more convincing and consistent so that effective and appropriate actions can be devised.

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7.0 POLICY ISSUES AND OPTIONS

The proposition that electric and magnetic fields (EMF) from such sources as high-voltage transmission lines, distribution facilities, home wiring, and electric appliances, may pose a risk to health has become widely recognized as a legitimate and worrisome hypothesis in need of thorough investigation (See OTA, 1989). Just in the past year or so, several Congressional Hearings have been held, the Office of Technology Assessment, Department of Energy, and the Environmental Protection Agency have issued reports, and a number of states have convened expert panels to investigate the possibility of adverse health effects from EMF. Media coverage has moved in parallel, providing a window for the public on the emerging debate. Coverage in newspapers and newsmagazines emphasizes state initiatives and the positions of various stakeholders, while more specialized periodicals, such as Science and IEEE Spectrum, summarize scientific findings to date and speculate on their import. Exposés in the New Yorker, and Family Circle offer accounts of personal tragedy and exposure to EMF. Despite all of this attention, the scientific evidence suggesting a link between magnetic fields and disease is considered inconclusive by many experts and appears inadequate to support an authoritative claim one way or the other (See Morgan and Nair, 1990). Further, there is a notable lack of consensus on whether EMF, as currently understood, constitutes a public policy problem. Even among those assured of its problematic status, there is no unifying presumption about the type of problem it represents or the collective action it warrants.

In the absence of conclusive science on the matter, the interpretations of other social and political institutions have effectively come into play, each bringing a somewhat different perspective to the EMF issue and a distinctive way of accommodating the perceived uncertainty over adverse health effects. The result is a somewhat confusing mixture of warnings and reassurances, of calls for more study, or for immediate action. Typically, such wide variation in responses by both people and institutions to environmental risks can be attributed to well documented biases that influence perceptions of risk and judgments about its acceptability (Fischhoff, et al., 1982). In the case of EMF, however, there is no benchmark for such judgment grounded in a scientific consensus on the empirical nature of the risk at issue. Differences in emphasis and interpretation, then, extend beyond the workings of judgmental biases to encompass the basic meaning assigned to the EMF issue. Policy questions about EMF exposure, accordingly, are not limited to clear-cut choices among control strategies or management options but include different ways of understanding and framing the key policy problem.

Political institutions can be expected to take different policy stands on the EMF issue, depending upon how they collectively weigh evidence and judge acceptability (See Clark, 1990). Part of the account offered here will trace those differences to an institution's structural and procedural attributes. With the problem posed by EMF exposure open to interpretation, however, disagreements over policy will span the language used to characterize EMF as a public concern as well as its empirical character. Accounts of contending claims for action and inaction must reach beyond institutional features to the contest over social and political meaning. This section will examine public policy on EMF on both of these levels. First, we will suggest several ways that judgmental biases about risk from EMF appear to parallel the structural and procedural features of different political institutions. Given the pattern of institutional experience with EMF across the states, the discussion will focus more intently on regulatory agencies and the courts than on other institutions. Attention will then turn to questions of how EMF has been depicted in public discourse, how its status as a problem is being defined, and to the assumptions and policy prescriptions that follow. This analysis will include the role of rhetorical devices, principally analogy, and consider four distinct problem definitions and their import for the design and choice of competing policy options.

7.1 EMF Policy and Political Institutions

Unlike assessments for most hazardous substances, the ground rules for measuring exposure to EMF, and thus characterizing the health risk, are themselves open to debate. Estimates of risk published in the scientific literature vary widely with definitions of exposure and the exposed population, attention to confounding influences, and to the precision and accuracy of measurement. In the view of the scientific community, the primary means to overcome these inconsistencies is to accumulate better evidence through more research, assuming that subsequent studies will introduce successive corrections and refinements, eventually allowing investigators to converge on a stable set of valid results. Arguments to quicken the pace of research sometimes appeal implicitly to prejudice against social and political methods of "resolving" scientific uncertainties and the desirability of preempting them. Nevertheless, in the interim, there will be efforts to anticipate possibly conclusive findings, and to take action to mitigate their likely social and economic impact. Until the scientific community has fashioned a consensus on EMF health effects, claims about how best to meet assumed mitigation needs or to manage suspected risks, must rely principally on a carefully limited selection of scientific sources and largely non-scientific backing.

Political institutions in our society can provide such backing, offering alternative means for resolving uncertainty, and standards of proof and persuasion that are very different from those of organized science. Accordingly, there is likely to be conflict among these institutions over how much risk there is, and how quickly they must decide. Several factions within the scientific community compound this conflict by airing their disagreements over the significance of EMF risk in non-scientific forums. Risk-accepting and risk-aversive factions have formed to dispute the magnitude of harm suggested by the available evidence. Conflict of this sort can easily test public patience with the pace of scientific progress on EMF issues and confuse calls for more careful study with veiled attempts at strategic delay. Critics of postponing action to await further research assign self-serving motives not only to the stakeholders, such as the electric power industry, but also to the scientists who will conduct the studies.

Across the states, a number of institutions, including courts, legislatures and administrative agencies, have explicitly addressed the uncertainty over the health effects of EMF. While the scientific community continues to play a prominent role in the EMF issue, other institutions whose judgment does not require an accumulation of research results are inclined to decide more quickly on action or inaction despite the remaining uncertainties. Their decisions will be based on interpretations of incomplete information, structural and procedural factors, and on their expectations of science and the findings it may eventually produce. The resulting diversity of action and understanding makes it difficult to find any reliable cues on the single, most appropriate, public policy response.

The principal task in this section of the report is to examine the judgmental biases, along with their structural and procedural correlates, that lie at the roots of the diversity among policy responses to EMF. Social and political institutions rather than whole states will serve as the focus. Notably, most of the conventional wisdom about state-to-state variation in policy making based on differences in political, demographic, and economic characteristics appear not to apply to the EMF issue. Knowing which states are considering EMF questions will be not nearly as informative as knowing which institutions within these states have assumed jurisdiction, since we expect institutions sharing judgmental biases to respond in similar ways across state lines. A few basic concepts adapted from the literature on decision theory will be used to characterize the judgmental biases of selected institutions and to simplify their link to structural and procedural differences. Since the relation between science and political institutions sets the context for much of the policy debate over EMF, science itself will be treated as a social institution whose procedural and structural features will serve as a basis for comparing scientific with non-scientific ways of framing EMF questions.

7.1.1 Judgmental Biases

In the face of uncertainty over a given hazard, institutions can choose either to act or not act, depending upon their bias, and may be proved wrong in either case. Although mistakes are to be expected, not all mistakes carry the same consequences. Borrowing an analytical distinction from decision theory, the core issue in the choice of action versus inaction appears as a tradeoff between two kinds of errors: the false positive, acting when no action was warranted; and the false negative, failing to act when action was warranted. Since, at the time of the choice, the uncertainty over the validity of the action has yet to be resolved, the recognition of error is necessarily retrospective. Nonetheless, attention to the tradeoff beforehand reveals a great deal about an institution's weighing of the possible political and economic consequences connected with each error and its relative tolerance for one kind over the other (Linder and McBride, 1984; Page, 1978). Each particular tradeoff affords a somewhat different role to science and invites a different measure of discretion and predictive judgment on the part of the policy maker (Gaines, 1990).

As an illustration, criminal courts, perhaps out of social consensus rather than judicial temperament, are predisposed toward false negatives since they assign an intolerable political cost to false positives; in this case, conviction and punishment of the innocent. Accordingly, their threshold for action is set quite high, demanding a close scrutiny of plausible evidence of guilt, their warrant for action. In contrast, civil courts manifest a less pronounced bias, shifting more of the costs of error to the claimants in deference to the status quo (See Huber, 1988).

Greater complexity can be introduced into the tradeoff by recognizing the parallel between the costs of errors and the values assigned to correct responses. Not all correct responses share the same consequences nor are valued in quite the same way. An institution's inaction, even if that response is proved correct by subsequent developments, may have very different consequences than a correct response that involved action

(Wildavsky, 1990). Further, the relative value of each type of correct response, from this perspective, can be linked to the relative costs assigned to each kind of error. Institutions that place a high value on correct rejections of ambiguous evidence and on the avoidance of false positives, for example, will tend to have a higher threshold for action than other institutions facing the same level of uncertainty. In contrast, those placing a high value on anticipating the need for action and who find false negatives to be the more objectionable of the two kinds of errors will tend to have a lower threshold for action, again independently of the balance of the evidence.

The simplest way to represent the bias in how institutions structure the uncertainty surrounding adverse health effects is in a two-way table. On the left-hand side of Table 7.1 appears the two alternative positions that actors can take based on inconclusive evidence. The first is to conclude that substantial adverse effects are indeed likely and, accordingly, that widespread precautionary measures are in order. In other words, the risk posed to the public may be unacceptable and something should be done. This stance need not involve a denial of the inconclusiveness of the evidence but might be based instead on an aversion to the possible consequences of postponing action in error. Avoiding a false negative outweighs other concerns. The second position holds that adverse health effects are largely unsubstantiated and, thus, that control measures are premature. From this viewpoint, until the risk to the public is clarified, or at least shown to be potentially large, no action is warranted. Here, it is the consequences of acting without a firm warrant that seems most troublesome.

The two possible resolutions based on prospective evidence that will ultimately prove one or the other of these positions wrong appear at the top of the table: at some time in the future, either health effects prove to be significantly adverse, or not. The four discrete outcomes appear in the body of the table. It should be noted that this construction assumes that the evidence on the health effects of EMF will eventually become conclusive, if not scientifically, then socially or politically. Further, the gray areas between harmful and harmless, substantial and undefined, have been excluded to highlight the workings of the "bias" notion and to clarify its connection to certain institutions.

To the extent that such a bias exists, similar institutions across the states should respond in predictably similar ways to uncertainty, employing similar conventions of interpretation and sharing judgments that distinguish them from other kinds of institutions. Logically, we would expect the utility *commissions* of any two states, for example, to be more similar to each other in how they deal with scientific uncertainty, than either would be to a Health or Environmental Agency within their respective state. Under this interpretation, it clearly matters which kind of institution has assumed jurisdiction over the EMF issue, since different institutions will structure uncertainty differently and will employ different policy tools to assist in its resolution.

The tradeoff between false-positives and false-negatives or judgmental bias unique to each institution is effectively supported by both structural and procedural features. Typically, however, one set of features will appear more prominent in a given institution, permitting a more direct link to its imputed bias. Structural features, including norms, incentives and formal organization will be emphasized in discussing the legislature, media, and scientific establishment, while procedural ones will be the focus in a later treatment of regulatory agencies and the courts.

<u>The Science Community.</u> The scientific community as an institution has a high stake in avoiding false positives, public claims of an association later found to have been unjustified, for example, since its authority in public policy matters is linked both to its public image of skepticism and to the perceived conservatism of its procedural mechanism for validating evidence (Large and Michie, 1981). When this image is shaken because of premature claims that mislead the public or their officials, the credibility of science as a whole suffers. For instance, the scientific assurances given to

Table 7.1 - The Tradeoffs in Responses to Uncertainty

RESPONSE	EVENTUAL RESOLUTION EMF Proves Harmful	 EMF Proves Harmless
Yes, Risk is Substantial	Correct Response [precautions prove warranted	"False Positive" Error [sacrifice trust & investment in precaution]
No, Risk is Not Yet Defined	"False Negative" Error [assume responsibility for delayed response]	Correct Response [caution proves warranted]

the public throughout the decade of the 1950's that nuclear testing and radiation exposure posed no grave danger, in the view of some analysts, created a credibility problem with which the proponents of nuclear power must still contend (Bupp and Derain, 1978). Inferences about the relative benefits to the scientific community of either kind of correct response are more ambiguous.

Timely claims of problems in need of public action are a prime source of social support for the scientific enterprise; however, a large part of this support involves a reliance on the capacity of science to offer protection from the ill-founded claims of others on society's resources. Assuming that neither of these values can compensate for the costs of false positives, we can assume a relatively high threshold within organized science for supporting action in the face of uncertain evidence (Jasanoff, 1990). Ironically, for the individual scientist, the false negative may represent the more serious risk; a pattern of claims establishes one's reputation and status, even if some proportion of the claims are eventually refuted by the larger process of testing and replication.

The Media. Several other institutions can effectively exploit this irony by invoking the authority of science while inviting investigators to preempt the scientific process by making their intramural claims public. The print and electronic media have procedural devices for validating evidence, to avoid false positives, although by design they are less time and resource intensive and therefore less stringent than those of science. The false negative, in contrast, represents a threat to their economic prosperity. The media coverage given to EMF has been prompted in part by the general climate of public concern about concealed threats to health. It can also be seen, however, as an effort by news directors and managing editors to minimize the risk of missing a potentially significant phenomenon, given their perception of a shift on the part of some scientists now intent on doing the same. Being a part of a possible "scoop" may have sufficient appeal, for some in science as well as the media, to outweigh the risks of sounding a false alarm.

The Public Health Profession. The values of the public health profession, grounded in an ethic of disease prevention, militate in favor of precautionary measures in the face of uncertain harms. Here again, the individual scientist may be torn between conflicting imperatives: on the public health side, advocate action just in case the harm is real, versus, on the scientific side, maintain an open-minded yet neutral stance until sufficient evidence is in. In this instance, choosing is not so much a matter of professional judgment as it is a personal decision about where one's primary loyalties reside. When uncertainty is pervasive and evidence is inconclusive, there are no easy footholds for supporting one's position. Not knowing the chances of ultimately being proven wrong, one is left to decide, at least in part, on the basis of loyalties and how these affect one's views of the possible errors.

Science has traditionally served the public health profession not only in the identification of environmental harms, but also in their mitigation. A number of successful collaborations has resulted in public policy for controlling exposures to both natural and artificial substances, ranging from benzene to chloroform. For many within the profession, these successes reinforce a bias toward precautionary action and confidence in predictive judgment. A more subtle effect has been to create a powerful analogy that shapes subsequent considerations. Ambiguous risks can be given clear definition by assuming parallels to earlier success stories, perhaps most poignantly to stories involving the identification and control of hazardous exposures to widely used substances, such as asbestos and lead. Proven models of exposure, causal relations, appropriate control measures, patterns of institutional support and opposition, and recipes for successful policy campaigns find their way into current discussions about EMF. The policy import of these analogies will be discussed later in this section.

7.1.2 State Legislatures

Although state legislatures vary widely in their structures, partisanship, and professionalism, at the level of their individual members, it is safe to assume that they share a common desire to be reelected. Part of this desire is channeled into efforts to mitigate conflict either by building compromises, responding to public sentiment, or by handling divisive issues procedurally. Another part leads to efforts to transmit material or symbolic benefits to their constituents while spreading or deflecting costs that might accrue to them. To a large extent, the value associated with either type of correct response resisting action that was unwarranted or taking action that was/will reflect partisan affiliations, one political party taking pride in the former and the other party in the latter.

In the case of errors, however, partisanship is likely to be eclipsed by more elemental civic values linked to our common political tradition. The false positive translates into a waste of taxpayers' money, and the false negative into irresponsible disregard for public safety. Neither of these consequences is likely to be palatable to legislators of either party. As a result, we can expect legislatures in general to seek a hedge against errors of either type by committing resources to attempt to resolve the existing uncertainty. For some legislatures, sensitivity to these potential costs will be coupled with external pressure for a political resolution, perhaps in response to local conflicts over who should bear the costs of the uncertainty. In this instance, legislatures can either develop an additional hedge by freezing current conditions (and the distribution of costs) until more becomes known about the potential risks, or they can try to exit altogether by reassigning jurisdiction over the controversy to an administrative agency.

The choice between these three legislative strategies - commit to further study, freeze conditions, or reassign jurisdiction - will probably be dictated more by the structural and historical conditions within a given state's government, than by any particular substantive feature of the EMF issue. Some legislatures are more inclined to devote resources to the further study of technical issues, perhaps by virtue of being better equipped to act on technical information, while other legislatures, deferring to the expertise of administrative agencies, will assign jurisdiction to one of them should the issue not yet be under formal consideration (Feller, et al., 1979). Still other legislatures will choose to act based on the initiative of their "peer" or neighboring legislatures, or will await federal guidance (Sabatier and Whiteman, 1985).

In any event, political pressure to do something legislatively about EMF concerns is likely to arise from unresolved conflict surrounding transmission line siting disputes, with parties seeking legislative relief on the heels of disappointing judicial or administrative settlements. Each attempt to site a new transmission line or upgrade an existing one raises the possibility of public opposition and, in turn, creates an opportunity for disputing EMF claims. Where the conflict is especially contentious or where opposition has been widespread, the legislature is more likely to consider action. Legislative activity in states such as California, Florida, New York, and Washington, can be traced to basic conflicts over the location of transmission lines and a perceived need to mitigate them politically (See Banks, 1989). In Texas, by way of contrast, the Public Utility Commission took the initiative to gather and interpret technical information on EMF health effects before any formal consideration of the issue by the state legislature.

7.1.3 State Regulatory Agencies

Administrative agencies charged with regulatory responsibilities generally address scientific uncertainty through procedural mechanisms patterned after either the legislature or the courts. The formality of the agency's deliberations, its gathering and use of evidence, and its connection to judicial oversight will typically follow one of these two institutional designs. Along with their procedural mechanism, agencies are likely to find their particular "bias" toward the treatment of uncertainty set down in their authorizing legislation (Gelpe and Tarlock, 1974). Agencies charged with regulatory responsibilities over functional policy areas, environmental quality, energy, or health, for instance, tend to follow quasi-legislative procedures involving a notice and comment process, and informal hearings or consultations on any rules, orders, or decisions to be adopted as part of the state's Administrative Code. The setting of mandatory standards at both the federal and state level tends to conform to this pattern of informal rulemaking, in part, as a way of capitalizing on agency expertise.

In Texas, for example, agency decisions based on informal rulemaking are considered under the same presumptions of legitimacy that apply to legislative ones. The agency need only present a reasoned justification backed by more than a "...scintilla of evidence..." to meet legal challenges to its decisions. Such deference to agency discretion permits a large measure of predictive judgment to color the agency's treatment of uncertainty, especially in situations where scientific evidence appears inconclusive (APTRA, 1989).

In contrast, agencies charged with assigning property rights, duties, or privileges, or granting permission of some sort tend to adhere to quasi-judicial procedures involving evidentiary hearings based in testimony under oath, depositions and writs of subpoena, the compilation of a formal record, and case-by-case deliberation. Regulatory decisions on ratemaking, licensing and certification of various types tend to follow this more formalized procedure across the states and at the federal level (Breyer, 1982). By analogy, regulatory "standard setting" in this context is more likely to involve the promulgation of supplemental duties or guidelines for obtaining, or complying with the conditions of, one's authorization.

The quasi-judicial procedures that frame regulatory responsibilities for the taking or giving away of something of value have far more extensive "due process" protections for the affected parties than does informal rulemaking. Here, the resolution of uncertainty rests on the weight of the formal record, with questions of fact and of law settled in much the same way as in non-jury civil cases. The agency's discretion, however, is more narrowly defined and its predictive judgment given less opportunity to influence the final outcome than in informal rulemaking (McGarity, 1979). Nonetheless, any particular ruling is treated more as a precedent than as a general rule and can thus be more easily modified or withdrawn than can the standards coming out of an informal rulemaking procedure. In short, the "bias" toward how uncertainty is resolved is quite likely to resemble a judicial one, with responses subject to case-by-case revision.

In Texas, this more formalized regulatory process falls under the rubric of "contested cases". Not only are regulators bound by strict procedural requirements, but their decisions are subject to much closer scrutiny by the courts than for informal rulemaking. If a legal challenge is made, the state court can review the entire process as though no agency decision had been made; in other words, once a decision is challenged, no deference is paid to the agency's deliberations or conclusions. The agency's decision must be replicated by the court, otherwise, it will be modified or overturned.

Examples Within Regulatory Agencies. While much of the discussion so far has encouraged comparisons across different institutions, it is useful to add some empirical detail by examining the implications of structural and procedural variety within a given institution. From this perspective, the question is not so much, what is likely to happen once a regulatory agency, as opposed to some other institution, considers EMF issues, but rather, which kind of regulatory agency has assumed jurisdiction within a given state, and what kind of judgmental bias does this imply?

If it is a regulatory agency designed, at least in part, to address problems in terms of control strategies and authorized to promulgate mandatory standards through informal rule-making, we can expect a set of such standards, field limits or exposure limits, to emerge as the favored response once the agency decides to exercise its predictive judgment. Following the same logic, a utility or siting commission designed for adjudicatory proceedings and case-by-case rulings is more likely to defer to the predictive judgment of those outside the agency and to respond with guidelines for mitigating exposures in a particular context by a specific party rather than with general rules. This is not to suggest that once jurisdiction is settled the results are determinate, but only that we can expect certain institutional biases to come into play, given the uncertainty over what, if anything, should be done. Further, these biases, on balance, are assumed to incline participants to accommodate uncertainty in a characteristic way that has much to do with the nature of their institution.

Departments of Energy or Environmental Affairs, for example, are more likely to rely on codified field limits since much of their legal authority is framed in terms of the setting of standards. In other words, they are biased in favor of avoiding "false negatives" since the setting of standards that are binding across individual circumstance is more likely to err on the side of over-inclusiveness. The enabling statutes for agencies of this type will typically mandate precautionary action in the face of uncertainty; the justification in these instances may be based principally on a presumption in favor of protective measures when public health and safety are at issue. Not surprisingly, the few states that have formal field limits (Montana, Oregon, and Florida) are also those that vest authority over transmission line certification or operation in such agencies or their offspring.

In contrast, public utility commissions tend to rely on quasi-judicial procedures that bias them away from "false positives". Rules are more likely to be stated in general terms as guidance in making claims before the commission and to be applied on a case-by-case basis. Here, the presumption behind the process favors existing levels and forms of precaution over prospective ones. To the extent that public opposition or scientific findings begin to challenge these, the first step is likely to be either a clearer articulation of guidance regarding the treatment of EMF in the certification process, as in North Dakota and Colorado, or an effort to establish the status quo as a benchmark for assessing the need for any subsequent precautions, as in New York. The effect of these two approaches is not to prohibit field strengths above a certain threshold, say, by making them illegal as in the case of codified field limits, but rather to expand the burden of persuasion incumbent on the proponents of new high voltage lines or upgrades to incorporate EMF considerations in their applications.

To date, the legislatures or administrative agencies of about 17 states have explicitly considered the possible health effects of EMF; their policy responses range from the legislature's dismissal of health concerns for lack of sufficient evidence, as in Wyoming, to the codification of formal EMF limits, or transmission lines, by regulatory authorities as in Florida (Banks, 1989a). If recent litigation over condemnation and torts where EMF health risk has been posed as an issue is included (several examples of which appear in section 7.1.4) then the number increases to 25 states. Unlike other policy issues, such as taxation, there has been no particular pattern of leadership among the states, wherein the innovative approaches of a few states diffuse to the rest and create relatively uniform patterns. It may well be that the lack of policy agreement among the states simply reflects the uncertainty within the scientific community regarding the health risks from EMF. Based on the earlier discussion of institutional responses, however, diversity is also consistent with the fact that the same institution does not have exclusive jurisdiction over EMF issues in every state. Regulatory agencies are active in some states, legislatures in others, a mix of institutions, or none, in still others.

7.1.4 The Courts

Criminal courts share the same aversion to false positives that motivates the scientific process; however, they also share the irony of aligning the incentives for potential participants in their process in a way that expresses substantial concern for false negatives. The judgmental bias in civil courts depends in large part on the kind of changes in the status quo sought by the claimants. Increasingly, the courts are open to claimants willing to take on the burden of proving that EMF is potentially harmful either to their property values or to their health. While these claims might serve as a barometer of public concern, and are thus likely to attract media coverage, they also signify the way some courts have chosen in practice to accommodate evidence regarding EMF health effects along with the persistence of scientific uncertainty.

The courts effectively reverse the logic of the public utility commission, although the bias toward avoiding "false positives" (perhaps principally through an aversion to change in the status quo) and case-by-case consideration remains the same. In this forum, the burden of persuasion falls, not on the proponents of new lines or upgrades, but on their opponents, who attempt to prove that EMF considerations entitle them to compensation or relief of some sort. Here the court rules first on the admissibility of such claims and then upon whether the evidence behind these claims provides sufficient grounds for a judgment in favor or against them. Unlike the public utility commissions, the courts will rarely pass judgment on the substance of any EMF effects. Several cases can serve as prototypical examples.

Examples Within the Courts. By and large, most condemnation cases (claiming property for public conveyance) have ruled out any consideration of EMF health risks, since the statutory language authorizing "takings" is typically very explicit about what may and may not be admitted as grounds for compensation. Until this language is changed by the legislature, the courts are not very likely to expand the scope of conflict to incorporate these new elements with four notable exceptions, [Klein Independent School District v. Houston Lighting & Power (Klein); San Diego Gas & Electric v. Daley (San Diego); Miller v. State of New York (Miller); Zappavigna v. State of New York (Zappavigna)]. All of these cases involve the efforts of different courts to address public concern over the health effects of EMF. None of the findings deals directly with whether EMF is the cause-in-fact of adverse health effects. Rather, they deal with people's apprehensions about such effects and, in two of the four cases, with whether there are any reasonable grounds for this apprehensiveness.

In Klein, the jury, in effect, found that apprehension over EMF risks dictated caution and faulted the utility for not taking these concerns seriously. In San Diego the jury compensated a property owner for losses due to the apprehensiveness of buyers over potential health risks, given the proximity of his land to transmission lines. The Miller case in New York State dealt with the same issue, but added the burdens of proving that such apprehensiveness had depressed land values in the past, and that apprehensiveness itself had a reasonable basis. In all three cases, backing for the claims of specific health effects mattered far less than the doubts these claims raised about public safety, doubts that were kindled by the ambiguity and inconclusiveness of the scientific evidence. In the end, the court's judgment hinged on the credibility of the expert testimony and on whether the apprehensiveness borne of this testimony could or should have affected the particular behaviors (utility siting or valuation) for which a legal remedy was sought.

Since the OTA report (1989) cited the Klein case as one of the "growing pressures for states to take regulatory action to protect citizens against possible risks," it is useful to take a closer look. The Klein Independent School District filed objections with a county trial court to Houston Lighting and Power Company's condemnation of an easement across the School District's property for the siting of a 345-kV transmission line. Unlike most other condemnation cases where the amount of 'just compensation' is at issue, in this case the School District alleged that the utility had abused its discretion in taking the easement and had subsequently erected the transmission line in 'reckless disregard' for the school's use of the property. The trial court granted judgment against the utility, voiding the condemnation and awarding punitive damages for trespass. The State Court of Appeals overturned the award of punitive damages and claims of trespass but found a credible basis for the jury's finding that the utility had abused its discretion in taking the District's property.

The findings in this case did not address the claim "that there are potential health effects associated with exposure to powerline fields," as the OTA report alleges. While Klein may affect how utilities accommodate health concerns in future siting applications before the Public Utility Commission, its major import is procedural rather than substantive. The Court of Appeals' acknowledgment that, based on the expert testimony presented, the Klein jury could have believed that the utility exercised poor judgment, appears somewhat removed from the OTA report's suggestion that Klein constitutes a call for regulatory action to protect citizens. Similarly, the OTA report cited the "Cancerphobia" case (Zappavigna v. State of

New York) as another dramatic incident of pressure for public regulation of field exposures. This was a class-action suit by a group of land owners asking compensation for losses due to the apprehensiveness of buyers at the proximity of their land to a 345-kV transmission line; the key issue was which one of two opposite holdings (the San Diego case, where damages were awarded, or the Miller case, where they were denied) would be adopted. The judge found the Miller precedent the more compelling of the two and rejected the land owners' claims of buyer apprehension for lack of sufficient evidence. This case, if anything, undermines the warrant for regulation, assuming (as the OTA report seems to) that public concern is often a prime catalyst for regulatory action.

The policy significance of the "Cancerphobia" Case perhaps resides more in its scale than in its having upheld Miller on the matter of buyer apprehension. One reporting service noted that almost $3 million was spent on this litigation, with a substantial share going to expert witness fees (Mierrware News, 1989); this figure exceeds the annual budget for EMF research of the U.S. Department of Energy. In cases with multiple claimants and a corporate defendant, the stakes will typically be high enough to justify such large expenditures on both sides. Certainly, the law firms representing these clients stand to gain financially but, in legal proceedings on EMF health effects, another group of professionals stands to gain as well, the scientific expert witnesses.

The best scientists, however, do not necessarily make the best expert witnesses and vice versa, from the litigator's perspective, since the necessity of adopting legal conventions in addressing scientific matters requires the skills of a translator and not principally those of a scientific investigator. Furthermore, taking sides in an adversarial proceeding may require the kind of categorical statement that crosses the boundary from what can be scientifically supported to what can be argued, quickly escalating from scientific claims to meta-scientific ones (Merz, 1990). Statements by scientific experts in the Klein case, for example, holding that claimants "would probably experience an increased risk" or "a significantly increased risk" and that such risk is "unnecessary or "indefensible", or conversely that "there are no significant biological effects", clearly have abandoned scientific conventions in favor of legal or regulatory ones. Contesting scientific findings in an adversarial arena that admits only two sides of the issue appears antithetical to the notions of reasonable doubt, uncertainty, and perhaps ambiguity, that are prominent features of debate within science.

Still, the distortions that litigation can impose on scientific questions may be more than offset by the growth of research funds that typically accompanies the transformation of a scientific controversy into a legal and political one. On balance, when it comes to EMF issues, law and science seem to have a symbiotic relationship. While the questions surrounding EMF health effects may never be fully resolved to everyone's satisfaction, it is unlikely that a stable, public resolution will emerge from either research or litigation alone, but rather from their interplay, perhaps mediated by other public institutions.

Up to this point, the discussion has relied on the concept of judgmental bias to epitomize the ways that different social and political institutions can manage evidence and opinion on EMF health effects. Emphasis has been placed more on the concept's heuristic value than on its predictive validity, however, the intent is not to model institutional behavior, but to provide a plausible framework for making sense of the diversity of institutional responses to the EMF issue. Beyond the workings of bias, institutional diversity can be traced to more fundamental differences of interpretation and meaning that will affect how the EMF issue is both understood and translated into public policy.

The next sub-section selects two institutions (science and the courts) that play a prominent role in casting the public features of the EMF issue but, at the same time, represent extremes of contrasting interpretation, uses of language, and approaches to reasoning. While substantial literature addresses the fate of scientific evidence in the courts (O'Brien, 1987; Huber, 1988; Smith and Wynne, 1989), the discussion here emphasizes differences in the meaning assigned by each institution to certain terms, effectively providing the footing for disparate interpretations. Following these comparisons, the focus shifts to the more general issues of interpretation and meaning tied to the definition of the EMF issue as a public policy problem.

7.2. Contrasting Interpretations by Science and the Courts

Both science and law employ a complex procedural logic as a means of justifying decisions based on uncertain evidence. Both rely on elaborate rules of evidence to structure the drawing of inferences, and both erect high procedural thresholds for proof to avoid false positives. And while both embrace advocacy directed to one's peers, science tests these claims through an iterative process of consensus formation, law through an adversarial one. Despite their functional similarities, however, several basic differences create a gap between them when it comes to the handling of uncertainty.

7.2.1 Meanings Assigned to "Significance"

A prominent obstacle to the appropriate use and interpretation of scientific evidence by the law and policy making institutions is the disparity in meaning between ordinary and technical usages of the same terms. The term "significance" is notorious in this regard. Part of the problem can be attributed to the attachment of science to a frequency interpretation of probability, wherein chance is defined in terms of repeated outcomes. Policymakers, in contrast, tend to embrace a subjective notion that ties chance, not to random processes, but to credibility and degree of belief. A significant result to policymakers then is a credible or believable result; in this sense, one result may be relatively more significant than another. A credibility interpretation of chance and uncertainty has traditionally informed legal judgments about the probity of evidence, and varying standards of legal proof are often phrased in these terms.

A "preponderance of the evidence", the standard of proof in civil proceedings, for example, implies a greater than 50 percent certainty regarding the truth of the plaintiff's claims. Legal writings have also tied, "beyond a reasonable doubt", the standard for proof of guilt in criminal trials, to being at least 95 percent certain of the truth of the prosecution's charges before guilt can be established (Large and Michie, 1981). By coincidence, a 95 percent standard is also invoked in scientific treatments of evidence but with a very different interpretation. As will be discussed below, the 95 percent level in science is not so much a truth standard for judging claims as it is a criterion upon which to base predictive judgments. The former asks, "how certain are you about this claim?" while the latter asks, "what percentage of the time do you expect the evidence supporting it to recur?" Note that both admit there is a chance of being wrong. For the law, however, being wrong is either a cognitive failing or a deception, while for science, it is strictly controlled by a hypothetical model of future prospects (Latin, 1982).

Confusion of the two notions of significance plagued Judge Poulton in Rausch v. The School Board of Palm Beach County when he interpreted the significance levels of the epidemiologic evidence on EMF health effects as a calibration of the chances of harm noting, "...[even] a 1 percent chance that there is substantial danger is unacceptable" (quoted in Banks, 1989b). Surprisingly, the scientific community is not immune to this confusion as the science intrudes on the policy realm. The Bonneville Power Administration EMF report, a model exposition in many respects, appears to make the same mistake as Judge Poulton when it concludes from a review of community cancer studies that, "Statistically, this finding was of marginal significance, however" (BPA, 1989, p.43). As a final example, consider the confusion created by confounding the two notions, as when an expert witness in Houston Lighting and Power Company v. Klein Independent School District inferred from statistically significant cellular effects, a "significantly increased risk". Contrary to these uses, statistical significance has no bearing on either the "chances of harm" or the strength of any postulated cause and effect relationship.

The only valid interpretation of statistical significance is as the outcome of a test designed to answer only one question, "is the observed result due to chance as we have modeled it, or not?" If the chance model employed cannot account for a given result, then that result is deemed "statistically significant," and likely the product of something other than chance. This designation has nothing whatsoever to do with the magnitude or importance of the result and cannot be used to calibrate its credibility; it is an all or nothing determination that admits no measure of degree. Further, the appropriateness of the chance model and its link to how the data were generated must be stipulated in advance and then taken for granted in testing for significance. If the data were not sampled in ways consistent with the model of chance used to define statistical significance, then tests for significance performed on these data could easily be inappropriate.

7.2.2 Meanings Assigned to "Cause" and "Confidence"

As we will see below, much of the causal analysis underlying judicial proceedings involves a search for the precipitating event, known as the "cause-in-fact". Evidence about this cause is weighed relative to its credibility and to the probity of those testifying in its behalf. Proof of the event then is synonymous with belief in the evidence; the stronger the belief, the higher the standard of proof that can be met. Evidence supporting a claim about cause-in-fact beyond a reasonable doubt is evidence about which one can be (approximately) 95 percent certain; in other words, there is a 95 percent chance that the alleged cause-in-fact was responsible for the event in question (See Brennan and Carter, 1985). In contrast, scientific treatment of causal inference is very different.

Causal inferences are based on a summary measure of the relationship between an alleged cause and the event of interest. The measure itself often appears as a range of values intended to reflect the limitations of the chance model and the amount of information available for calculating such a summary. Nonetheless, the frequency notion of probability dictates that the observation itself not be subject to chance or uncertainty; only the sampling procedure can be.

Accordingly, statements about the measure and its accuracy must be confidence statements, not probability ones. A confidence level of 95 percent indicates that a given interval of summary estimates, bounded by the highest and lowest values that the summary might assume, has effectively been drawn at random from a collection of such intervals and will contain the "true" or population value in 95 out of 100 instances. This is not the same as saying that one is 95 percent certain that the range of summary estimates contains the population value. Not only will the range of summary estimates change from sample to sample, there is no way statistically to define the chance that the population value will lie in this interval, either it does or it doesn't.

The legal process is not well-suited to handling the inconclusiveness of chance models, such as random sampling, especially when it comes to establishing the probity of expert testimony about cause-in-fact. The expert's estimates of a relationship, say, a relative risk together with its highest and lowest plausible values, are translated by the rules of evidence into little more than a best guess (Latin, 1982). Some qualification in terms of the expert's relative certainty about it are typically sought, but any chance variability is confined to the observer and not to what was observed. A confidence interval then is likely to convey the investigator's confidence that the "true" estimate falls within the reported range; a 95 percent confidence level in these terms meets the highest standard of proof that the legal system imposes. Unfortunately, the conventional statistical formulation admits no assessment of confidence in the sense of degree of belief or relative certainty and confines chance variability, not to the investigator or to the relationship being investigated, but exclusively to the sampling procedure.

The statement, "my research shows that the 'true' relative risk could be as great as the value 'x' but is highly unlikely to be less than the value 'y'", followed by,"...there is only a 1 in 20 chance that I could be wrong" is a policy claim and not a statistical one. Both senses of "confidence" are combined into a meaningless composite. Statistically, it is the confidence interval itself (the range from the largest value 'x' to the smallest value 'y') that is the random component subject to chance variability and error. If a large number of intervals are computed independently on separate occasions, each with the same confidence level, say, .95, then in the long run of several hundred or so tries, 95 percent of these intervals will cover the 'true' value. The chance process in this instance is both immutable and impersonal, and has absolutely no bearing on whether the investigator should be trusted or has been proven wrong in the past. Hunches about how certain he or she is, or about how likely it is that the 'true' risk actually appears within the interval they have computed, simply cross over the bounds of acceptable scientific inference and are, for the most part, untenable. Ironically, these are exactly the kinds of judgments that have the greatest legal import.

While science assigns uncertainty to its causal inferences rather than to the judgment of its investigators, law does the opposite. Law conceives of cause largely in mechanistic terms and attempts to narrow explanations to the single antecedent event or condition that can best clarify an assignment of responsibility; it admits no degrees of causality or uncertainty in this regard and draws fine distinctions as a matter of policy about the extent of a given party's involvement. Uncertainty about cause arises principally from doubt about the credibility of witnesses and the plausibility of their sometimes conflicting statements.

With their respective procedural logics at odds, the transfer of knowledge between science and law is, at best, strained. On the one hand, legal cause can be established without benefit of scientific conclusiveness; while on the other hand, even when science can be conclusive, it may still not be decisive since law invariably looks to other sources as well for its evidence. To hold up litigation as a mirror of public concern and then to call on science for the definitive appeasement of this concern (as several EMF reports suggest) is to misapprehend this basic point.

7.3. Rhetoric and Public Interpretation

The debate over EMF health effects is suffused with analogy and metaphor as a means of persuading others that a particular interpretation is sound or that a proposed action is warranted. Critics of the electric power industry, for example, may use EMF as a symbol of the industry's alleged disregard for the public's welfare or as a catalyst for opposition to the siting of transmission lines. In either instance, EMF provides a useful way of capturing what critics find objectionable about the industry or its practices.

In a few cases, the metaphor of "fields" is transformed into "invisible rays" to take advantage of the public fears and trepidation connected with ionizing radiation. Titles such as "Killing Fields" and "Currents of Death" witness the modern incarnation of an ancient approach to dealing with uncertainty through the medium of the morality play (See Philips, et al., 1990; Brodeur, 1989, 1990). All of the basic elements are there: a conspiracy of evil overtaking good, suppressing the truth, except for the valiant efforts of a few notables, and so on. Despite the oddity of the juxtaposition, this mode of absorbing uncertainty has several advantages over the others mentioned above. It simplifies and imposes a measure of order on complex developments while appealing to a well-tested formula that evokes basic sentiments common to many of our cultural myths. Few would argue, however, that its claims provide an appropriate basis for making public policy.

7.3.1 Analogy

There is a great deal of effort devoted to making EMF familiar by comparing it to other hazardous agents. Such comparisons frame our understanding of the issues surrounding EMF's possible health effects and, more subtly perhaps, evoke criteria and control experiences that at least appear to be relevant. Comparisons with everyday risks, for example, place possible health effects in the context of useful activities and establish a connection between EMF sources and those that are both familiar and widely tolerated. While on the surface, attention is focused on numerical comparisons to establish a reference for the magnitude of risk at issue, the unspoken analogy works on the qualitative aspects of the EMF risk, making it appear less mysterious, less threatening, and tied by association to other beneficial or voluntary activities (Douglas, 1988).

Analogies not only color our interpretation of the available evidence, they can circumscribe the kinds of institutional responses deemed appropriate. Comparisons with environmental hazards, such as air and water pollution, evoke criteria that suggest a threshold for possible effects, thereby making EMF amenable to conventional control strategies, such as regulatory standard setting or emission fees. Moreover, once the analogy takes hold, the arguments over alternative responses must be dealt with on their merits. The question of whether such strategies are even appropriate is effectively displaced by the debate over which one is best.

Analogy also operates at the level of institutional tradeoffs. Here the focus is on emphasizing the risks of one kind of error and, perhaps at the same time, minimizing the risks connected with the other. Selected examples of past errors and their consequences are presented as precedents that bear on the EMF case and used as the basis for justifying a given response. Arguments for precautionary action of different kinds, for example, typically place a ceiling on the economic costs of a false-positive error (taking action later proven needless or unjustified) and a floor on the political costs of a false negative (taking no action to address EMF concerns when, in retrospect, action should have been taken). Estimates of the latter costs are extrapolated from the utilities' experience with public opposition to transmission line siting or upgrades and may be inflated to include prospective settlement and adjustment costs (Morgan, et al., 1988). Precautionary action then becomes justified as a cost-avoidance strategy on the part of the utilities, despite the flaws in the analogy between opposition to "fair market" appraisals in condemnation hearings and public concerns over EMF risk.

7.3.2 The Political Contest Over Problem Meaning

Fundamentally, the kind of language used to characterize a problem and delimit its solution is contingent on how the issue was initially framed. For the EMF issue, the initial assertions of claims and grievances were prompted primarily by utility industry efforts to site a new generation of higher-voltage transmission lines. The organized opposition to these siting plans typically grounded their claims in the language of rights and health, and adopted a moral vocabulary that would prove to be more potent than an assertion of simple self interest (Furby, et al., 1988). These definitional activities appear to have proceeded on two fronts for official recognition and intervention. In the courts, claimants attempted to redefine siting disputes in terms of threats to health or the well-being of mothers and children. As noted in an section 5 most of these efforts were unsuccessful in winning official sanction for this definition; however, involving the courts brought several kinds of professionals into the definitional process. The first and most significant were the scientist-entrepreneurs who discovered a welcome opportunity for doing career enhancing work in the construction of supportive scientific evidence. The media were also introduced to the definitional conflict and played a role in channeling it into a controversy among competing spokespersons for the affected public and the utilities.

The second front was in the formal proceedings of the administrative agencies responsible for granting siting approval. In this context, a second round of definitional activities were begun. Rather than debating the issue as framed by those initiating the claims, agencies invited a wide assortment of experts to participate in its redefinition as an empirical matter to be resolved, not through public debate, but through scientific investigation. In several states, most notably, New York and California, the utilities were asked to underwrite the costs of this definitional change, in some instances, as the price of interim siting approval (Banks, 1990). The Electric Power Research Institute, a consortium of utilities, currently funds the largest share of these investigations while trying to guard its neutrality in the awarding of funds to avoid even the appearance of a pro-utility bias. Nonetheless, it has helped to create a community of experts who have a vested interest in EMF as a research problem and to expand the scope of the original issue beyond the siting of transmission lines.

So successful has been this effort that the administrative agencies in several states have tried to regain control over the definitional process by calling for a federal program of funding that would emphasize research into interventions via control technology (a familiar regulatory regime) and public information (Task Force on Transmission Line Health and Safety, 1989). As long as research funds are available, the scope of the issue will probably continue to expand, taking in an increasingly wider range of exposures, including household appliances and worksite equipment, and potential health effects. In the absence of a conclusive resolution ruling out any harmful health effects, the dispute over EMF may ultimately turn not so much on persuasiveness of scientific evidence, as on the costliness and differential impact of the suggested interventions. However the scientific uncertainty is resolved, at some point the question of acceptability must be faced. As a practical matter, the available interventions and their impact will prompt yet another redefinition of the EMF issue, this time in terms of the feasibility and acceptability of its control.

7.4 Contending Definitions of the Public Policy Problem

Most of the EMF investigations that explicitly offer public policy recommendations draw on a distinctive definition of the key problem in need of remedy. For many, the problem at issue is not the presence of adverse health effects per se but trouble with how we accommodate the uncertainty surrounding such effects. The remedy to this kind of problem basically involves either stepping up or changing this mode of accommodation. In other words, either we are not doing the right thing, or not enough of it, to avoid trouble. Each problem definition and implied remedy is associated, in turn, with a preferred set of policy options. Not all policy proponents find it necessary to invoke principles, such as equity, acceptability, or prudence, to support their choice of policy options; those that do, typically have a larger gap to close between the obvious remedy suggested by their problem definition and the policy options they favor. Several illustrations will be offered. While more than one definition and set of options is typically invoked in practice, it is instructive to consider which definition predominates, especially in discussions of what might happen if the preferred policy options are not adopted.

The EMF "problem" prompting action has been framed in several different ways, each with a distinctive emphasis that suggests the kind of remedy needed. As suggested earlier in our discussion of the range of institutional responses to uncertainty, each problem-remedy pair conveys a particular "bias" regarding the more likely kind of error (false positive or false negative) and its possible toll. Some policy advocates, in common with some institutions, find the avoidance of false positives in dealing with uncertainty to be the primary concern; others find false negatives to be equally abhorrent. Similarly, each problem definition betrays a basic assumption about how science relates to public policy making. Some find scientific consensus on technical matters to be authoritative and decisive (or ought to be) in policy deliberations. Others find such consensus compelling, but often not entirely relevant, and thus more contributory than decisive in deliberations on public issues. Still others find such consensus, especially on regulatory matters, to be hopelessly biased by its sponsors and partisan rather than contributory in its influence on public debate.

Extending the earlier argument about institutional biases and contrasting interpretations, the selection of policy options will emerge as a product of the way the problem-to-be-remedied is framed. At least four distinctive problem definitions can be found in the literature addressing policy options. Each represents contrasting interpretive and valuative commitments, expressed here largely in terms of institutional bias and a favored set of institutional roles. From this perspective, efforts to depict the problem of choosing among policy options as either a technical problem to be solved by selecting the proper analytical tool, such as cost/benefit analysis, or a context-free choice among disembodied regulatory regimes are misleading at best (See Wirick, 1990). Instead, policy options must be judged on the basis of the commitments to interpretation and certain values they represent, as well as for the reasons offered in their favor. A summary of the four definitions and their respective commitments appears in Table 7.2.

Table 7.2 - Problem Definitions & Policy Options

Problem Definition	"PUBLIC CONCERN [a&b]"	"RISING TIDE OF EXPOSURE CONTROLS [a&b]"	"PUBLIC HEALTH EMERGENCY"	"INCONCLUSIVE SCIENCE"
Remedy	a. Information b. Symbolic Action	Anticipation & Initiative	Regulation	Research
Principle	a. Right-to-Know b. Equity	a. Prudent Avoidance b. Mitigation	Lowest Achievable Exposure Levels	Conclusiveness
Options	a. Communication b. R-O-W Field Limits	a. Reduce Exposures b. Engineering Fixes	Health-Based Standards	Targeted Funding
Bias [Type of Error to Avoid]	a. False Pos > False Neg b. False Neg > False Pos	False Neg > False Pos	False Negative	False Pos > False Neg
Authority & Policy Role of Science	Compelling & Contributory	Authoritative & Decisive	Biased & Partisan	Authoritative & Decisive
State Examples[1]	a. New Jersey b. Florida	a. Colorado b. New York[2]	Illinois[3]	California

[1] State assignments are neither mutually exclusive nor exhaustive; states listed are intended as examples, in either being the first or doing the most within a particular category.

[2] New York has charged the utilities to develop both mitigation measures and an implementation plan by 1993

[3] An Illinois House Resolution (#1064, October 30, 1989) adopts this definition in most respects but falls short of mandating health-based standards.

7.4.1 Growing "Public Concern"

The growing level of public concern poses either an educational or a political problem, depending on one's tradeoff between false positive and false negative errors. Those finding the prospect of a false positive the more objectionable of the two kinds of errors will tend to promote public awareness and the provision of information on both sides of the health effects question; the untoward consequences of the absence of public information, however, seem to be expressed more often in terms of public over-reaction to a de minimis risk than as under-reaction to a substantial one (Sandman, 1989). Accordingly, the machinery of risk communication should be engaged, with its emphasis on addressing scientifically-unfounded, public fears. Further, from this point of view it is the experts' calibration of actuarial risk that defines the content of the message, with few exceptions, and not the public's views of the social elements of risk (Jasanoff, 1986). Science, in this instance, is the communicator's primary authority and aspires to be decisive on all matters of environmental hazard.

Conversely, those finding a false negative more troublesome tend to advocate some kind of symbolic action to allay public fears. Here, the prospects of political retribution of some sort from unrequited public concern that might eventually prove correct weighs heavily on the choice of policy options (See Wirick, 1990). The notion of welfare-based, rather than health-based, EMF limits as a policy option can best be understood in this light. The political logic behind welfare-based limits, however, is not to improve welfare in a material way, but to keep it, or more precisely, perceptions of it, from changing for the worse. Limits intended to forestall any decline in physical or psychological well-being connected with EMF naturally embrace the status quo as their benchmark. The costs of complying with limits defined by the status quo typically lie in the future, while the symbolic benefits of taking seemingly dramatic action to contain an 'uncertain threat to the well-being of the public' lie in the immediate present. Further, in fashioning such limits, there is no need to sort out the complex technical issues of exposure and dose, nor to upset the existing balance of political interests both inside and outside of government. Science, in this instance, makes a contribution to these deliberations. Yet, it appears to hold more relevance for assessing the odds of a false negative than for determining what policy option to pursue.

Besides their political expediency, welfare-based limits rest on a presumption in favor of treating existing levels of exposures as de facto both safe and legitimate. Allusions to "acceptability" and "equity" as principles linking the problem of public concern to welfare-based limits tend to reinforce this presumption (See OTA, 1989). The moral weight of acceptability as a principle is tied to the tenuous notion that the status quo most accurately captures public preferences regarding exposures to risk; the pattern of existing exposures then is presumed to be acceptable and can thus be used as a benchmark for establishing parity across all sources of exposure. To avoid the appearances of expediency, this account must assume that: 1) risks unknown to the public at the time preferences were revealed in the status quo are effectively zero, 2) risks from different sources are perfectly comparable and can be evaluated in terms of a common numerate such as mortality rates, and 3) there is a safety threshold above which, more exposure always means greater risk (Schrader-Frechette, 1985). In addition there must be a plausible argument linking the acceptability of the risks embodied in the status quo to some notion of consent. *None of these conditions is met.*

The moral content of equity as a principle in this instance depends on how one interprets the claims of those who feel they have been wronged by the status quo. If the status quo is blameless (although it seldom is) then future wrongs can be avoided by options grounded in this principle. Otherwise, equity must function as a compensatory principle, shifting past burdens as well as reassigning new ones. Claims that welfare-based limits can be justified out of equity considerations assume that additional future exposures are the only relevant feature of exposure inequity. Further, once public action is taken to define existing levels of exposure as permissible levels, these levels become legitimate by intent rather than remaining an unintended byproduct of decisions made with goals other than equity in mind. Such action imparts a false sense of confidence in the protection that those permissible levels afford. Moreover, any subsequent action must then be phrased in terms of changing existing policy and arguing its inadequacies. In short, not only is the rationale for welfare-based standards weak, but their use may ultimately prove counterproductive.

7.4.2 "A Rising Tide of Exposure Controls"

The prospects of hasty control measures by public authorities and of numerous compensatory awards by the courts have focused attention within the electric power industry on how best to avoid the harsh consequences of a false negative error in judgment (Morgan, 1989; DeCicco, et al., 1989). Unlike responses to public concern as a political problem, however, anticipating pressures for exposure control raises the problem of planning for economic and engineering changes. Remedies, in this instance, are intended to anticipate the worst in the face of uncertainty; if EMF proves to have significant health effects, an early preparatory response might not only cushion the electric power producer against abrupt policy changes, but also preempt more coercive measures. In the words of one proponent, "Unless anticipatory engineering and economic studies are undertaken now a lot of wasteful and ineffective effort can be expected in a scramble to take protective measures if and when experimental evidence someday clearly links fields to health risks" (Morgan, 1990, p. 123).

Yet, the key to fashioning an anticipatory remedy is to decide how much to do and when to do it. The model of technical rationality behind most economic planning offers a simple guideline: keep the response proportional to the expected risk. As a principle of social investment, this guideline holds that the amount spent on exposure control should reflect the value derived from avoiding exposures. Under uncertainty over the effects of exposure, however, the value of avoidance itself becomes unclear, and we are left back where we started with the notion of avoiding the consequences of a false negative. Nonetheless, the connection between proportional responses and the canons of rationality remains. The term, prudence, commonly used in rate reviews as a criterion for judging the appropriateness of investments, has been extended to cover policy options that, in proponents' judgment, constitute a proportional response. Ambiguity also surrounds the concept of prudence applied to investments in avoidance, since one's sense of proportionality will vary with beliefs about the certainty and level of the risk. Short of knowing the value of avoiding exposures, we are left to anticipate the eventual outcome of the scientific debate and to hedge against a false negative, accordingly.

Depending on one's predictions about the science and aversion to false negatives, two levels of hedging are possible, each interpreting prudence in a different way. The aggressive hedge interprets prudence expansively: prudence in the choice of avoidance options calls for investments in practicable engineering controls that will mitigate EMF (OTA, 1989). This view anticipates that science will eventually support the need for field reduction and that, unless preemptive measures are taken now, coercive measures imposed by government are likely in the future. A more passive hedge interprets prudence more narrowly: prudence suggests that people be kept out of fields whenever it is inexpensive to do so. Relatedly, people should be encouraged to avoid fields when they can. This is a common strategy among advocates of lifestyle changes. From this perspective, engineering controls may appear out-of-proportion to the risk that EMF presents, but marginal changes in personal behavior or in the siting of new facilities seem to offer a reasonable hedge.

For those who frame the EMF problem in this way, accepting one version of prudence over another (aggressive mitigation over expedient avoidance) comes down to a priori beliefs and apprehensions. In either event, the intent is to stay a step ahead of any rising tide of control expectations without stepping too far out in front or in the wrong direction. In contrast to the policy option of field limits described above, prudence dictates departures from the status quo, but ones small enough to be corrected if later they prove to have been taken in error. Further, it advises policy making institutions against acting too precipitously or out-of-turn, in deference to the decisive role that scientific information should play. For those focused on public concern as the primary problem, however, prudence offers little constructive guidance. For Utility Commissions that traditionally have employed siting rules that call for the avoidance of population centers, historical sites, and existing facilities, the more reasonable of the two hedges against EMF risk may already appear to be in place.

In the context of a myriad of well-documented risks faced every day, and increasing sensitivity to the health implications of each consumption decision and behavior, a vague prescription to people to be prudent about EMF, just in case, sends a mixed message. On the one hand, the basic proportions of the risk that EMF might pose to personal health are viewed as still open to question; on the other hand, advice about limiting certain kinds of personal exposures is forthcoming, as though some pragmatic approximation of the risk were all that was necessary. The threshold of safe exposure remains undefined, and ad hoc guidelines for field avoidance are indefinite as to whether the prescribed changes in behavior will do any good and, if so, how much good. Counseling prudence may make sense in situations where foresight and hedged investments can save money. As a strategy for addressing public concern, however, raising the specter of an illusive threat to be countered with a few changes around the house (changes that may or may not do any good) offers a weak basis for a health promotion campaign. In health education and promotion efforts, the risk of premature or misleading admonitions may very well outweigh possible gains from guessing correctly.

7.4.3 "Public Health Emergency"

Viewing EMF as a proven disease-causing agent emphasizes the moral and legal imperatives behind its control. Fundamental changes in personal behavior and in industrial design and practices are called for, from this perspective, to minimize exposure to harmful fields. Here, the possibility of a false positive has been ruled out altogether, and those who admit such a possibility are viewed as obstructionist (Brodeur, 1989a, 1989b). This perspective has a very different view of the policy role and status of science. There is no quest for scientific conclusiveness, no need to predicate public intervention on the emergence of scientific consensus, and no reason to postpone action until more is known about what should be done in this particular instance. All that is needed is some suggestive evidence and a venue in which to advocate the lowest achievable exposure levels. At the root of this impatience, relative to the other definitions of the EMF problem, is a mistrust of the scientific community and skepticism about their claim to objectivity.

The scientific community's aversion to false positives is taken by the advocates of the "contrary" view as a convenient disguise for a political and social conservatism born of the need to protect the sponsors of research. In other words, the scientific community is not only corruptible but the findings of research are especially prone to the influences of ideology. Under these circumstances, the influence of science on public policy is seen as essentially a partisan one, competing on the same footing as self-serving claims of stakeholders. The irony in this view is that if the results of science are principally a product of extra scientific influences and to be mistrusted, then there is no special warrant for or against public action in any set of results. The evidence supporting claims of a public health emergency becomes devalued in the same way as the evidence refuting them.

One can, of course, assign pedigree to scientific results based, not on their methodological rigor, but on their ideological purity, that is, on whether they support one's point of view. Nonetheless, the marshaling of evidence and its use in argument will follow very different rules, according to this construction, and will often be subject to partisan tests of legitimacy. From this perspective, the sponsorship of a study and the affiliation of its investigators will matter more than the quality of the design itself. In turn, the quality of the design will be judged primarily on the partisan implications of its results -- either in support or in opposition to a given point of view.

While the use of predictive judgment to avoid false negatives, especially when the public's safety appears to be at stake, is a bias common to public health professionals, in this instance there is a more subtle bias at work. If we examine the history of efforts to control exposures to other everyday substances, such as lead and asbestos, the definition of the problem, the predictive interpretation of the scientific evidence, and the control options advocated, follow a very similar pattern. Erring on the side of safety appears to have a generic quality to it, shaped in large part by the power of analogy. The fact that arguments for maximum regulatory controls, in the face of scientific inconclusiveness in the cases of lead and asbestos, were eventually born out by later evidence reinforces this pattern, as well as the bias against false negatives (See Brodeur, 1974, 1985). In effect, the problem definition transforms EMF exposure, via a few highly selective analogies to earlier success stories among anti-exposure campaigns, into yet another episode of enlightened advocacy protecting the health of the public against the predation of industry (See Murray, 1988).

Unlike the asbestos and lead cases, where the debate turned on the question of how much scientific evidence was necessary to vindicate the call for drastically reducing current exposure limits, the EMF debate has not yet defined what exposure and dose mean. Where the former were arguing over different estimates of safe levels of exposure and proposals to ratchet down existing regulatory controls, the latter is still sorting out what forms control might take and whether safety will reliably increase as exposure is reduced. Finally, the sheer volume of the research record on lead and asbestos exposures and the overall magnitude of the adverse health effects documented therein strain the credibility of any analogy between these cases and EMF. Given the current state of scientific knowledge, the definition of the EMF problem as a public health emergency appears ill-founded.

7.4.4 The "Inconclusive Science"

This fourth definition of the problem begins with the notion that the science of EMF is still in its adolescence. Accordingly, until it reaches maturity, there will be false leads, unreplicable results, intramural conflicts, and a large measure of inconclusiveness (California, 1989; Panel, 1990). At this point, it is premature to select one set of results over another in an attempt to anticipate how things will turn out. The bias under uncertainty is to avoid false positives; but the motive, in this instance, is not so much to escape the consequences as it is to resist preempting the full play of the scientific process. From this perspective, science when given its full play can be authoritative, or at least beneficial, and can exert a decisive influence over policy questions that hinge on technical issues. In the ideal, science can quantify the evaluation of optims in risk-benefit terms. The remedy for inconclusiveness then is twofold: resources to underwrite the necessary research, and time to permit the developmental process of scientific trial and error to come to maturity.

The key to resolving inconclusiveness, from this fourth perspective, is not more research per se but better-funded research targeted to the areas of greatest potential return (US Environmental Protection Agency, 1990). Further, the funding and targeting must be accomplished in such a way as to placate those who have less confidence in science's ability to either settle EMF policy questions or avoid sponsor-induced biases. The proposed remedy is typically to vest the responsibility for targeting and funding in governmental authorities with experience in both science policy and the resolution of technical issues. Several bills have been introduced in the U.S. Congress to define a federal role in EMF research and to allocate responsibility for funding and targeting (U.S. House of Representatives, 1990). Should no decisive findings emerge after an initial round of new federal investment and research direction, we might expect the same institutional biases operating at the state level under conditions of scientific inconclusiveness to shape the course of federal activity. Even if most states steer clear of research management functions, staying abreast of the emerging scientific evidence remains an important state responsibility.

7.5 Conclusion: Multiple Interpretations and Institutional Design

The principal question addressed in this analysis has not been EMF health effects per se but rather the ambiguity surrounding them and the diversity of interpretations that result. In general, the indecisiveness bred by ambiguity is a corrosive force on institutions, and on the public trust upon which they depend; it clouds with doubt the proper public response to pressing issues, representing a vacuum of sorts that comes to be filled with diverse claims, but yielding no point of reference for their assessment. Each of the biases, interpretations, and problem definitions posed above represents an attempt to impose some structure on this situation, to resolve some measure of this ambiguity by means of assumptions and recipes. Once stated, however, these alternative constructions merely shift the ambiguity from one place to another. We may claim to know how best to weigh the evidence bearing on a problem, for example, but are left asking, "which problem definition is best?"

Alternatively, we might reconsider how selected institutions accommodate this ambiguity and find some reassurance in attending to aspects of the problem they emphasize. As noted earlier, different institutions will convey distinctive biases; some institutions, however, will accommodate more than one of the above-mentioned, four types of problem definition in its claims about an appropriate public policy. Settling on a bias leaves unresolved the question of proper definition and policy stance. The best way to address ambiguity in the absence of scientific agreement may rest, not on the arbitrary choice of one definition to the exclusion of others, or on ad hoc prioritizing by experts, but on the development of a public process for discussion and deliberation to lay the foundation for converging on a collective interpretation and public definition. In place of a confrontation among advocates, there might be a forum for deliberation open to possibilities for learning and accommodation among advocates and uncommitted alike. Although some problem definitions can be viewed more favorably than others and some remedies rejected as ill-conceived, as long as the proper interpretation of EMF health effects remains ambiguous, these matters will be contested and thus can benefit from public discussion, as well as expert advice.

To foster such discussion, an institution must have sufficient expertise to be capable of brokering the relevant science and yet able to balance the counsel of technical experts with public values and concerns. Until the scientific community can offer a conclusive answer to the question of health effects, if such an answer is possible, the EMF debate will continue to revolve around questions of interpretation. By providing an arena within which viewpoints may be exchanged in a fair and open way, an institution may do much to stem the corrosive effects of ambiguity, even if only on an interim basis.

If we assume further that the interpretations of both science and the courts will continue to play as large a role in framing the eventual resolution as they have in structuring the problem, then whatever institution provides the arena must also be well-equipped to accommodate the interplay of legal and scientific reasoning. While the courts have traditionally managed this interplay, they have done so through highly structured adversarial proceedings that merely channel rather than mitigate conflict. Procedural safeguards are surely important to the operation of any public forum for deliberating contentious issues. Nonetheless, the adversarial conditions accompanying the "case and controversy" requirements for judicial process can be divisive when applied to larger issues of public concern, appearing to pit law against science or science against itself. What is needed then is an institution familiar with safeguards for ensuring the fairness of a public forum and yet one not bound to either an adversarial construction or the formalities of evidentiary hearings.

If the primary criterion for determining which institution should sponsor public discussion were its judgmental bias, the Public Utility Commission (PUC) might appear to have the advantage. It is a quasi-judicial agency accustomed to procedural protections and open proceedings, and it has cooperative relations with the state's major public utilities and expertise in addressing the legal and economic implications of policy issues. Judgmental bias aside, however, most of its deliberations involving the public have been framed in adversarial rather than conversational terms. And while it is well-positioned to monitor the progress of EMF-related activities in other states and provide a clearinghouse for technical information about EMF, the PUC in Texas, as in many states, is legally bound to limit its focus on electric power to transmission lines. Advocates for defining the EMF problem as a public health emergency, moreover, might find the PUC's relations with utilities and emphasis on economic implications to be inhibiting and exclusionary. Others who define the problem in terms of public concern, might take exception to the absence of any mandate or experience on the part of the PUC for getting information to the public or for handling field investigations of public complaints. Finally, those viewing scientific inconclusiveness as the key EMF problem might find the PUC's lack of scientific expertise in health research to be limiting.

The State Department of Health, while sharing only a few of the PUC's procedural strengths, counters most of its substantive weaknesses. The Health Department has scientific and investigatory expertise in a wide range of health matters. More importantly, it has extensive experience in conducting on-site community meetings to address local health concerns and the capacity for educating and informing the public. Nonetheless, until the scientific evidence on health effects is conclusive, the PUC should continue its initiative in monitoring new developments in EMF research. Given the balance of strengths and weaknesses between the two agencies, the Health Department should pursue a collaborative arrangement with the PUC for establishing a public forum on the EMF issue. Such collaboration might involve the PUC and its advisory committee on health effects in the development of information while the Health Department assumes the lead in its dissemination and in the conduct of the forum itself. Public discussion might continue through periodic forums until the ambiguity surrounding health effects has been resolved.

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GLOSSARY OF TERMS

ABNORMALITY - The quality or state of being abnormal, i.e, deviating from the normal or average; markedly irregular; characterized by deficiency or disorder.

ACCLIMATIZATION - adaptation of an organism to a new environmental condition, e.g., temperature, altitude, climate, or situation.

ACCURACY - the degree to which a measurement, or an estimate based on measurements, represents the true value of the attribute that is measured.

ACQUISITION - to gain, acquire/possess something through an active process of search, capture, exchange, etc.

ACUTE - sharp, severe; having a rapid onset, severe symptoms and a relatively short course. In toxicology, refers to single large exposure to a substance (acute exposure), or to the development of symptoms of poisoning soon after a single exposure (dose) to a substance (acute toxicity).

ACUTE LEUKEMIA - leukemia characterized by sudden onset and rapid progression of the disease. (see LEUKEMIA)

ADRENAL - referring to the adrenal gland and its functions; complex endocrine organ(s) near the anterior border of the kidney consisting of a mesodermal cortex that produces steroids like sex hormones, and hormones concerned especially with metabolic functions and an ectodermal medulla that produces andrenalin.

ADRENO-CORTICOTROPHIC HORMONE (ACTH) - a protein hormone of the anterior lobe of the pituitary gland that stimulates the adrenal gland cortex.

AGE-ADJUSTED - a statistical method used in rate calculations to minimize the effects of different age distribution among study subjects or populations. Only properly adjusted rates can be compared with each other.

ALIPHATIC HYDROCARBONS - a series of chemical compounds made exclusively of carbon and hydrogen in which the carbon atoms form straight or branched chains rather than rings. Propane and butane are examples.

ALL (ACUTE LYMPHOID LEUKEMIA) - see LYMPHATIC LEUKEMIA.

ALLOGENEIC - sufficiently unlike genetically to interact antigenically; e.g., when a foreign protein or carbohydrate substance (as a toxin or enzyme) introduced into the body stimulates the production of an antibody.

ALTERNATING CURRENT (AC) - an electric current that reverses its direction at regularly recurring intervals, (e.g., 50- 60 Hz). Tne abbreviation AC is commonly used to describe periodically varying electrical quantities.

AC ELECTRIC FIELD - the electric field produced by AC power systems defined by its' space components along three orthogonal axes. The magnitudes of the components are expressed by their root mean square (rms) values in V/m or kV/m. The phases in time of the components need not be the same.

AC MAGNETIC FIELD - the magnetic flux density produced by AC power systems defined by its' space components along three orthogonal axes. The magnitude of the components are expressed by their rms values in Gauss (G) or milliGauss (mG).

ALTERNATIVE HYPOTHESIS - a numerical statement concerning the parameters of one or more distributions that is mutually exclusive to the null hypothesis. Sometimes called the research hypothesis because it is, in most cases, the hypothesis that the investigator would like to prove.

AML (ACUTE MYELOGENOUS LEUKEMIA) -

See MYELOGENOUS LEUKEMIA.

AMBIENT - encompassing or surrounding area.

AMPERE - the unit of electrical current which results from 1 coulomb of charge passing through a conductor in one second.

AMPLITUDE - the maximum departure of the value of an alternating current or wave from the average value.

7, 12 - DIMETHYLBENZENE (a) ANTHRACENE - a substance known to be a potent cancer promoter, often used in cancer promotion research.

ANALYSIS OF VARIANCE (ANOVA) - widely used statistical methods that isolate and assess the contribution of categorical independent variables to variation in the mean of a continuous dependent variable. The observations are classified according to their categories for each of the independent variables, and the differences between the categories in their mean values on the dependent variable are estimated and tested for statistical significance. These methods can be used to determine equality of treatment means adjusted for cofactors, or they can be used to estimate components of variance attributable to each random source of variation.

AROMATIC HYDROCARBONS - a series of chemical compounds made exclusively of carbon and hydrogen in which the carbon atoms form closed rings rather than straight or branched chains. Benzene and naphthalene are examples. Many have a fragrant odor.

ASSOCIATION - association refers to the statistical dependence between two variables, that is, the degree to which the rate of disease in persons with a specific exposure is either higher or lower than the rate of disease among those without that exposure.

There are several factors to be considered in evaluating whether or not an association observed in an epidemiologic study is causal, these include:

1. The strength of the association: A strong association is more likely to be causal than a weak one.

2. Specificity of the association: The exposure to the supposed causative agent in every diseased patient tends to support causality.

3. Dose-response relationship: In a causal relationship, increased exposure to the agent usually produces an increased risk in the exposed population.

4. Consistency of the association: The repeated finding of the association in several studies of different populations tends to support causation.

5. Time sequence: Clear antecedence of the exposure of interest to the outcome by a period of time is necessary to judge causality to be reasonable.

ASSAY - examination and determination as to characteristics (as weight, measure, or quality). Analysis to determine the presence/absence or quantity of one or more components.

ASTROCYTOMA - a tumor intermingled with the essential elements of nervous system tissue especially the brain, spinal cord, and ganglia, but composed of the star-shaped cells (astrocytes) that are part of the supporting tissue of the nervous system. Astrocytomas in children and persons less than 20 years of age usually arise in a cerebellar hemisphere, and in adults they usually occur in the cerebrum, sometimes growing rapidly and invading extensively.

ATHERMAL - a state, condition, or reaction of a substance or organism which is independent of and unaffected by temperature.

ATTRIBUTABLE RISK - the difference in disease rates between exposed and non-exposed groups. It can serve as a measure of the proportion of a disease in a population that can be explained by the exposure under study.

AUTOPSY COHORT - a defined group of persons who have been autopsied after death. Since autopsies are done on non-randomly selected persons in the population, findings from autopsy cohorts should be generalized cautiously.

AVERSION - tending to avoid or causing avoidance of a noxious or punishing stimulus, as in behavioral modification through the use of stimuli.

BACTERIUM - any of a class of microscopic plants having round, rodlike, spiral, or filamentous single-celled or noncellular bodies of ten aggregated into colonies or motile by means of flagella, living in soil, water, organic matter, or the bodies of plants and animals, and being autotrophic, saprophytic, or parasitic in nutrition and important to man because of their chemical effects and as pathogens.

BEHAVIOR - anything that an organism does involving action, and response to stimulation; the response of an individual, group or species to its environment.

BENIGN - having a gentle disposition; of a mild character; non-cancerous/non-malignant.

BIAS - Eviation of research results or inferences from the truth. Any trend in the collection, analysis, interpretation, publication, or review of data which tend to produce results that differ systematically from the "true values" of the population variables being studied (e.g. disease rates). Many varieties of bias have been described. Unlike conventional usage, the term "bias" does not refer to a partisan point of view.

BIAS, RESPONSE - a condition present in a study subject that affects the accurate recording of the response. Particularly, in epidemiologic questionnaire studies where recall of events is frequently more intense in diseased individuals than in non-diseased controls, this may lead to an inaccurate evaluation of a response factor.

BIAS, SELECTION - systematic error in research results due to difference in characteristics between those who choose or volunteer to participate in a study and those who do not or systematic differences in characteristics between those who are selected for study and those who are not.

BIAS, OBSERVATIONAL - a condition present in the person recording the observation or in the measurement instrument that prevents an accurate recording of the data point.

BIOLOGICAL PLAUSIBILITY - a guideline used to judge whether an observed association between an exposure and a disease is a causal one. An association meets the standard of biological plausibility if it fits with existing biological or medical knowledge.

BIOPHYSICAL MECHANISMS - physical and/or chemical interactions of electric and magnetic fields with biologic systems.

BIOMARKER - an indication of variation in cellular or physiological components or processes, structures or functions that are measurable in a biological system or sample.

BLOOD CHEMISTRY - the assay/analysis of the various chemical components of blood, including counts/ratios of various cell types, ionic concentrations, and hormonal levels, etc.

BONE MARROW - a soft highly vascular modified connective tissue that occupies the cavities and cancellous part of most bones.

MEMBRANE - BOUND - the presence of elements/molecules, (e.g., calcium) in the structure of the cell membrane, capable of being released in the event of an appropriate triggering signal.

BOVINE - relating to oxen and/or cows, or a closely related animal.

CANCER - a disease characterized by malignant, uncontrolled growth of cells of body tissue; a malignant tumor of potentially unlimited growth that expands locally by invasion, and systemically by metastasis.

CANCER CLUSTER - a series of cancer cases that occur close together in time and/or location. The term is normally used to describe a grouping of relatively rare diseases, such as leukemia.

CANCER INITIATOR - a chemical substance or physical stimulus that causes or facilitates (makes easier) the beginning of cancer.

CANCER PROMOTER - a chemical substance or physical stimulus that furthers the growth or development of cancer.

CAPACITOR - a device made of two conducting surfaces separated by an insulator capable of storing electric charge.

CARCINOGEN - a chemical, biological or physical agent capable of producing tumor growth.

CARCINOGENESIS - a series of stages at the cellular level culminating in the development of cancer.

CARDIOVASCULAR - relating to, or involving the heart and blood vessels.

CASE - in epidemiology, a person identified as having the particular health endpoint (e.g., disease) under investigation.

CASE-CONTROL STUDY - a type of epidemiologic investigation that begins with the identification of both a group of persons who have developed the disease under study, the cases, and a group of persons who have not developed the disease, the controls. An attempt is then made to compare the previous exposure experience of the cases with that of the controls to determine if the two groups differ significantly in the frequency or level of a particular exposure.

CATEGORICAL DATA - observations that are classes of distinct groups, usually recorded as discrete numerical values; e.g., classes of dead or alive can be recorded as 0 or 1 respectively. Likewise, white, Hispanic, black, native American, etc. can be assigned values 0,1,2,3, etc., also known as qualitative data or discrete data.

CAUSATION - a condition in which a situation, event, or agent produces an effect in an outcome variable of study.

CELL - a small, usually microscopic mass of protoplasm bounded externally by a semipermeable membrane, usually including one or more nuclei and various nonliving products, capable alone or interacting with other cells of performing all the fundamental functions of life, and forming the least structural unit of living matter capable of functioning independently.

CELL MEMBRANE - the semi-permeable material forming the boundary of a cell that encloses and supports the cell, and controls efflux and influx of cell metabolites, nutrients, wastes, etc.

CENTRAL NERVOUS SYSTEM (CNS) - the part of the nervous system which in vertebrates consists of the brain and spinal cord, to which sensory impulses are transmitted and from which motor impulses pass out, and which supervises an coordinates the activity of the entire nervous system.

CHI-SQUARE (X^2) TEST - a common statistical method for comparing proportions or percentages of a characteristic in one or more groups. For example, a chi-square test might be used in a case- control study to determine whether the proportion of those exposed to a particular environmental agent differs significantly between the case group and the control group. Two major chi-square tests, Pearson chi-square test and Mantel-Haenszel test, are used frequently in epidemiologic studies.

CHROMODACRYORRHEA - a gland secretion indicative of stress.

CHROMOSOME - a very long molecule of DNA, complexed with protein containing genetic information.

CHRONIC - a condition or situation marked by long duration or frequent recurrence.

CHRONIC LEUKEMIA - a type of leukemia which is not acute. CLL is an abbreviation of chronic lymphoid leukemia.

CIRCADIAN RHYTHM - biological processes which occur in synchronogical daily cycles of approximately one day (24 hours).

CIRCUIT - A closed conducting path for the flow of current.

CLINICALLY OVERT - a term describing an illness in which the symptoms have become obvious.

COHORT - in epidemiology an identified group of persons with some common point of reference, i.e. birth year, place of employment, who are free of disease, but who have various degrees of exposure to the agent under study. The group is followed over time to determine the occurrence of disease among members of the cohort.

COHORT STUDY - a type of epidemiologic study in which the frequency of morbidity or mortality from a specific disease of interest in a group exposed to a suspected risk factor is compared to that in a group of unexposed people.

COLON - the part of the large intestine that extends from the cecum to the rectum.

CONCEPTION - the capacity, function, or process of becoming pregnant; in sexual reproduction, the act of egg fertilization.

CONDUCTANCE - the ease with which a material conducts current.

CONDUCTOR - a material that allows the flow of charge. The wires on transmission lines are conductors.

CONFIDENCE INTERVAL - A range of values bracketing a risk estimate which is calculated in a such a way that the range has a 95% probability of including the true value of the risk.

CONFOUNDING - a situation in which an observed association between an exposure and a disease is influenced or distorted by other variable(s) that are associated with the exposure and affect disease occurrence.

CONFOUNDING VARIABLE/CONFOUNDER - a variable that can distort the real association between exposure and outcome. An extraneous variable that may explain an observed association (or lack of an association) between an exposure and a disease in an epidemiologic study. A confounder can create a spurious association between an exposure and a disease, or it may mask, weaken, or exaggerate a real association. The variable is not an intermediate between the exposure and the outcome. It is a risk factor of the outcome, but it is not the variable of interest under investigation. Confounding must be ruled out before confidence can be placed in any observed association. Such a variable must be controlled in order to obtain an undistorted estimate of the effect of the study factor on risk. (See STRATIFICATION)

CONTINGENCY TABLE - a cross classification of categorical data arranged in a table (of 2 or more dimensions) such that each row and column expresses the frequency of occurrence in the sample of subjects possessing the characteristics defined by the row and column variables; e.g., a 2x2 contingency table of disease and exposure to a certain factor may be given by:

CONTINGENCY TABLE

		Factor +	Factor -	Total
Disease or condition	+	a	b	a+b
	-	c	d	c+d
		a+c	b+d	n

CONTROL - in case-control studies, an individual in the group of people that have not developed the disease of interest. (See CASE- CONTROL STUDY)

CONTROL GROUP - in experimentation, the group of subjects that are treated as in a parallel experiment except for omission of the procedure or agent under test and which is used as a standard of comparison in judging experimental effects.

CORRELATION - the establishment of a mutual or reciprocal relation between/among phenomena; to show a causal relationship between two or more events; a relation of phenomena as invariable accompaniments of each other.

CORRELATION - a linear relationship between two or more sets of variables. A linear association. Correlation, like association, does not imply causality.

CORTICOSTERONE - a colorless crystalline steroid hormone ($C_{21}H_{30}O_4$) of the adrenal cortex that is important in protein and carbohydrate metabolism.

COULOMB - the unit of electric charge (C). One electron (or proton) has a charge of about 1.6 x 10^{-19}C.

CUMULATIVE EXPOSURE - the total exposure to an agent, (such as magnetic fields,) experienced by a person during a specified time period, e.g., one hour, one year, or a lifetime of work.

CUMULATIVE INCIDENCE - the number or proportion of a group of people who experience the onset of disease during a specified time interval.

CURRENT - the flow of electrically charged particles. The unit of the ampere (A) expresses the force due to the magnetic field.

CYCLOTRON RESONANCE - for an ion, the condition for which the product of the charge-to-mass ratio and the static magnetic field yield a value of periodic motion at the same frequency as externally applied energy.

CYTOLYSIS - the usually pathologic dissolution or disintegration of cells.

CYTOTOXICITY - the ability of a chemical substance and/or a physical stimulus to kill (poison) cells.

DELETERIOUS - having a harmful effect.

DEMOGRAPHIC INFORMATION - the characteristics of a population such as place of residence, age, sex and race, birth and death rates, and socioeconomic conditions.

DEOXYRIBONUCLEIC ACID (DNA) - the nucleic acid molecule in chromosomes that contains the genetic information

DESYNCHRONIZATION - to upset, destabilize or destroy the recurrence, periodicity, or coexistence in time of various functions/activities of a biological system.

DETECTION - to discover or determine the existence, or the presence of something.

DEVELOPMENTAL EFFECTS - effects in the developing offspring due to exposure before conception (either parent), prenatally, or postnatally to the time of sexual maturation. Developmental effects may be expressed at any time in the life span of the organism. Developmental effects are a subset of reproductive effects.

DIRECT CURRENT (DC) - an electric current flowing in one direction only and substantially constant in value.

DIAGNOSTIC CRITERIA - information, usually clinical information such as physical symptoms and laboratory test results, used to determine whether a person has a suspected disease.

DIELECTRIC - an insulator or non-conductor.

DIELECTRIC STRENGTH - the maximum electric field strength that a material can withstand without breaking down and conducting.

DISTRIBUTION LINES - power lines that distribute electricity from substations to individual industrial, commercial, public and private users/customers.

DOSE - the amount of a physical or chemical agent interacting with /or absorbed by a person or organism.

DOSE-RESPONSE STUDY - an investigation that attempts to statistically define the functional relationship between a response (usually a disease incidence) and the dose of a specific agent.

DOUBLE-BLIND EXPERIMENT - an experimental procedure in which neither the subjects nor the experimenter know the makeup of the test and control groups during the actual course of the experiments.

EFFECT MEASURE - a quantity that measures the effect of a factor on the frequency or risk of a health outcome.

EFFLUX - the action or process of flowing out, as in the flow of ions through a semi-permeable cell membrane.

ELECTRIC DIPOLE - two separated electric charges; a molecule (or other structure) having the effective centers of positive and negative charges separated.

ELECTRIC FIELD - a vector field describing the electrical force per unit charge in space. Electrical charges are a source of electric fields. The electric field from a power line is an alternating, 60-Hz field due to charges on the conductors. The intensity of the electric field is expressed in volts per meter (V/m) or kilovolts per meter (kV/m).

ELECTRIC AND MAGNETIC FIELDS (EMF) - components of the electromagnetic spectrum which describe how energy travels through space.

For 60-hertz and other low frequencies, these vectors may be considered separately.

ELF (EXTREMELY LOW FREQUENCY) - usually taken to denote the frequency range below 300 Hz.

EMBRYO - an animal in the early stages of growth and development (differentiation) that are characterized by cleavage, the laying down of fundamental tissues, and the formation of primitive organs and organ systems (a vertebrate at any state of development prior to birth or hatching).For humans, this stage lasts between the second through eighth weeks after conception.

EMBRYONIC - an animal in the early stages of growth and differentiation prior to birth or hatching.

ENDOCRINE SYSTEM - the glandular system which produces secretions that are distributed in the body through the blood stream, and aid the nervous system in controlling and coordinating the body functions.

ENDODERMAL SINUS TUMORS (EST) - a frequently fatal tumor of germ cell origin, generally found in the ovary.

ENDPOINT - an observable or measurable biological, chemical or functional event used as an index of the effect of a chemical, physical or biological agent on a cell, tissue, organ, organisms, etc.

ENZYME - a protein molecule that acts as a catalyst in living organisms.

EPIDEMIOLOGY - the study of the occurrences and, distribution,of a disease or physiological condition. in human populations and the factors that influence this distribution.

EPINEPHRINE - a colorless crystalline slightly basic adrenal hormone ($C_6H_{13}NO_3$) which acts in the sympathetic nervous system which is used medicinally as a heart stimulant, a vasoconstrictor, and a muscle relaxant (also known as adrenaline).

ERYTHROCYTE - a red blood cell - tiny, disk-shaped cells, without nuclei, made in the marrow of the bones. The red blood cell's red color is due to the presence of the pigment hemoglobin, which combines with oxygen from the lungs to form oxyhemoglobin which carries oxygen to the cells of the body.

ESTIMATION - the process by which unknown parameters of a function or distribution are given approximate values (called estimates) based on available information.

EXPOSED GROUP - the experimental group of test organisms receiving a dose of a substance, to determine the effect(s) of the substance.

EXPOSURE - the joint occurrence in space and time of a person and the physical or chemical agent of concern, expressed in terms of the environmental level of the agent.

EXPOSURE ASSESSMENT - measurement or estimation of the magnitude, frequency, duration and route of exposure of an organism to environmental agents. The exposure assessment may also describe the nature of exposure and the size and nature of the exposed populations.

EXPOSURE METRIC - the means by which exposure to an agent of interest (e.g., magnetic fields) is measured or estimated. For example, in an occupational mortality study, the job title "electrician" listed on the death certificate might serve as the "exposure metric" to estimate the likelihood of exposure.

EXPOSURE-RESPONSE RELATION - a relationship between exposure and the effect produced by exposure. Response can be expressed either as the severity of injury or proportion of exposed subjects affected.

EXTRAPOLATION - an estimate of response or quantity at a point outside the range of the experimental data.

FARADAY'S LAW OF INDUCTION - the induce voltage in a circuit is equal to the negative rate at which the magnetic flux through the circuit is changing.

FATTY ACID - any of numerous saturated aliphatic monocarboxylic acids ($C_nH_{2n+1}COOH$) including many that occur naturally, usually in the form of esters in fats, waxes, and essential oils.

FERTILITY - ability of a living plant or animal to grow or develop; capability to breed or reproduce the species.

FIBROBLAST - a mesenchyme (early connective tissue) cell which is one of the building blocks for connective tissue (tissue that binds and supports the body parts). Fibroblasts are cells in the "extracellular matrix", or the network of molecules connecting the space outside the cells. Fibroblasts are responsible for producing material such as fibrin and other collagens, which form a large fraction of the matrix.

FIELD - a set of values of a physical quantity occurring at different points in space.

FIELD INTENSITY (FIELD STRENGTH) (E & H) - a vector quantity which describes the forces of interaction of macroscopic electric currents. 1.) Electric Field intensity is measured in units of volts per meter (V/m) 2.) Magnetic Field intensity is measured in amperes per meter (A/M), but is often indicated by a related quantity called magnetic flux density which is the number of field lines that cross a unit of surface area. Unit of magnetic flux density most commonly used is the gauss (G).

FISHER EXACT TEST - a statistical test for association based on the distribution of frequencies within a 2x2 table.

FOLLICLE - a small anatomical cavity or deep narrow-mouthed depression. As related to hair: the tabular epithelial sheath that surrounds the lower part of the hair shaft and encloses a the bottom of vascular papilla supplying the growing basal part of the hair with nourishment.

FOLLOW-UP - a process in epidemiology by which study subjects are tracked and observations of variables of interest are made over time. Follow-up has two critical features: completeness and duration. Completeness refers to the proportion of the study sample followed. Duration refers to the length of time the sample is followed.

FORAGE - to wander in search of food; food for animals, usually secured by browsing or grazing.

FREQUENCY - the number of complete cycles of a periodic waveform per unit time. The units of frequency are Hertz (Hz), which is one cycle per second.

50-60 HZ FREQUENCIES - the number of complete cycles of a periodic waveform per unit time. Units of frequency are the hertz (Hz) which is equivalent to cycles per second. The frequencies of AC power systems in Europe and North America are 50-Hz and 60-Hz, respectively.

GAUSS - the historical unit of magnetic flux density, often used to express the magnitude of a magnetic field. One gauss is 10^{-4} tesla.

GENE - the simplest complete functional unit in a DNA molecule. A linear sequence of nucleotides in DNA that is needed to synthesize a protein and/or regulate cell function.

GEOMAGNETIC FIELD - the earth's natural magnetic field.

GEOMETRIC MEAN - one of several measures of central tendency. Used when a data set encompasses a very wide range of values. It is calculated by converting each observed value to its logarithm, determining the arithmetic mean of the logarithms, and then converting back to a direct count by taking the antilogarithm. (See also MEAN)

GESTATION - the period of intrauterine fetal development from conception to birth, usually 38 weeks.

GLIOMA - a type of cancer of the central nervous system, or a specific tumor composed of the supporting cells of the brain, spinal cord, or other nervous system tissue.

GLYCOPROTEIN - a conjugated protein in which the non-protein group is a carbohydrate.

GROUNDING - connecting a conductor to something that will accept excess charge, for example, the earth.

HALL-EFFECT - the generation of an electrical potential perpendicular to both the electric current flowing along a thin conductive lateral and an external magnetic field applied at right angles to the current upon application of the field.

HARMONICS - component frequencies of an electromagnetic wave that are integral multiples of the fundamental frequency.

HEMATOPOIETIC CANCERS - cancers of the blood-making organs, especially the bone marrow and lymph nodes.

HERTZ - one cycle per second.

HORMONE - the secretions of endocrine glands which act as "chemical messengers", controlling and regulating the body's life functions.

HOST ORGANISM - a living animal or plant affording subsistence or lodgement to another organism (usually a parasite); an organism into which a tissue or part is transplanted from another.

HYDROCARBON - a compound made exclusively of carbon and hydrogen atoms. Hydrocarbons are commonly found in petroleum, natural gas and coal.

HYPERTENSION - a condition in which the patient has a higher blood pressure than judged to be normal.

HYPOTHALAMO-YPOPHYSEALADRENAL SYSTEM - neuroendocrine system that plays a part in controlling behavior, metabolism, maintenance of body temperature, etc.

HYPOTHALAMUS - a basal part of the diencephalon (posterior subdivision of forebrain) that lies beneath the thalamus on each side, forms the floor of the third ventricle, and is usually considered to include vital autonomic regulatory centers.

HYPOTHESIS - a supposition, arrived at from observation or reflection, that leads to refutable predictions.

HYPOTHESIS TESTING - the systematic verification or rejection of a scientific proposition or argument.

ICD (INTERNATIONAL CLASSIFICATION OF DISEASES) - the classification of specific health conditions by an international group of experts for the World Health Organization (WHO). Every health condition is assigned a specific numerical code. The complete list is periodically revised , in the *Manual of the International Statistical Classification of Diseases, Injuries and Causes of Death*. The Ninth Revision of the Manual (ICD-9) was published by WHO in 1977 after ratification of 1976.

IMMUNE SYSTEM - the body's primary defense against abnormal growth of cells (i.e., tumors) and infectious agents such as bacteria, viruses and parasites.

IMMUNOGLOBULIN - a protein (such as an antibody), which is made up of amino acid chains usually linked by disulfide bonds.

INCIDENCE OF A DISEASE - the number of new cases (persons becoming ill) during a given time period in a specified population.

INCIDENCE RATE - the rate at which new events occur in a population. The numerator is the number of new events that occur in a defined period; the denominator is the population at risk of experiencing the event during this period, sometimes expressed as person-time.,e.g., (100,000 persons in a year)

INCUBATION - the period between the infection of an organism by a pathogen and the manifestation of the disease it causes; the maintenance of controlled conditions for the cultivation of organisms or the housing of young or sick organisms.

INDUSTRIAL HYGIENIST - a professional whose job is to recognize, evaluate, and control environmental factors or stresses in the work place which may cause sickness, impaired health, or significant discomfort and inefficiency among workers or among other exposed persons.

INFERENCE - the act of making a decision or evaluation concerning one or more characteristics or properties of a population based on information obtained from a sample. Reasoning from a part to the whole. Based on the assumption that the sample represents the whole population.

INITIATION - the first (initial) stage of carcinogenesis (onset of cancer) caused by carcinogenic agents, (e.g., ionizing radiation, certain chemicals), wherein cellular genetic material, (i.e., DNA) is irreversibly changed or mutated.

INITIATOR EFFECT/INITIATION - the transformation of a normal cell of the body to a neoplastic (cancer) cell by means of a permanent change or mutation in the nuclear DNA. Initiation results from a limited exposure to a carcinogen, is accomplished rapidly, and is irreversible.

INSULATOR - a non-conductor of electrical charges.

INTRAUTERINE EXPOSURE - exposure experienced by the fetus in the uterus during pregnancy, e.g through the placenta.

IN VITRO - describes studies that are done in the laboratory, literally "in glass", as distinct from those performed using living animals.

IN VIVO - experiments performed "in the living body" of a plant or animal.

ION EFFLUX - the movement of ions, charged atoms or molecules, from a sample into a surrounding solution.

IONIZATION - the dissociation of compounds into ions through loss of electron(s)

IONIZING RADIATION - any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter. Ionizing radiation possesses sufficient energy to remove electrons from the atoms or molecules it encounters, and is capable of causing injury to living cells. Examples of ionizing radiation: Xrays, gamma rays and alpha and beta particles .

IRRADIATED - exposed to the emission of radiant energy (energy that travels through space, even in the absence of matter).

ISCHEMIC HEART DISEASE - localized and temporary lack of blood in the heart due to an obstruction of the flow of arterial blood.

LATENCY, LATENT PERIOD - the delay between exposure to a disease- causing agent and the appearance the disease. For example, after exposure to ionizing radiation there is an average latent period of five years before development of leukemia, and more than 20 years before development of certain other malignant conditions.

LECITHIN - any of several waxy hydroscopic phosphatides that are widely distributed in animals and plants, form colloidal solutions in water, and have emulsifying, wetting, and antioxidant properties.

LEUKEMIA - an acute or chronic disease (cancer) in man and other warm-blooded animals characterized by an abnormal increase in the number of white blood cells.

LYMPHATIC CANCERS - acute and chronic cancers of all structures involved in the conveyance of lymph from the tissues to the blood stream. The lymph system includes the lymph capillaries, lacteals, lymph nodes, lymph vessels, and main lymph ducts.

LYMPHATIC LEUKEMIA/LYMPHOID LEUKEMIA - leukemia in which there is marked increase in the size of the spleen and lymph glands with great increase in white blood cells in the blood; acute forms occur in children and young adults.

LYMPHOCYTE - a colorless weakly motile cell produced in lymphoid tissue that is the typical cellular element of lymph, and constitutes 20 to 30 percent of the leukocytes of normal human blood.

LYMPHOMA - a general term for an abnormal (neoplasm) growth in the lymphatic system. Included in this general group are Hodgkin's disease, lymphosarcoma, and malignant lymphoma.

MAGNETIC DIPOLE - two separated magnetic poles; an object such as a permanent magnet, particle or current loop, that gives rise to a magnetic field. The object acts as if it consists of two magnetic poles of opposite sign separated by a small distance.

MAGNETIC FIELD STRENGTH - a vector field describing the force per unit charge experienced by magnetic objects or moving electrical charges in space. The unit is the ampere per meter (A/m).

MAGNETIC FLUX DENSITY - a vector field, which is related to the magnetic field by the magnetic permeability of the medium. The SI unit is the tesla (T). The historical unit is the gauss (G), which equals 10^{-4}T.

MALFORMATION - a permanent structural change in a developing organism that may adversely affect survival, development or function.

MANTEL-HAENSZEL TEST - a summary chi-square test developed by Mantel and Haenszel for stratified data and used when controlling for confounding. (see CHI_SQUARE TEST)

MALIGNANT - tending to produce death or deterioration through the process of infiltration, metastasis (spreading throughout the body) and destruction of tissue.

MALIGNANCY - a neoplasm or tumor that is invasive with a tendency to metastasize.

MAMMARY (GLAND) - one of the large compound modified sebaceous glands that in female mammals are modified to secrete milk, usually situated in pairs (ventrally), and usually terminating

MATCHED CONTROLS - in a case-control study, controls selected so that they are similar to the cases in specific characteristics such as age, sex, race, and socioeconomic status. (see CASE-CONTROL STUDY)

MATCHING - the process of making a study group and a comparison group comparable with respect to extraneous or potentially confounding factors.

MATCHING VARIABLE - a characteristic such as age or sex used to select matched controls, such that those characteristics are similar in cases and controls. (See MATCHED CONTROLS)

MEAN - one of several measures of central tendency of the distribution of a set of values. The arithmetic mean is the sum of all values in a set, divided by the number of values in the set. (See also GEOMETRIC MEAN and MEDIAN)

MECHANISTIC - mechanically determined - natural processes (as of life) can be mechanically determined and capable of complete explanation by the laws of physics and chemistry; the fundamental physical or chemical processes involved in or responsible for an action, reaction, or other natural phenomenon (as organic evolution).

MEDIATE - to occupy a middle position; to effect by action as an intermediary; to transmit as intermediate mechanism or agent. To intervene between conflicting processes/substances (in a chemical or biological process) to promote harmony or compromise.

MEDIAN - one of several measures of central tendency of the distribution of a set of values. The median represents the middle figure when the measurements are arranged in ascending order. Half the measurements are below the median value, half are above.

MELATONIN - a vertebrate hormone of the pineal gland that produces darkening of the skin by causing concentration of melanin in pigment-containing cells. Melatonin influences sleep, perception of pain, psychological depression and social behavior.

MENARCHE - the onset of menstruation, normally occurring between the 10th and 17th year.

METABOLISM - the biochemical reactions by which energy is made available for the use of an organism from the time a nutrient substance enters, until it has been utilized and the waste products eliminated.

METASTASIS - movement of bacteria or body cells (especially cancer cells) from one part of the body to another by means of the lymphatics or blood stream. In cancer cases the result of metastasis is a secondary growth arising from the primary growth in a new location.

MICROGAUSS ()(uG) - one millionth of a gauss, or 10^{-6} G.

MICROWAVE - a comparatively short electromagnetic wave, between 100 centimeters and one centimeter in wavelength and corresponding frequency from 1Ghz-300 G hz. A form of non-ionizing radiation used in communications & other technologies that can also cause significant tissue heating.

MILLIGAUSS (mG) - one thousandth of a gauss, or 10^{-3} G.

MISCLASSIFICATION ERROR - the erroneous classification of an individual into a category other than that to which he or she could be assigned. In an epidemiologic study of EMF exposure, for example, including electricians who routinely work on dead circuits in the "exposed" group would result in misclassification error.

MITOGEN - a substance that induces mitosis (replication of a cell's nuclear material).

MITOGENESIS - the process by which a substance induces mitosis (replication of a cell's nuclear material).

MITOSIS - cellular and nuclear division that involves duplication of the chromosomes of a parent cell and formation of two daughter cells.

MODEL - (1) Mathematical model. A mathematical representation of a natural system intended to mimic the behavior of the real system, allowing description of empirical data, and predictions about untested states of the system.

(2) Biological model. A condition or disease in animals similar to the condition or disease in human being.

MODULATOR - something that regulates a process or concentration according to measure or proportion; something that varies the amplitude, frequency, or phase of a carrier or signal.

MORBIDITY - any departure from a state of physiological or psychological well-being,used in public health data to describe disease states.

MORTALITY - death; or the number of deaths in a given time or place; or the death rate.

MOTOR BEHAVIOR - movement of an organism in response to a stimulus.

MULTIPLE MYELOMA - a neoplastic disease characterized by the infiltration of bone and bone marrow by myeloma cells forming multiple tumor masses. It occurs commonly in the sixth decade of life, and more frequently in males.

MULTIVARIATE ANALYSIS - a set of statistical techniques used when the variation in several variables is studied simultaneously.

MUTAGEN - any agent that causes genetic changes. Many medicines, chemicals and physical agents, such as ionizing radiation and ultraviolet light, can be mutagens under the right conditions.

MYELOGENOUS LEUKEMIA/MYELOID LEUKEMIA - leukemia involving the blood-making bone marrow, especially that of the ribs, sternum and vertebrae. (see LEUKEMIA)

MYOCARDIAL INFARCT - necrosis or death of tissue in the heart following the c

NEGATIVE STUDY - a finding or study which confirms the null hypothesis, i.e., the association between exposure and disease is not different from a measure of no association. Example: a study with a relative risk of one or a risk difference of zero.

NEOPLASIA - the pathologic process that results in the formation and growth of a neoplasm. The development of new tissues or neoplasms. (See NEOPLASM)

NEOPLASM - a new and abnormal formation of tissue as a tumor or growth that serves no useful function, but continues to grow after the stimuli that initiated the new growth cease, and at the expense of the healthy organism.

NEOPLASTIC - pertaining to, or of the nature of, new, abnormal tissue growth.

NET CURRENT - the vector sum of the currents in all the wires (primaries, secondaries, and neutrals) of a set of conductors.

NEUROBLASTOMA - a malignant, bleeding tumor comprised principally of cells resembling embryonic nerve tissue. Neuroblastoma occurs frequently in infants and children in the mediastinal and retroperitoneal regions and metastasizes widely. It occurs chiefly in infants and children.

NEUROENDOCRINE HORMONE - of or pertaining to hormones that influence the activity of nerves (neurosecretion).

NEUROLOGICAL - of or pertaining to the functioning of the nervous system.

NEUROTRANSMITTER - a chemical substance that transmits nerve impulses across the space between nerve endpoint called the synapse.

NEUTRAL - the wire at ground potential carrying the return current of energized wires.

NON-HODGKIN'S LYMPHOMA - see LYMPHOMA.

NONIONIZING RADIATION - radiation which does not transfer sufficient energy to remove electrons, or break chemical bonds, to form ions in the material it encounters. Examples of nonionizing electromagnetic radiation include ultraviolet and visible light, infrared and microwave radiation, radio and television waves and power-frequency fields (60 Hz) also included may be laser sources (coherent light) and ultrasound (sonic radiation).

NONPARAMETRIC METHODS (DISTRIBUTION-FREE METHODS) - statistical procedures that are derived in such a way that they do not rely on the form of the underlying distribution.

NOREPINEPHRINE - a crystalline compound $C_8H_{11}NO_3$ that occurs with epinephrine, has a strong vasoconstrictor action, and mediates transmission of sympathetic nerve impulses.

NULL HYPOTHESIS - the statistical hypothesis that one variable has no association with another variable or set of variables, or that two or more population distributions do not differ from one another. In simplest terms, the null hypothesis states that the results observed in a study, experiment, or test are no different from what that might have occurred as a result of the operation of chance alone.

OBSERVED-TO-EXPECTED (O/E) RATIO - in an epidemiologic study, the ratio of the observed number of cases of a disease in the population under study to the number that would be expected on the basis of the disease experience of a reference group.

ODDS RATIO - a calculation used frequently in case-control studies to compare the exposure experience of diseased and non-diseased groups. The odds ratio can serve as an estimate of the relative risk of disease associated with the exposure.

OHM - the unit of electrical resistance.

ONCOGENE - a mutation of a naturally occurring gene involved in growth regulation that results in uncontrolled growth. Oncogenes are associated with the development of some forms of cancer.

ONE-SIDED TEST - a statistical significance test based on the assumption that the data have only one possible direction of variability.

ORNITHINE DECARBOXYLASE (ODC) - an enzyme found in cells, essential for cell growth because it helps synthesize biochemicals that are necessary for DNA and protein synthesis.

OVARIAN - Concerning the two glands in the female which produce the reproductive cell, the ovum, and two known hormones.

PAH - see POLYCYCLIC AROMATIC HYDROCARBON.

PARAMETER - in mathematics, a constant in a formula or model; in statistics and epidemiology, a measurable characteristic of a population. "True parameter values" are usually unknown and must be estimated from the data.

PARITY - the status of a woman with respect to the number of full- term children she has borne, excluding miscarriages or abortions in early pregnancy, but including stillbirths.

PATHOLOGIST - a specialist in diagnosing disease-related changes in tissues removed at operations and postmortem examinations.

PEAK INCIDENCE - the highest recorded incidence of a particular disease in a particular population.

PEER REVIEW - a review, usually of a study report, by persons who have similar expertise as the author(s) in the subject area of the study.

PERIODICITY - the quality, state, or fact of being regularly recurrent, (i.e., returning or happening time after time).

PERIPHERAL - located away from a center or central portion; involving the surface or external boundary of a body.

PEROXIDATION - to treat something with a peroxide (a substance having a high proportion of oxygen making it a strong oxidizing/bleaching agent).

PERSON-YEAR - a unit of measurement obtained by summing the lengths of time (usually one year) for each person and used as a denominator in incidence and mortality rate calculations.

PERSON-YEARS AT RISK - the sum of the years that the persons in the study population have been exposed to the condition of interest. With this approach, each person contributes only as many years of observation to the study as he is actually observed at risk; if he leaves, contracts the disease under study or dies after one year, he contributes one person-year; if after ten, ten person-years.

PHASE SHIFTS - modulation of the phase of a periodic waveform in time or space from a chosen instant or position, or a shift in the time of occurrence of peak and levels of hormone concentrations in animals during a 24-hour period.

PHORBOL ESTERS - substances, (e.g., TPA, or 12-0-tetradecan{oy/pho]ol-13-acetate) which are potent promoters of cancer and often used as experimental standards in cancer promotion experiments.

PHOSPHOLIPID - a complex phosphoric ester lipid that is found in all living cells in association with stored fats.

PHOTON - a particle of electromagnetic energy.

PHYSIOLOGICAL - dealing with the functions and activities of life or of living matter (as organs, tissues, or cells), and of the physical and chemical phenomena involved; the organic processes and phenomena of an organism or any of its parts or of a particular bodily process.

PHYTOHEMAGGLUTANIN - a protein extract of the red kidney bean that has been used to agglutinate red blood cells, and to induce structural changes, followed by mitosis, in white blood cells in culture.

PIR (PROPORTIONAL INCIDENCE RATIO) - the proportion of new cases of a specific disease among new cases of all diseases in a given population, compared to the proportion of new cases of that disease among new cases of all diseases in a reference population. The PIR may be used, for example, to determine if, compared to the occurrence of other diseases, leukemia occurs more frequently among electricians than among the general public. Calculated as follows: Percent new cases of disease due to leukemia in study population divided by percent of new cases of disease due to leukemia in reference population.

PLASMA - the fluid part of blood, lymph, or milk as distinguished from suspended material.

PLASMA MEMBRANE - the membrane surrounding plant and animal cells.

PMR (PROPORTIONAL MORTALITY RATIO) - the proportion of deaths due to a particular cause in one population, compared to the proportion of deaths due to that cause in another population. The PMR is used, for example, to determine if the proportion of deaths due to leukemia is greater among electricians than among the general public. The comparison of the PMRs from different populations can give rise to misleading conclusions if the populations have different distributions of causes of death. Calculated as follows: percent of deaths due to specific disease in study population divided by percent of deaths due to specific disease in reference population.

POCKELS EFFECT - is the change in refractive properties of certain crystals in the presence of an applied electric field and is proportional to the first power of the electric field strength.

POLYCYCLIC AROMATIC HYDRO-CARBON - a series of organic compounds that have two or more usually fused rings in the molecule. Some polycyclic aromatic hydrocarbons are known human carcinogens.

POPULATION - the entire set of subjects that are the object of a study or investigation.

POSITIVE FINDINGS/POSITIVE STUDY - a finding or study in which the association between exposure and disease is appreciably different from a measure of no association.

POST-NATAL - subsequent to birth; relating to all organism immediately after birth.

POTENTIAL - electrical potential energy, defined at a point by the work necessary to bring a unit positive charge to the point from an infinite distance. The difference in potential between two points is defined by the work necessary to carry a unit positive charge from one to the other. The unit is the volt (V).

POWER - the time rate at which work is done. Electrical power is proportional to the product of current, voltage, and power factor. The unit is the watt (W).

POWER FACTOR - is the cosine of the angle of phase difference between the voltage and current.

POWER (STATISTICAL) - the probability of rejecting the null hypotheses when it is false. Power is equal to 1 minus the probability of a type II error. In epidemiology, the probability that a real association between an exposure and a disease, if it exists, will be detected in a statistical hypothesis test.

PRECISION - the closeness of an observation to the mean derived from repeated sampling of the same population. Precision can be estimated by standard error or standard deviation.

PREDISPOSING FACTOR - a condition or characteristic that contributes to an individual's susceptibility to a disease.

PREVALENCE - the total number of existing cases of a disease or other condition in a specific population at a specific point in time.

PREVALENCE RATE - the total number of existing cases of a disease or other condition in a specific population at a specific point in time divided by the size of the population at that time.

PRIMARY - (of a distribution line) The set of wires at voltages higher than the residential service voltage (120 V) that are connected to distribution transformers.

PROBABILITY DISTRIBUTION - a mathematical function that assigns a probability to the occurrence of a specific value or range of specific values that can be assumed by the random variable.

PROGRESSION - a continuous and connected series (sequence) of events, actions, etc. In the three-stage model of carcinogenesis, the state where a benign tumor becomes malignant.

PROLACTIN - a protein hormone of the anterior lobe of the pituitary that induces lactation (milk production).

PROLIFERATION - production of new cells through the process of cell division.

PROMOTER EFFECT - the facilitation of the growth of dormant cancer cells into tumors.

PROMOTION - The second hypothesized stage in a multistage process of cancer development. The conversion of initiated cells into tumorigenic cells.

PROSPECTIVE STUDY - a type of epidemiologic study in which study subjects free of disease are followed into the future to determine their morbidity or mortality experience.

PROTEIN - any of numerous naturally-occurring extremely complex combinations of amino acids that contain the elements carbon, hydrogen, nitrogen, oxygen, usually sulfur, and occasionally other elements. Proteins are essential constituents of all living cells, and are synthesized from raw materials by plants but assimilated as separate amino acids by animals.

PULSED FIELD - an electric/magnetic field produced or modulated (as electromagnetic waves) by brief duration-pulses of electric current or voltage. Pulsed fields are fields which are turned on quickly for only a brief period.

PRR (PROPORTIONAL REGISTRATION RATIO) - the proportion of a specific kind of cancer among all new cases of cancer registered for one group of people, compared to the proportion of that kind of cancer in another group. Similar to the PIR, the PRR is used to determine, for example, whether the proportion of leukemia compared to other cancers is higher among electricians than it is among the general public. (See also REGISTRY)

PUTATIVE - commonly accepted or supposed.

p-VALUE

See STATISTICAL SIGNIFICANCE.

QUALITATIVE DATA - information collected in a study which can be classified into categories; such as sex, race, hair color and nationality.

QUANTITATIVE DATA - information collected in a study which can be classified on some continuous scale, such as age, height, weight and blood pressure.

RANDOM VARIABLE - a variable whose values follow a probability distribution.

RANDOMIZATION - a process by which study subjects are assigned to experimental test conditions such that each subject has an equal chance of being selected for each condition.

REFERENCE GROUP - a standard against which the disease experience of the population that is being studied is compared.

REGISTRY - in epidemiology the term "registry" is applied to the file of all cases of a particular disease in a defined population such that the cases can be related to a population base, e.g. all cancer cases in the state of Iowa. With this information, incidence rates can be calculated.

REGRESSION - statistical procedures that allow the selection of the best numerical relationship among two or more variables. Given data on a dependent variable y (disease outcome) and one or more independent exposure-related variables, $x_1, x_2, x_3, ..., x_n$, regression analysis involves finding the "best" mathematical model to describe y as a function of the $x_1, x_2, x_3, ..., x_n$. Types of regression include: simple linear regression that is a straight- line fit to data points observed in a two-dimensional grid; multiple regression that is basically linear regression in n-space; polynomial regression that is a polynomial-curve fit to data points observed in a two-dimensional grid; nonlinear regression that fits functions other than polynomials to data; and logistic regression that is a categorical data method fitting functions to data adjusted by the logistic transformation.

RELATIVE RISK - the ratio of the risk of disease or death among an exposed group of study subjects to the risk among an unexposed group. A risk measure based on disease or death rates that is used frequently in cohort studies. The relative risk indicates the increased (or decreased) degree of risk among the exposed subjects compared to the non-exposed. A relative risk value of 1.0 indicates no association between the exposure and the disease. A relative risk of 2 would indicate that the exposed group is twice as likely as the non-exposed group to experience the health effect being studied (death or disease).

RELIABILITY - the degree to which the results obtained by a measurement procedure can be replicated. Lack of reliability may arise from divergences between observers or instruments of measurement, or from instability of the attribute being measured.

REPLICATION - the action or process of reproducing an exact replica (copy) of something.

REPRODUCTIVE EFFECTS - effects on reproduction which may include, but not be limited to, alternations in sexual behavior onset of puberty, fertility, gestation, parturition, lactation, pregnancy outcomes, premature reproductive senescence, or modifications in other functions that are dependent on the integrity of the reproductive system.

RESISTANCE - the ratio of the voltage across an object to the current following through it.

RESISTANCE - the property of material that determines the current produced by a given difference of potential. The unit of measurement is the ohm. A difference of potential of one volt will produce a current of one ampere in a circuit where the resistance is one ohm.

RESPIRATION - the physical and chemical processes by which an organism supplies its cells and tissues with the oxygen needed for metabolism and relieves them of the carbon dioxide formed in energy-producing reactions.

RETROSPECTIVE STUDY - a research design that is used to test etiologic hypotheses in which inferences about exposure to the putative causal factors are derived from historical data relating to exposure characteristics of the persons under study.

RIBONUCLEIC ACID (RNA) - Ribose and nucleic acids (any of various acids composed of a sugar or derivative of a sugar, phosphoric acid, and a base and found both in cells and cell nuclei. Vital to cellular processes, especially the coding of proteins.

RIGHT-OF-WAY - the legally defined corridor of land on which a transmission line is located.

RISK - the probability that an event will occur, e.g., that an individual will become ill or die within a stated period of time.

RISK ASSESSMENT - Activity of evaluating the toxic properties of an environmental agent and the conditions of human exposure to it in order to ascertain the likelihood that exposed humans will be adversely affected, and to characterize the nature of the effects they may experience. Risk assessment may contain some or all of the following four steps:

Hazard Identification The determination of whether a particular agent is or is not causally linked to particular health effect(s).

Dose-Response Assessment The determination of the relation between the magnitude of exposure and the probability of occurrence of the health effects in question.

Exposure Assessment The determination of the extent of human exposure.

Risk Characterization The description of the nature and often the magnitude of human risk, including attendant uncertainty.

RISK ESTIMATE - the quantitative estimate of the likelihood of adverse effects resulting from a specified exposure. The relative risk and odds ratio are examples of risk estimates.

RISK FACTOR - an aspect of lifestyle, environmental exposures, or an inherited characteristic, which on the basis of epidemiologic evidence, is shown to be associated with adverse health effects.

RMS (Root Mean Square) - the square root of the average of the squares of individual values. For a sinusoidal variable, such as the amplitude of 60-Hz alternating current, the rms value equals the peak value divided by the square root of two. Measured and calculated EMF levels are usually rms values.

SAMPLE - any selected subset from a population.

SAMPLE SIZE - the number selected (sampled) from a population to be the subjects of study.

SECRETION - 1) The process of segregating, elaborating, and releasing some material either functionally specialized, (i.e., saliva), or isolated for excretion, (i.e., urine). 2) A product of secretion formed by an animal or plant, especially one performing a specific useful function in the organism.

SELECTION BIAS - error in the results of a study due to systematic differences in characteristics between those who are selected for study and those who are not. For example, selecting only HMO patients as study subjects might exclude persons who are not employed or employable. Thus the study's results would not accurately reflect disease patterns in the general population which includes unemployed people.

SEROTONIN - A phenolic amine ($C_{10}H_{12}N_{2}O$) that is a powerful vasoconstrictor and is found especially in the blood serum and gastric (stomach) mucosa of mammals. Serotonin stimulates or inhibits many of the nerves and muscles, depending on the amount and the phase of the organ in its function. It can stimulate or depress heartbeat, contract blood vessels and change blood pressure. It prevents clotting, and provides reflexes such as coughing or hyper ventilation. In humans, serotonin also serves as a chemical transmitter in the brain. Serotonin and its product melatonin influences sleep, perception of pain, psychological depression and social behavior.

SEROTONIN N-ACETYL TRANSFERASE (SNAT) - an enzyme that affects the proper functioning of serotonin, especially in relation to vasoconstriction.

SHAM GROUP - the experimental group that is treated as in a parallel experiment except for omission of the procedure or agent under test, and which is used as a standard of comparison in judging experimental effects (also called Control Group).

SHIELDING - the cutting off or blockage of an organism from exposure to a stimulus, (e.g., EMFs) by the physical presence of another organism between the shielded organism and the stimulus.

SIBLINGS - children borne by the same mother.

SIEMENS - the SI term for the mho, the historical unit of conductance.

SIGN TEST - a statistical test that is used to test data independent of any assumption about the distribution of the data. This test is used to compare the locations of two distributions when the samples are dependent. It is one of the distribution-free test alternatives for the t-test.

SIGNIFICANCE LEVEL - The probability predetermined by the investigator) that the test statistic will assume a value that will lead to a rejection of the null hypothesis when the null hypothesis is true.

SINUSOIDAL - a regularly alternating electric field.

SMR (STANDARDIZED MORTALITY OR MORBIDITY RATIO) - a risk estimate which compares the numbers of deaths or illness observed in the study group with the number expected based on a comparison group (typically national or regional rates)while adjusting for differences in the age and sex of the study group members. The ratio is usually multiplied by 100, so an SMR of 100 would mean that the expected and observed deaths are essentially equal in number, and no excess risk is evident in the study group.

SOLVENT - a substance usually liquid capable of dissolving or dispersing one or more other substances. Most industrial solvents are volatile organic compounds such as xylene, toluene, and perchloroethylene.

SQUARE-WAVE PULSE - the rectangular wave form of an electric/magnetic field that varies periodically and abruptly from one to the other of two uniform values.

STANDARD DEVIATION - a measure of the variation in a set of observations. The mean of the observed values indicates where the values for a group are centered. The standard deviation is a summary of how widely dispersed the values are around this central value.

STATIC FIELDS - electric and magnetic fields that do not vary in intensity or strength with time.

STATISTICAL POWER - see POWER.

STATISTICAL SIGNIFICANCE - a finding of an epidemiologic study is considered to be statistically significant if, according to certain assumptions and based on a mathematical probability, the finding has a low likelihood of being due to chance or random variation. A test of statistical significance is a measure of whether a difference observed between the exposed and non-exposed groups in a study is statistically different from a chance occurrence. The probability of an observed difference being due to chance may be expressed as a "*p*" value.

STATISTICS - the science of collecting, summarizing and analyzing data that are subject to random variation such that the uncertainty of inductive inferences may be evaluated. The term is also applied to the data themselves and to summarizations of the data, e.g. a statistic may be a value that is computed from sample data or any function of a random variable.

STEADY-STATE - a state or condition of a system or process that does not change in time.

STEREOTYPE - something conforming to a fixed or general pattern (Ex. Stereotypical behavior-a standardized way of acting held in common by members of a group).

STEROID - any of numerous compounds containing the carbon ring system of the sterols and including the sterols and various hormones and glycosides.

STILL BIRTH - the birth of a dead fetus (dead at birth).

STIMULUS - an agent (as an environmental change) that directly influences the activity of living protoplasm (as by exciting a sensory organ or evoking muscular contraction or glandular secretion).

STRAIN - (1) A group of presumed common ancestry with clear-cut physiological but usually not morphological distinctions. 2) Excessive physical or mental tension.

STRATIFICATION - an analytic technique that separates a sample into several subsamples according to specific criteria such as age, sex, or socioeconomic status. The effect of confounding variables may be controlled by stratifying the data for analysis of results. For example, lung cancer is known to be associated with smoking. To examine the possible association between atmospheric pollution and lung cancer while controlling for smoking, the population may be divided into strata according to smoking status. The association between air pollution and cancer can then be appraised separately within each smoking status stratum.

STRESS - constraining force or influence - a force exerted when a physical, chemical or emotional factor that causes bodily or mental tension and may be a factor in disease causation.

SUBSTATION - a subsidiary station in which electric current is transformed.

SURVIVAL ANALYSIS - the development and application of statistical models and methods for analyzing data representing survival times, waiting times, or occurrence times to selected events.

SURVIVABILITY - 1) Resulting in or permitting survival. 2) The ability to remain alive or exist despite negative and potentially life-threatening stimuli.

SYNERGISM - synergism exists between two environmental agents if the risk of disease that results from exposure to both agents is greater than the sum of the risks for each individual exposure.

SYSTEM - 1) A regularly interacting or interdependent group of items forming a unified whole; 2) A group of body organs that together perform one or more vital functions.

SYSTEMATIC ERROR - distortion of study results due to non-random events. (See BIAS)

TENSION - the stress resulting from unrest, or imbalance caused by the imposition of stimuli, often with physiological manifestation.

TERATOGENIC - tending to cause developmental malformations and monstrosities (abnormal in growth or structure).

TERATOGENIC - a substance that produces abnormalities in the embryo or fetus by disturbing the mother's health or by acting directly on the fetus in utero.

TESLA - the unit of magnetic flux density(T), equivalent to 10^4 gauss (G) or 1 Wb/m^2.

TESTOSTERONE - a male hormone that is produced by the testes or made synthetically, and is responsible for inducing and maintaining male secondary sex characteristics, and is a crystalline hydroxy steroid ketone {$C_{19}H_{28}O_2$.}

THRESHOLD - 1) The point at which a physiological or psychological effect begins to be produced; 2) A level, point, or value above which something will take place, and below which it will not.

THYROID - a large endocrine gland of craniate vertebrates, lying at the base of the neck and producing especially the hormone thyroxine.

TIME-VARYING FIELDS - electric and magnetic fields that change in intensity or strength with time. Examples include 60 Hz, modulated, and transient fields.

TIME-WEIGHTED EXPOSURE - a way of averaging an individual's exposure to an environmental agent over a specified period of time. Specifically, the integration of a monitoring curve of exposure to an environmental agent, divided by the total time the person was exposed. Time-weighted occupational exposures are generally standardized to an 8-hour workday.

TISSUE - an aggregate of cells usually of a particular kind together with their intercellular substance that form one of the structural materials of a plant or an animal.

TRANSCRIPTION - the process of constructing a messenger RNA molecule using a DNA molecule as a template with resulting transfer of genetic information to the messenger RNA.

TRANSDUCTION - 1) The action or process of transducing (to convert [as energy or a message] into another form); especially the transfer of genetic determinants from one microorganism to another by a viral agent (as a bacteriophage). 2) To bring about the transfer (as a gene) from one microorganism to another by means of a viral agent.

TRANSFORMER - a device for changing from one set of voltage and current levels to another.

TRANSMISSION LINES - power lines/wires mounted on metal or wooden structures up to 50 meters in height which transmit (carry) electricity at voltages up to 765 kV and currents of up to 2000 Amperes, from the power station to load centers and substations.

t-TEST - a statistical test used to evaluate whether two arithmetic averages differ when the sample size is small. It is one of several methods that can be used to evaluate whether or not the result of an epidemiologic study is statistically significant. (See STATISTICAL SIGNIFICANCE)

TUMOR - an abnormal mass of tissue that is not inflammatory, arises without obvious cause from cells of preexistent tissue, and possess no physiologic function.

TUMOR REGISTRY - see REGISTRY.

TYPE I ERROR - the rejection of the null hypothesis when it is true.

TYPE II ERROR - the failure to reject the null hypothesis when it is false (alternatively, this is the rejection of the alternative hypothesis when it is true).

ULTRADIAN -A biological activity or function being, having, characterized by, or occurring in periods or cycles of less than 24-hour duration.

VALIDITY - the degree of accuracy of a measurement. The degree to which a measurement measures what it purports to measure. In epidemiology, validity may also refer to the degree to which study results may be generalized to populations beyond the study sample, i.e. external validity.

VARIABLE - any attribute, phenomenon, event, or measure that can assume different values.

VARIANCE - a measure of dispersion of a set of observations defined for a sample as the sum of squares of deviations from the mean divided by one less than the total number of observations. Standard deviation is the square root of the variance. (See STANDARD DEVIATION)

VASOCONSTRICTION - narrowing of the lumen (bore or opening) of blood vessels, especially as a result of vasomotor (nerves or centers controlling the size of blood vessels) action.

VOLTAGE - 1) Electric potential or potential difference expressed in volts. 2) Voltage is a measure of the electric potential energy that makes electric charges flow through a circuit.

WILCOXON TEST - a distribution-free statistical test is used with matched pairs of observations to test the null hypothesis of no difference in the matched populations. This test is commonly used in a pre-post test type study. (See SIGN TEST)

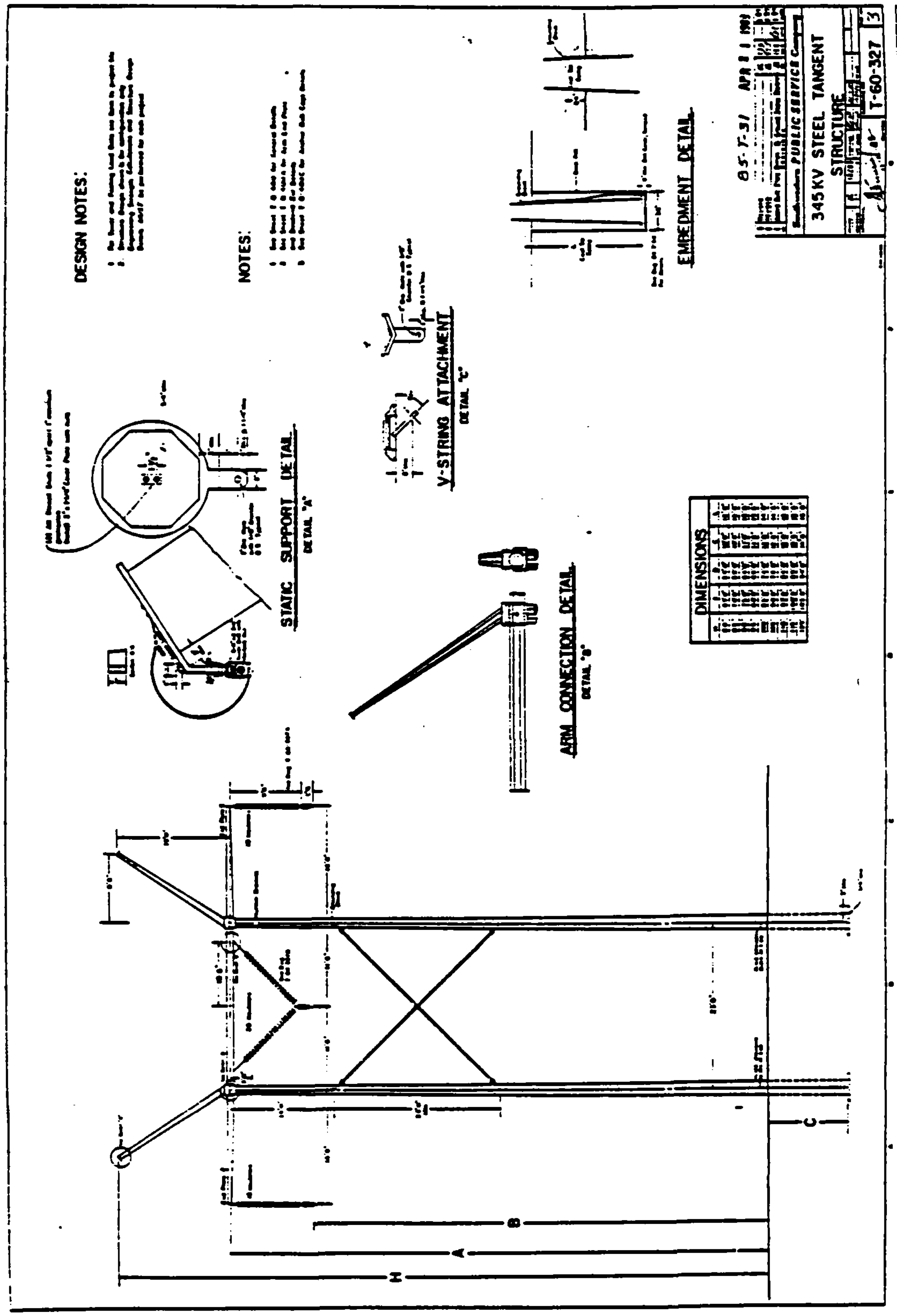
WINDOW EFFECT - for particular values of frequencies and intensities, some electric and magnetic field intensities produce an effect on test organisms/tissues, but others don't.

Conversely, if an effect is observed at a particular value of field, it might be "turned out" by changing the frequency of the field.

"WINDOWED" RESPONSE - **effects found within bands or ranges of frequency or intensity separated by bands or ranges without effect; nonlinear exposure-response relation.**

APPENDIX A COMPUTER CALCULATION OF ELECTRIC AND MAGNETIC FIELDS

A.1 345-KV Transmission Line Configuration



A.2 Corona Electric Field Report

ELECTRIC FIELD CALCULATIONS

SOUTHWESTERN PUBLIC SERVICE CO., 345KV TUCO/OKLAUNION TRANSMISSION LINE

2-795MCM CONDUCTORS/PHASE, 2-3/16" SHIELD WIRE, 33' MINIMUM CLEARANCE

	DIST. FROM REFERENCE (FEET)	HEIGHT (FEET)	MAXIMUM GRADIENT (KV/CM)	SUBCON. DIAM. (IN)	NO. OF SUBCON.	PHASE ANGLE (DEGREES)
PH. A	-27.50	33.00	15.73	1.11	2.	0.
PH. B	.00	33.00	16.71	1.11	2.	-120.
PH. C	27.50	33.00	15.73	1.11	2.	120.
GND	-21.50	58.30	5.76	.38	1.	0.
GND	21.50	58.30	5.76	.38	1.	0.

SENSOR HT. = 3.3 FT.

DIST FROM REFERENCE (FEET)	E-FIELD (KV/METER)	THETA (DEGREES)	EY-FIELD (KV/METER)	THETAY (DEGREES)	EX-FIELD (KV/METER)	THETAX (DEGREES)	SPACE POTENTIAL (VOLTS)
.0	3.324	90.0	3.324	60.0	.769	-30.0	3251.7
10.0	3.302	88.0	3.300	15.6	.906	-67.7	3264.1
20.0	4.258	84.2	4.237	-25.0	.786	-82.6	4198.8
30.0	5.159	88.9	5.158	-42.5	.307	-113.2	5101.4
40.0	4.800	93.3	4.792	-48.5	.294	150.1	4765.7
50.0	3.729	95.7	3.710	-50.4	.370	133.0	3712.4
60.0	2.679	96.5	2.662	-50.8	.302	129.5	2671.7
70.0	1.892	96.5	1.880	-50.7	.213	128.6	1888.8
80.0	1.350	96.2	1.342	-50.4	.145	128.6	1348.7
90.0	.983	95.7	.978	-50.1	.098	128.8	982.6
100.0	.733	95.3	.730	-49.8	.068	129.2	732.2
110.0	.558	94.9	.556	-49.5	.048	129.6	557.7
120.0	.434	94.6	.432	-49.3	.035	130.0	433.5
130.0	.343	94.2	.342	-49.2	.025	130.4	343.1
140.0	.276	94.0	.275	-49.1	.019	130.7	275.9
150.0	.225	93.7	.225	-49.1	.015	131.0	225.1
160.0	.186	93.5	.186	-49.2	.011	131.2	186.0
170.0	.155	93.3	.155	-49.3	.009	131.4	155.5
180.0	.131	93.1	.131	-49.4	.007	131.5	131.3
190.0	.112	92.9	.112	-49.6	.006	131.6	111.8
200.0	.096	92.8	.096	-49.8	.005	131.6	96.1
210.0	.083	92.6	.083	-50.0	.004	131.7	83.2
220.0	.073	92.5	.072	-50.2	.003	131.7	72.5
230.0	.064	92.4	.064	-50.5	.003	131.7	63.6
240.0	.056	92.3	.056	-50.8	.002	131.6	56.1
250.0	.050	92.2	.050	-51.1	.002	131.5	49.7
260.0	.044	92.1	.044	-51.4	.002	131.5	44.3
270.0	.040	92.0	.040	-51.7	.001	131.4	39.7
280.0	.036	92.0	.036	-52.1	.001	131.2	35.7
290.0	.032	91.9	.032	-52.4	.001	131.1	32.2
300.0	.029	91.8	.029	-52.8	.001	130.9	29.2
310.0	.027	91.8	.026	-53.2	.001	130.8	26.5
320.0	.024	91.7	.024	-53.5	.001	130.6	24.2
330.0	.022	91.6	.022	-53.9	.001	130.4	22.1
340.0	.020	91.6	.020	-54.3	.001	130.2	20.3
350.0	.019	91.5	.019	-54.7	.001	130.0	18.6
360.0	.017	91.5	.017	-55.1	.000	129.8	17.2
370.0	.016	91.5	.016	-55.5	.000	129.6	15.9
380.0	.015	91.4	.015	-55.9	.000	129.4	14.7
390.0	.014	91.4	.014	-56.3	.000	129.2	13.7
400.0	.013	91.3	.013	-56.7	.000	128.9	12.7
410.0	.012	91.3	.012	-57.1	.000	128.7	11.8

DIST FROM REFERENCE (FEET)	E-FIELD (KV/METER)	THETA (DEGREES)	EY-FIELD (KV/METER)	THETAY (DEGREES)	EX-FIELD (KV/METER)	THETAX (DEGREES)	SPACE POTENTIAL (VOLTS)
420.0	.011	91.3	.011	-57.5	.000	128.5	11.1
430.0	.010	91.2	.010	-57.9	.000	128.2	10.3
440.0	.010	91.2	.010	-58.3	.000	128.0	9.7
450.0	.009	91.2	.009	-58.7	.000	127.7	9.1
460.0	.009	91.1	.009	-59.1	.000	127.5	8.5
470.0	.008	91.1	.008	-59.5	.000	127.2	8.0
480.0	.008	91.1	.008	-59.9	.000	126.9	7.6
490.0	.007	91.1	.007	-60.3	.000	126.7	7.2
500.0	.007	91.0	.007	-60.7	.000	126.4	6.8

A.3 Corona Magnetic Field Report

B.P.A. CORONA AND
FIELD EFFECTS PROGRAM

INPUT DATA LIST

SOUTHWESTERN PUBLIC SERVICE CO., 345KV TUCO/OKLAUNION TRANSMISSION LINE
2-795MCM CONDUCTORS/PHASE, 2-3/16" SHIELD WIRE, 33' MINIMUM CLEARANCE
1 0 3 5 345.0 10.00 1.00

(ENGLISH UNITS OPTION)

LINE GRADIENTS COMPUTED BY PROGRAM

PHYSICAL SYSTEM CONSISTS OF 5 CONDUCTORS, WHICH 3 ARE ENERGIZED PHASES

MF EF									
4.921	6.562,	9.842	.000	1.000	75.000	3.280	.000		
PH. A	A	-27.50	33.00	2	1.11	18.00	199.2	.0	.00
PH. B	A	.00	33.00	2	1.11	18.00	199.2	-120.0	.00
PH. C	A	27.50	33.00	2	1.11	18.00	199.2	120.0	.00
GND	A	-21.50	58.30	1	.38	.00	.0	.0	.00
GND	A	21.50	58.30	1	.38	.00	.0	.0	.00
51	.0	10.0							
0	.0	.0							

MAGNETIC FIELD CALCULATIONS 1000 AMPS

SOUTHWESTERN PUBLIC SERVICE CO., 345KV TUCO/OKLAUNION TRANSMISSION LINE

2-795MCM CONDUCTORS/PHASE, 2-3/16" SHIELD WIRE, 33' MINIMUM CLEARANCE

	DIST. FROM REFERENCE (FEET)	HEIGHT (FEET)	L-N VOLTAGE (KV)	MAXIMUM GRADIENT (KV/CM)	SUBCON DIAM. (IN.)	NO. OF SUBCON.
PH. A	-27.50	33.00	199.2	15.73	1.11	2.
PH. B	.00	33.00	199.2	16.71	1.11	2.
PH. C	27.50	33.00	199.2	15.73	1.11	2.

SENSOR HT. = 3.3 FT.

D(FT)	B-FIELD (GAUSS/1000AMP)	THETA	BY-FIELD (GAUSS/1000AMP)	THETAY	BX-FIELD (GAUSS/1000AMP)	THETAX
.0	.19058038	61.9	.19058038	-30.0	.10181256	240.0
10.0	.19248731	61.7	.18694734	-49.1	.10044863	197.2
20.0	.18819978	50.3	.15313294	-61.0	.12708905	157.7
30.0	.16792006	28.9	.08363277	-72.1	.15135049	141.1
40.0	.13577562	10.7	.02561703	244.9	.13550900	135.8
50.0	.10378126	16.0	.02892969	163.9	.10060552	134.6
60.0	.07850940	28.0	.03699331	148.8	.06969700	134.9
70.0	.06019853	37.3	.03660011	145.0	.04802834	135.6
80.0	.04714161	44.4	.03305174	143.7	.03374459	136.5
90.0	.03772133	49.9	.02888295	143.4	.02433943	137.5
100.0	.03078302	54.2	.02498904	143.4	.01802359	138.3
110.0	.02555809	57.7	.02161276	143.6	.01367249	139.1
120.0	.02153971	60.5	.01876447	143.9	.01059633	139.8
130.0	.01838965	62.9	.01638242	144.1	.00836824	140.4
140.0	.01587789	65.0	.01439091	144.4	.00671860	141.0
150.0	.01384461	66.7	.01271991	144.7	.00547298	141.5
160.0	.01217648	68.2	.01131021	144.9	.00451575	142.0
170.0	.01079153	69.6	.01011356	145.2	.00376854	142.4
180.0	.00962942	70.7	.00909124	145.4	.00317701	142.8
190.0	.00864495	71.8	.00821231	145.6	.00270278	143.1
200.0	.00780379	72.7	.00745204	145.8	.00231825	143.4
210.0	.00707949	73.6	.00679057	145.9	.00200322	143.7
220.0	.00645141	74.3	.00621188	146.1	.00174271	144.0
230.0	.00590326	75.0	.00570300	146.2	.00152543	144.2
240.0	.00542204	75.7	.00525332	146.4	.00134278	144.5
250.0	.00499731	76.2	.00485416	146.5	.00118815	144.7
260.0	.00462057	76.8	.00449831	146.6	.00105636	144.9
270.0	.00428485	77.3	.00417981	146.8	.00094335	145.1
280.0	.00398442	77.7	.00389366	146.9	.00084590	145.2
290.0	.00371449	78.2	.00363568	147.0	.00076141	145.4
300.0	.00347109	78.6	.00340231	147.1	.00068781	145.5
310.0	.00325084	78.9	.00319054	147.1	.00062339	145.7
320.0	.00305090	79.3	.00299782	147.2	.00056677	145.8
330.0	.00286885	79.6	.00282194	147.3	.00051680	145.9
340.0	.00270261	79.9	.00266100	147.4	.00047254	146.0
350.0	.00255042	80.2	.00251338	147.5	.00043319	146.1
360.0	.00241072	80.5	.00237764	147.5	.00039808	146.3
370.0	.00228220	80.8	.00225256	147.6	.00036668	146.4
380.0	.00216368	81.0	.00213705	147.6	.00033849	146.4
390.0	.00205416	81.2	.00203017	147.7	.00031311	146.5
400.0	.00195275	81.5	.00193107	147.8	.00029021	146.6
410.0	.00185867	81.7	.00183903	147.8	.00026949	146.7
420.0	.00177122	81.9	.00175340	147.9	.00025070	146.8
430.0	.00168981	82.1	.00167358	147.9	.00023361	146.8
440.0	.00161388	82.2	.00159908	148.0	.00021804	146.9
450.0	.00154295	82.4	.00152943	148.0	.00020383	147.0

D(FT)	B-FIELD (GAUSS/1000AMP)	THETA	BY-FIELD (GAUSS/1000AMP)	THETAY	BX-FIELD (GAUSS/1000AMP)	THETAX
460.0	.00147660	82.6	.00146422	148.0	.00019082	147.1
470.0	.00141444	82.7	.00140308	148.1	.00017890	147.1
480.0	.00135612	82.9	.00134568	148.1	.00016795	147.2
490.0	.00130134	83.0	.00129173	148.2	.00015788	147.2
500.0	.00124981	83.2	.00124094	148.2	.00014859	147.3

A.4 Transpac Electric Field Report

ELECTRIC FIELDS ANALYSIS PROGRAM OUTPUT:
SUMMARY OF LINE DATA USED IN CALCULATIONS:

CASE DESCRIPTION:
SOUTHWESTERN PUBLIC SERVICE CO., 345KV TUCO/OKLAUNION TRANSMISSION LINE
AT X AND Y COORDINATES: -27.5000 33.0000
BUNDLE IDENTIFICATION: PHASE A
LINE HAS 2 ACSR 795 26/7 SUBCONDUCTORS

SUBCOND. DIA. = 1.1080 INCHES
BUNDLE SPACING= 18.0 INCHES
NOMINAL VOLTAGE IS 345.0 kV
NOMINAL PHASING IS 0.0 DEGREES

AT X AND Y COORDINATES: 0.000000 33.0000
BUNDLE IDENTIFICATION: PHASE B
LINE HAS 2 ACSR 795 26/7 SUBCONDUCTORS

SUBCOND. DIA. = 1.1080 INCHES
BUNDLE SPACING= 18.0 INCHES
NOMINAL VOLTAGE IS 345.0 kV
NOMINAL PHASING IS -120.0 DEGREES

AT X AND Y COORDINATES: 27.5000 33.0000
BUNDLE IDENTIFICATION: PHASE C
LINE HAS 2 ACSR 795 26/7 SUBCONDUCTORS

SUBCOND. DIA. = 1.1080 INCHES
BUNDLE SPACING= 18.0 INCHES
NOMINAL VOLTAGE IS 345.0 kV
NOMINAL PHASING IS 120.0 DEGREES

AT X AND Y COORDINATES: 21.5000 58.3000
BUNDLE IDENTIFICATION: RIGHT SHIELD
LINE HAS 1 EHS STEEL 3/8 CL A SUBCONDUCTORS

SUBCOND. DIA. = 0.3600 INCHES
CONDUCTORS ASSUMED GROUNDED,
VOLTAGE SET TO ZERO.

AT X AND Y COORDINATES: -21.5000 58.3000
BUNDLE IDENTIFICATION: LEFT SHIELD
LINE HAS 1 EHS STEEL 3/8 CL A SUBCONDUCTORS

SUBCOND. DIA. = 0.3600 INCHES
CONDUCTORS ASSUMED GROUNDED,
VOLTAGE SET TO ZERO.

AVERAGE MAX SUBCONDUCTOR SURFACE GRADIENTS, kV/cm :

PHASE A	15.7 kV/cm
PHASE B	16.7 kV/cm
PHASE C	15.7 kV/cm
RIGHT SHIELD	6.0 kV/cm
LEFT SHIELD	6.0 kV/cm

FIELD IS CALCULATED AT AN ELEVATION OF 3.28084 FEET
MAX E FIELD IS 5.16 KV/M
PLOT IS IN PER-UNIT OF MAX FIELD

0.25 0.50 0.75 1.00

X	E kV/m
0.0	3.33
10.0	3.30
20.0	4.26
30.0	5.16
40.0	4.80
50.0	3.73
60.0	2.68
70.0	1.89
80.0	1.35
90.0	0.98
100.0	0.73
110.0	0.56
120.0	0.43
130.0	0.34
140.0	0.28
150.0	0.23
160.0	0.19
170.0	0.16
180.0	0.13
190.0	0.11
200.0	0.10
210.0	0.08
220.0	0.07
230.0	0.06
240.0	0.06
250.0	0.05
260.0	0.04
270.0	0.04
280.0	0.04
290.0	0.03
300.0	0.03
310.0	0.03
320.0	0.02
330.0	0.02
340.0	0.02
350.0	0.02
360.0	0.02
370.0	0.02
380.0	0.01
390.0	0.01
400.0	0.01
410.0	0.01
420.0	0.01
430.0	0.01
440.0	0.01
450.0	0.01
460.0	0.01
470.0	0.01
480.0	0.01
490.0	0.01
500.0	0.01

A.5 Transpac Magnetic Field Report

MAGNETIC FIELDS ANALYSIS PROGRAM OUTPUT:
SUMMARY OF LINE DATA USED IN CALCULATIONS:

CASE DESCRIPTION:
SOUTHWESTERN PUBLIC SERVICE CO., 345KV TUCO/OKLAUNION TRANSMISSION LINE

EARTH RESISTIVITY SET TO 33.3 OHM-METERS
EARTH PERMITTIVITY SET TO 2.8 (RELATIVE)
EFFECTS OF SHIELD CURRENTS INCLUDED.

AT X AND Y COORDINATES: -27.5000 33.0000
BUNDLE IDENTIFICATION: PHASE A
LINE HAS 2 ACSR 795 26/7 SUBCONDUCTORS

NOMINAL CURRENT IS 1000.0 AMPS
NOMINAL PHASING IS 0.0 DEGREES

AT X AND Y COORDINATES: 0.000000 33.0000
BUNDLE IDENTIFICATION: PHASE B
LINE HAS 2 ACSR 795 26/7 SUBCONDUCTORS

NOMINAL CURRENT IS 1000.0 AMPS
NOMINAL PHASING IS -120.0 DEGREES

AT X AND Y COORDINATES: 27.5000 33.0000
BUNDLE IDENTIFICATION: PHASE C
LINE HAS 2 ACSR 795 26/7 SUBCONDUCTORS

NOMINAL CURRENT IS 1000.0 AMPS
NOMINAL PHASING IS 120.0 DEGREES

AT X AND Y COORDINATES: 21.5000 58.3000
BUNDLE IDENTIFICATION: RIGHT SHIELD
LINE HAS 1 EHS STEEL 3/8 CL A SUBCONDUCTORS

SUBCOND. DIA. = 0.3600 INCHES
SUBCOND. RESISTANCE = 7.1900 OHMS/MI
REAC. AT 1 FT SP. = 1.5200 OHMS/MI
CONDUCTORS ASSUMED GROUNDED,
VOLTAGE SET TO ZERO.
EFFECTS OF SHIELD CURRENTS INCLUDED.

AT X AND Y COORDINATES: -21.5000 58.3000
BUNDLE IDENTIFICATION: LEFT SHIELD
LINE HAS 1 EHS STEEL 3/8 CL A SUBCONDUCTORS

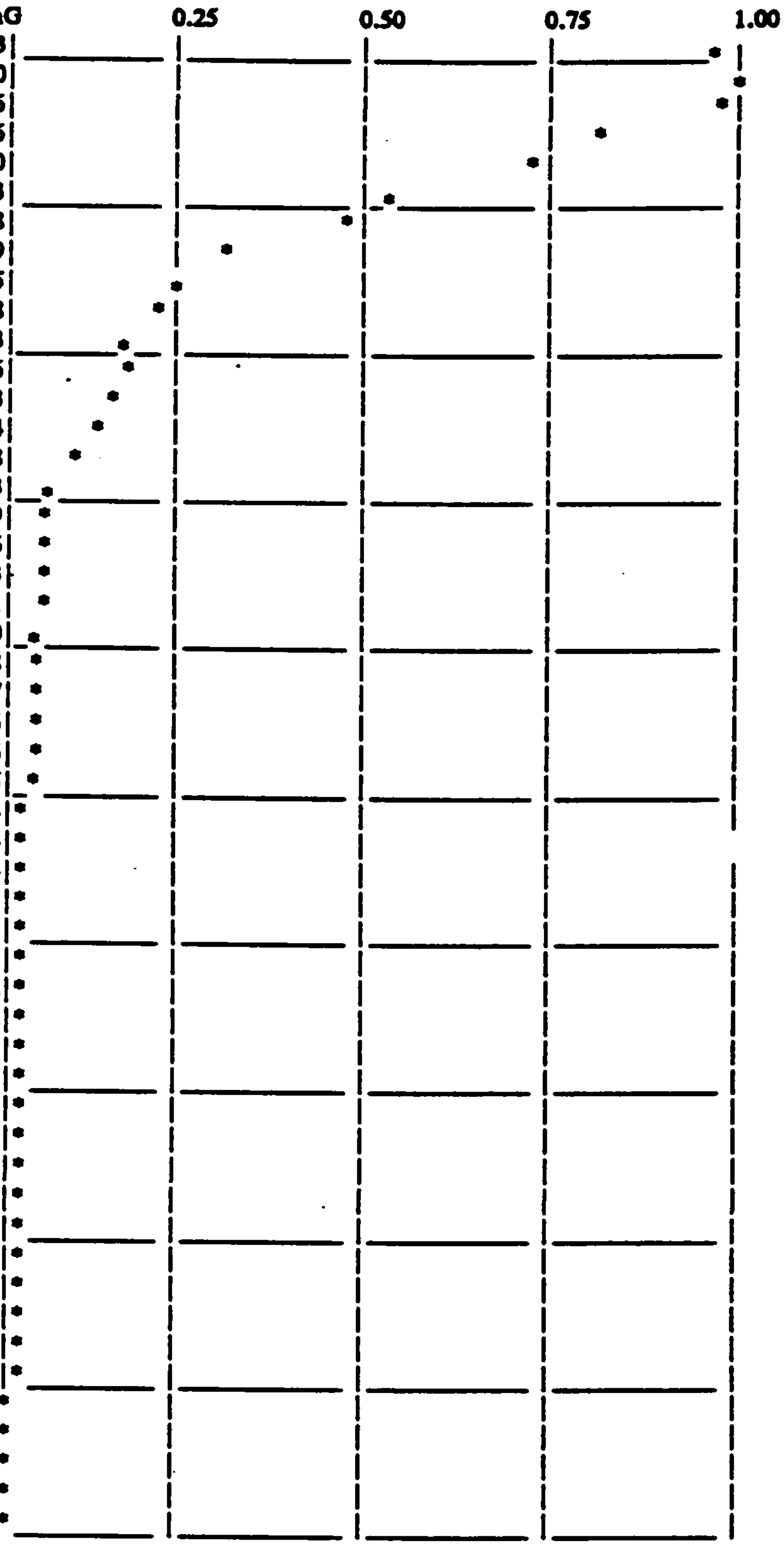
SUBCOND. DIA. = 0.3600 INCHES
SUBCOND. RESISTANCE = 7.1900 OHMS/MI
REAC. AT 1 FT SP. = 1.5200 OHMS/MI
CONDUCTORS ASSUMED GROUNDED,
VOLTAGE SET TO ZERO.
EFFECTS OF SHIELD CURRENTS INCLUDED.

CALCULATED SHIELD CURRENTS ARE:

RIGHT SHIELD 11.0 AMPS
LEFT SHIELD 10.6 AMPS

FIELD IS CALCULATED AT AN ELEVATION OF 3.28084 FEET
MAX B FIELD IS 192.57 mG
PLOT IS IN PER-UNIT OF MAX FIELD

X	B mG
0.0	3.33
10.0	3.30
20.0	4.26
30.0	5.16
40.0	4.80
50.0	3.73
60.0	2.68
70.0	1.89
80.0	1.35
90.0	0.98
100.0	0.73
110.0	0.56
120.0	0.43
130.0	0.34
140.0	0.28
150.0	0.23
160.0	0.19
170.0	0.16
180.0	0.13
190.0	0.11
200.0	0.10
210.0	0.08
220.0	0.07
230.0	0.06
240.0	0.06
250.0	0.05
260.0	0.04
270.0	0.04
280.0	0.04
290.0	0.03
300.0	0.03
310.0	0.03
320.0	0.02
330.0	0.02
340.0	0.02
350.0	0.02
360.0	0.02
370.0	0.02
380.0	0.01
390.0	0.01
400.0	0.01
410.0	0.01
420.0	0.01
430.0	0.01
440.0	0.01
450.0	0.01
460.0	0.01
470.0	0.01
480.0	0.01
490.0	0.01
500.0	0.01



A.6 Expocalc Electric Field Report

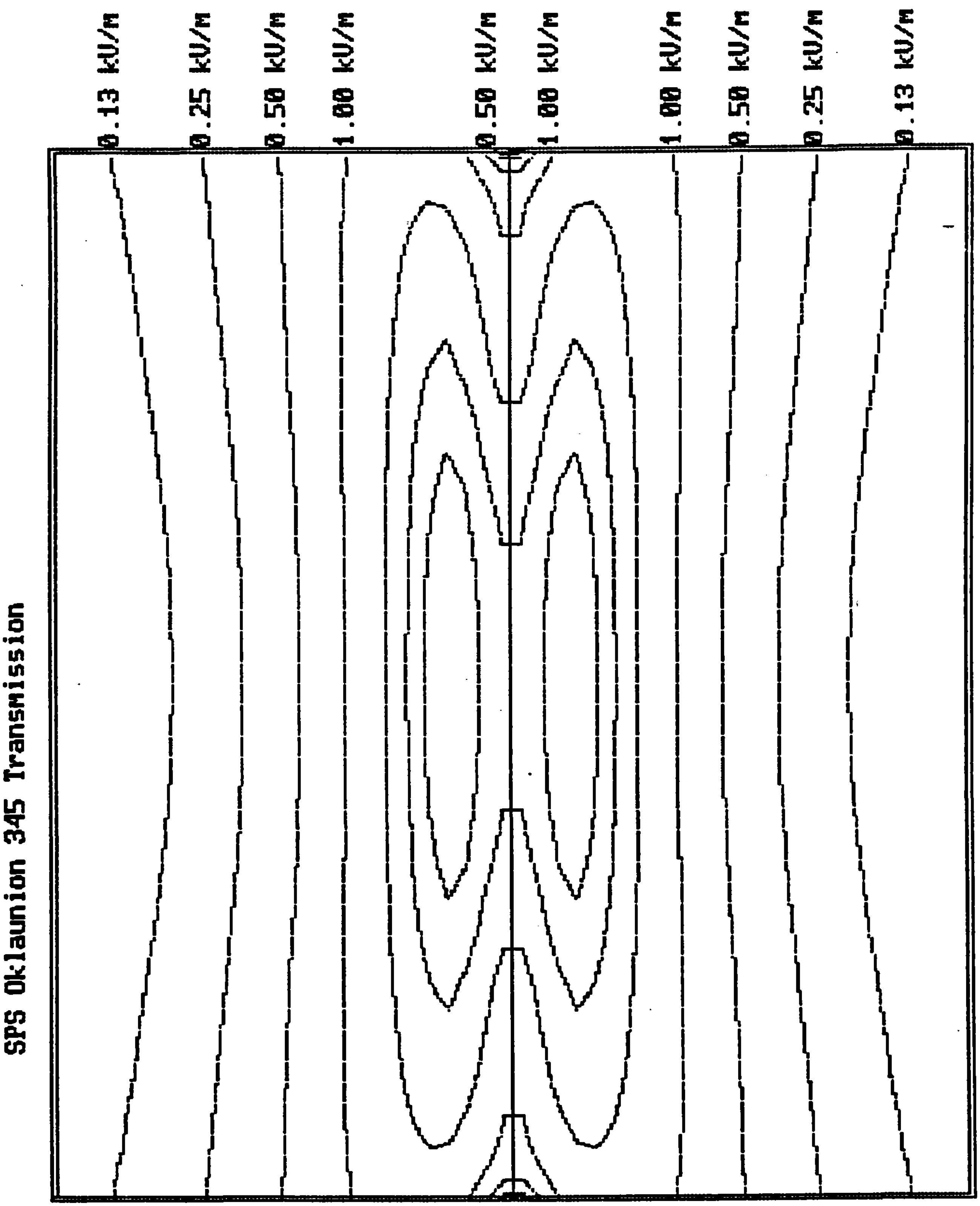
File: sps345ok Date: Fri 2/16/90 Time: 5:51 PM

Electric Field Profiles - kV/m

Sensor Height - 3.28 ft.

Distance from CL (ft)	Ground Clearance(s)-to Center of Bundle or Conductor (ft) 33.0	43.0	53.0	63.0
0	3.324	1.633	0.853	0.460
10	3.302	1.936	1.186	0.759
20	4.259	2.673	1.756	1.196
30	5.159	3.249	2.182	1.528
40	4.800	3.276	2.315	1.684
50	3.729	2.864	2.180	1.669
60	2.679	2.302	1.896	1.537
70	1.892	1.780	1.574	1.349
80	1.350	1.359	1.275	1.148
90	0.983	1.041	1.024	0.962
100	0.733	0.806	0.823	0.800
110	0.558	0.631	0.664	0.664
120	0.434	0.501	0.540	0.553
130	0.343	0.403	0.443	0.462
140	0.276	0.329	0.366	0.389
150	0.225	0.271	0.306	0.329
160	0.186	0.226	0.257	0.280
170	0.156	0.190	0.218	0.240
180	0.131	0.162	0.187	0.207
190	0.112	0.138	0.161	0.179
200	0.096	0.119	0.140	0.156
210	0.083	0.104	0.122	0.137
220	0.073	0.091	0.107	0.121
230	0.064	0.080	0.094	0.107
240	0.056	0.071	0.084	0.095
250	0.050	0.063	0.075	0.085
260	0.044	0.056	0.067	0.076
270	0.040	0.050	0.060	0.069
280	0.036	0.045	0.054	0.062
290	0.032	0.041	0.049	0.056
300	0.029	0.037	0.044	0.051
310	0.027	0.034	0.040	0.047
320	0.024	0.031	0.037	0.043
330	0.022	0.028	0.034	0.039
340	0.020	0.026	0.031	0.036
350	0.019	0.024	0.029	0.033
360	0.017	0.022	0.026	0.031
370	0.016	0.020	0.024	0.028
380	0.015	0.019	0.023	0.026
390	0.014	0.017	0.021	0.025
400	0.013	0.016	0.020	0.023
410	0.012	0.015	0.018	0.021

Distance from CL	Ground Clearance(s)-to Center of Bundle or Conductor (ft)			
420	0.011	0.014	0.017	0.020
430	0.010	0.013	0.016	0.019
440	0.010	0.012	0.015	0.018
450	0.009	0.012	0.014	0.016
460	0.009	0.011	0.013	0.015
470	0.008	0.010	0.012	0.015
480	0.008	0.010	0.012	0.014
490	0.007	0.009	0.011	0.013
500	0.007	0.009	0.011	0.012
510	0.006	0.008	0.010	0.012


SPS Oklaunion 345 Transmission
0.13 kV/m
0.25 kV/m
0.50 kV/m
1.00 kV/m
0.50 kV/m
1.00 kV/m
1.00 kV/m
0.50 kV/m
0.25 kV/m
0.13 kV/m

A.7 Expocalc Magnetic Field Report

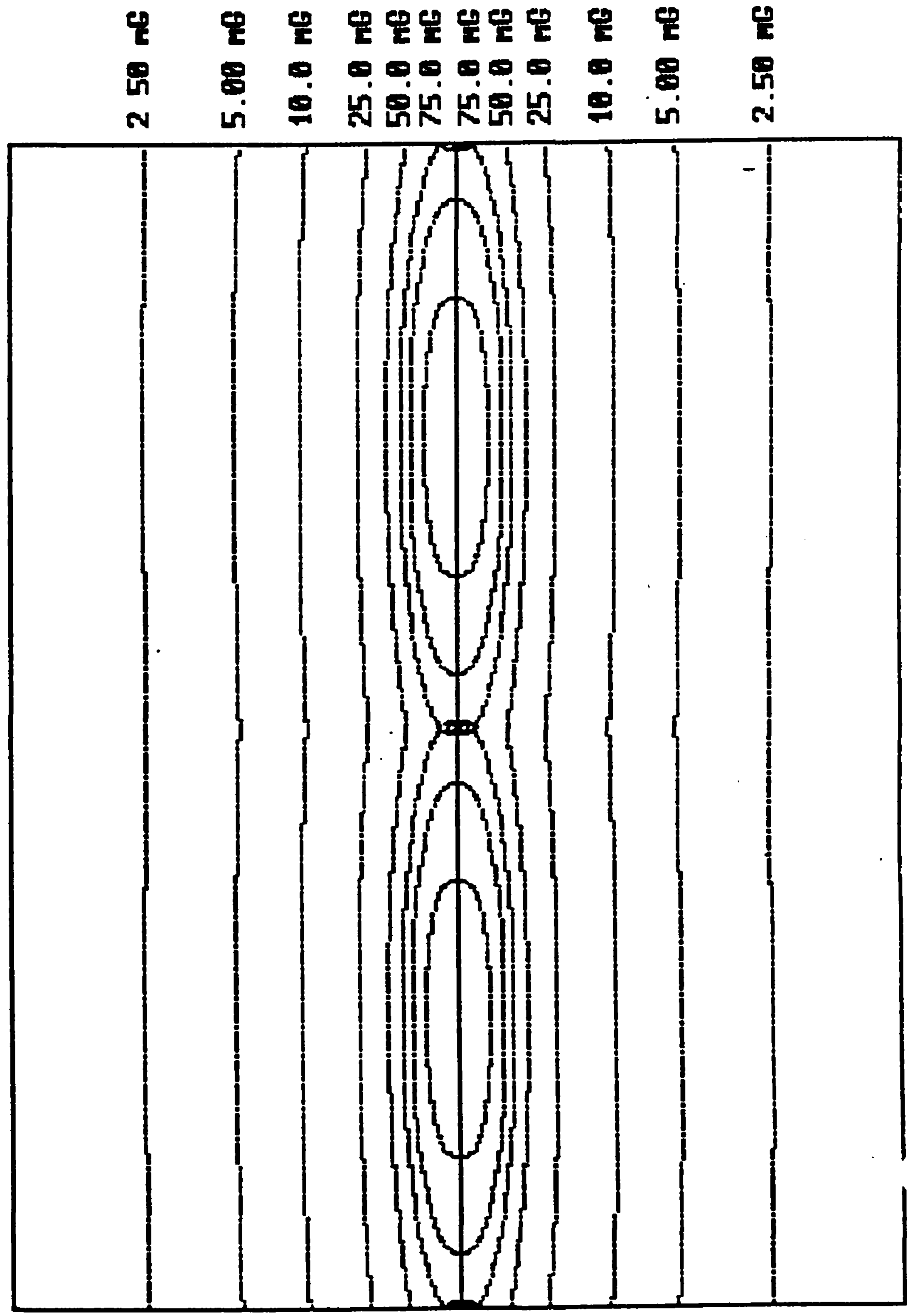
File: sps345ok Date: Fri 2/16/90 Time: 5:52 PM

Magnetic Flux Density Profiles - mG

Sensor Height - 3.28 ft.

Distance from CL (ft)	Ground Clearance(s)—to Center of Bundle or Conductor (ft)			
	33.0	43.0	53.0	63.0
0	190.58	133.88	96.79	72.28
10	192.49	132.47	95.39	71.27
20	188.20	126.61	90.97	68.26
30	167.92	114.54	83.43	63.43
40	135.78	97.78	73.61	57.26
50	103.78	80.11	62.99	50.48
60	78.51	64.44	52.92	43.77
70	60.20	51.77	44.15	37.61
80	47.14	41.94	36.86	32.22
90	37.72	34.39	30.95	27.63
100	30.78	28.57	26.18	23.79
110	25.56	24.04	22.35	20.59
120	21.54	20.46	19.24	17.93
130	18.39	17.61	16.70	15.72
140	15.88	15.30	14.61	13.86
150	13.84	13.40	12.88	12.29
160	12.18	11.84	11.43	10.97
170	10.79	10.53	10.20	9.84
180	9.63	9.42	9.16	8.86
190	8.64	8.48	8.27	8.02
200	7.80	7.67	7.50	7.30
210	7.08	6.97	6.83	6.66
220	6.45	6.36	6.24	6.10
230	5.90	5.82	5.73	5.61
240	5.42	5.36	5.27	5.17
250	5.00	4.94	4.87	4.79
260	4.62	4.57	4.51	4.44
270	4.28	4.24	4.19	4.13
280	3.98	3.95	3.90	3.85
290	3.71	3.68	3.64	3.60
300	3.47	3.44	3.41	3.37
310	3.25	3.23	3.20	3.16
320	3.05	3.03	3.00	2.97
330	2.87	2.85	2.83	2.80
340	2.70	2.69	2.67	2.64
350	2.55	2.54	2.52	2.50
360	2.41	2.40	2.38	2.36
370	2.28	2.27	2.26	2.24
380	2.16	2.15	2.14	2.12
390	2.05	2.04	2.03	2.02
400	1.95	1.94	1.93	1.92

Distance from CL (ft)	Ground Clearance(s)—to Center of Bundle or Conductor (ft)			
	33.0	43.0	53.0	63.0
410	1.86	1.85	1.84	1.83
420	1.77	1.76	1.76	1.74
430	1.69	1.68	1.68	1.67
440	1.61	1.61	1.60	1.59
450	1.54	1.54	1.53	1.52
460	1.48	1.47	1.47	1.46
470	1.41	1.41	1.40	1.40
480	1.36	1.35	1.35	1.34
490	1.30	1.30	1.29	1.29
500	1.25	1.25	1.24	1.24
510	1.20	1.20	1.19	1.19



SPS Oklaunion 345 Transmission

A.8 Comparison of Programs' Calculated Results

	ELECTRIC FIELD STRENGTH			MAGNETIC FIELD FLUX DENSITY		
Distance (ft.)	E-field BPA (V/m)	E-field Expocalc (V/m)	E-field Transpac (V/m)	Bfield BPA (mG)	Bfield Expocalc (mG)	Bfield Transpac (mG)
0	3324	3324	3330	190.6	190.6	190.4
2	3316	3316	3320	190.7	190.7	190.6
4	3294	3294	3290	191.1	191.1	191.0
6	3271	3271	3270	191.6	191.6	191.6
8	3267	3267	3270	192.1	192.1	192.1
10	3302	3302	3300	192.5	192.5	192.6
12	3394	3394	3400	192.6	192.6	192.7
14	3548	3548	3550	192.3	192.3	192.5
16	3755	3755	3760	191.6	191.6	191.8
18	3999	3999	4000	190.2	190.2	190.4
20	4258	4259	4260	188.2	188.2	188.5
22	4512	4512	4510	185.5	185.5	185.8
24	4741	4741	4740	182.1	182.1	182.4
26	4932	4932	4930	178.0	178.0	178.3
28	5073	5073	5070	173.3	173.3	173.6
30	5159	5159	5160	167.9	167.9	168.3
32	5187	5187	5190	162.1	162.1	162.4
34	5160	5160	5160	155.8	155.8	156.2
36	5082	5082	5080	149.3	149.3	149.6
38	4959	4959	4960	142.6	142.6	142.9
40	4800	4800	4800	135.8	135.8	136.1
42	4613	4613	4610	129.0	129.0	129.4
44	4405	4405	4410	122.4	122.4	122.7
46	4185	4185	4190	115.9	116.0	116.3
48	3957	3957	3960	109.7	109.7	110.1
50	3729	3729	3730	103.8	103.8	104.1
52	3503	3503	3500	98.1	98.1	98.5
54	3283	3283	3280	92.8	92.8	93.1
56	3072	3072	3070	87.7	87.7	88.0
58	2870	2870	2870	83.0	83.0	83.3
60	2679	2679	2680	78.5	78.5	78.8
62	2499	2499	2500	74.3	74.3	74.6
64	2331	2331	2330	70.4	70.4	70.7
66	2174	2174	2170	66.8	66.8	67.1
68	2028	2028	2030	63.4	63.4	63.7
70	1892	1892	1890	60.2	60.2	60.5
72	1766	1766	1770	57.2	57.2	57.5
74	1650	1650	1650	54.4	54.5	54.7
76	1542	1542	1540	51.8	51.9	52.1
78	1442	1442	1440	49.4	49.4	49.7

	ELECTRIC FIELD STRENGTH			MAGNETIC FIELD FLUX DENSITY		
Distance (ft.)	E-field BPA (V/m)	E-field Expocalc (V/m)	E-field Transpec (V/m)	Bfield BPA (mG)	Bfield Expocalc (mG)	Bfield Transpec (mG)
80	1350	1350	1350	47.1	47.1	47.4
82	1265	1265	1270	45.0	45.0	45.3
84	1186	1186	1190	43.0	43.0	43.3
86	1113	1113	1110	41.1	41.1	41.4
88	1046	1046	1050	39.4	39.4	39.6
90	983	983	980	37.7	37.7	37.9
92	926	926	930	36.2	36.2	36.4
94	872	872	870	34.7	34.7	34.9
96	822	822	820	33.3	33.3	33.5
98	776	776	780	32.0	32.0	32.2
100	733	733	730	30.8	30.8	31.0
110	558	558	560	25.6	25.6	25.7
120	434	434	430	21.5	21.5	21.7
130	343	343	340	18.4	18.4	18.6
140	276	276	280	15.9	15.9	16.0
150	225	225	230	13.8	13.8	14.0
160	186	186	190	12.2	12.2	12.3
170	155	156	160	10.8	10.8	10.9
180	131	131	130	9.6	9.6	9.8
190	112	112	110	8.6	8.6	8.8
200	96	96	100	7.8	7.8	7.9
210	83	83	80	7.1	7.1	7.2
220	73	73	70	6.5	6.5	6.6
230	64	64	60	5.9	5.9	6.0
240	56	56	60	5.4	5.4	5.5
250	50	50	50	5.0	5.0	5.1
260	44	44	40	4.6	4.6	4.7
270	40	40	40	4.3	4.3	4.4
280	36	36	40	4.0	4.0	4.1
290	32	32	30	3.7	3.7	3.8
300	29	29	30	3.5	3.5	3.6
310	27	27	30	3.3	3.3	3.3
320	24	24	20	3.1	3.1	3.1
330	22	22	20	2.9	2.9	3.0
340	20	20	20	2.7	2.7	2.8
350	19	19	20	2.6	2.6	2.6
360	17	17	20	2.4	2.4	2.5
370	16	16	20	2.3	2.3	2.4
380	15	15	10	2.2	2.2	2.3
390	14	14	10	2.1	2.1	2.1
400	13	13	10	2.0	2.0	2.0
410	12	12	10	1.9	1.9	1.9

	ELECTRIC FIELD STRENGTH			MAGNETIC FIELD FLUX DENSITY		
Distance (ft.)	E-field BPA (V/m)	E-field Expocalc (V/m)	E-field Transpac (V/m)	Bfield BPA (mG)	Bfield Expocalc (mG)	Bfield Transpac (mG)
420	11	11	10	1.8	1.8	1.9
430	10	10	10	1.7	1.7	1.8
440	10	10	10	1.6	1.6	1.7
450	9	9	10	1.5	1.5	1.6
460	9	9	10	1.5	1.5	1.6
470	8	8	10	1.4	1.4	1.5
480	8	8	10	1.4	1.4	1.5
490	7	7	10	1.3	1.3	1.4
500	7	7	10	1.2	1.3	1.3

APPENDIX B - FUNDAMENTALS OF EPIDEMIOLOGY[1]

B.1 Epidemiologic Methods

Epidemiology is generally defined as the study of the distribution of disease in human populations and the determinants of that distribution. Characteristics of people and their environment may be examined for possible causal associations with the occurrence of human disease.

Because epidemiology draws its conclusions from observations of the natural distribution of disease, it possesses both unique strengths and limitations. Since humans are the subjects of study, epidemiology avoids the problem of extrapolating from animal experiments in which both the exposure conditions and the appropriateness of the animal model are often questioned.

On the other hand, epidemiologic research generally provides less conclusive findings than laboratory research does. The inability of epidemiologic research to offer direct proof of a cause-and-effect relationship results from its observational methodology. In a laboratory investigation of a suspected harmful agent, it is assumed that the animals under study differ only on the basis of their exposure regimen. Any ensuing differences that are found between exposed and non-exposed animals can then reasonably be attributed to the exposure itself. Since obvious ethical and practical prohibitions on experimentation with humans exist, data must be collected on the "natural" occurrence of the disease and agent under study in human populations. However, human exposure to an agent is not a random phenomenon occurring among members of a homogeneous population. Exposed and non-exposed groups will differ in terms of age, residence, occupation, gender, and many other factors. Some of these variables are known to influence disease occurrence and can be accounted for in the design or analysis of a study.

Other factors associated with both the disease and the exposure may not be known to the investigator and, therefore, cannot be accounted for. Such "confounding" factors may lead to an incorrect interpretation of the relationship between the agent and the disease under study.

Other examples of the methodology problems that can alter or bias observational studies include: uncertainties in determining the actual exposure status of individuals, variations in disease definitions and diagnoses in different geographic areas or in different hospitals, loss of study subjects who leave the area, unwillingness of subjects to participate, and inaccuracies in frequently used data sources such as death certificates and clinical records. Practical solutions to many of these problems have been developed by epidemiologists, although frequently these sources of bias are not adequately addressed.

Although each epidemiologic investigation poses its own unique problems and solutions, the overall approach of a study generally follows one of a several basic study designs. The choice of a study design will depend on many factors such as time and cost limitations, frequency of the disease(s) to be studied, frequency of the exposure, intended use of the information, and the availability of required data. Several commonly used designs are described below, along with a brief consideration of their particular advantages and limitations.

The terms incidence and prevalence will be used in the following descriptions of epidemiologic study designs. These two commonly used measures of disease occurrence have distinctly different meanings in epidemiology. In a population-based study, the prevalence of disease is the proportion of individuals in a population with the disease at a given point in time. For example, the number of persons with lung cancer in a population of 100,000 on December 31, 1989 might be 30. The prevalence of lung cancer in this population at this point in time is 30/100,000 or, .0003. This figure would include *all* persons with lung cancer on December 31, regardless of whether the person has had the disease for one day or three years. Prevalence is dimensionless, i.e., it has no units.

In a case-control study, on the other hand, disease defines the two types of individuals to be studied, those with disease (cases) and those without (controls). Here, the concern is to compare these two types of individuals with respect to the proportion having a history of an exposure or characteristic of interest. For example, in a case-control study of persons with lung cancer, it would be of interest to compare the proportion having a history of cigarette smoking in case and control subjects.

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[1] •Source: Based on materials initially prepared by Robert S. Banks, R.S. Banks Associates, Inc. for Electric Power Research Institute Seminar on New EMF Epidemiologic Results and Their Implications, October 16-19, 1990. Substantial revisions and additions have been made by Boji Huang, M.D., and P.A. Buffler, Ph.D., University of Texas Health Science Center at Houston, School of Public Health, and R. A. Beauchamp, Texas Department of Health.

In contrast to prevalence, incidence is a measure of the *new* cases of disease occurring in a population in a given time interval. If 15 of the 30 persons with lung cancer in the previous example were first diagnosed in 1989, the incidence of lung cancer in this population would be 15 per 100,000 *per year* (also written 15/100,000/yr or 15 per 100,000 person-years). The dimension of time is the defining characteristic of incidence, making this measure of disease occurrence a *rate*. The term rate always implies that the measurement of disease or death in a population is related to a specified period of time. Thus, although some scientists refer to prevalence as prevalence rate, the expression is a misnomer.

Cross-Sectional or Prevalence Studies

Cross-sectional studies examine factors of interest in a defined population at a particular point in time. The study group may represent a random sample of a community, working at a particular occupation, or a sample chosen on the basis of some sociological or environmental variable. Through a questionnaire, physical examination and/or other means, the presence or absence of the disease(s) in question is determined for each individual, along with other characteristics or exposures of interest (e.g., age, whether the person smokes, exercise level, blood pressure, diet).

Some of the advantages of cross-sectional studies include:

- They can generally be performed relatively quickly and inexpensively.
- They provide valuable descriptive information on the existing patterns of disease occurrence.
- They can examine a variety of factors and diseases simultaneously.

The major limitations include:

- The "snapshot" approach may not allow one to determine whether exposure actually preceded development of the disease.
- Diseases that generally have a longer duration are more likely to be detected than diseases with the same incidence rate but with a shorter duration. Thus an association between an exposure and a disease of short duration may be missed.
- Individuals who survive longer with a disease are more likely to be found than those with shorter survival times. Therefore, the cases with short survival will not be available for study; thus, remaining cases may not be typical of all cases and a potential association between exposure and disease may be masked or exaggerated.

Cohort Studies

Cohort Studies start with the selection of groups of disease-free individuals on the basis of some exposure variable. Exposed and non-exposed individuals are then followed-up to determine subsequent development of disease. There are two types of cohort or follow-up studies: prospective (or concurrent) and retrospective (or nonconcurrent or historical). These two types differ in terms of when exposure and disease occur in relation to the onset of the study.

Prospective (Concurrent) Cohort Studies. Prospective cohort studies are most similar to the classic laboratory study. These studies first identify a group of persons (cohort) who are currently free of disease, but who differ in terms of exposure to the agent under study. For example, the cohort may be a specified group of reproductive-age women, and the exposure variable may be the use of oral contraceptives. The cohort is then "followed-up" at some future time to determine the occurrence of disease(s) in the cohort. How soon follow-up begins or the length of time it must be conducted, depends on the disease outcome(s) of interest and their characteristics (e.g., induction or latency periods). Incidence can then be compared in exposed and non-exposed groups. These rates, which must be adjusted for differences in age and other characteristics of the study subjects, are typically expressed as a ratio or "relative risk" for the exposed group.

The advantages of prospective cohort studies are significant:

- They allow the direct determination of incidence among exposed and non-exposed groups. This permits calculation of the increased disease risk (relative risk) associated with the exposure. They also permit calculation of the "attributable risk," which is that portion of the incidence of a particular disease that is due to a specific cause.
- They may yield more extensive and more reliable data on exposure levels, as well as on confounding factors (e.g., cigarette smoking).
- Many different disease outcomes can be investigated in a single study.

- Relatively rare exposures (or occupations) can be investigated.

Prospective cohort studies also have a number of limitations:

- They often require many years of follow-up since many diseases have long latencies.

- A very large cohort and/or a long follow-up period would be required to investigate relatively rare diseases, including most cancers.

- Substantial effort and expense are necessary to follow a large number of people over a long period of time.

There are no known EMF prospective cohort studies.

Retrospective (Historical or Nonconcurrent) Cohort Studies. Retrospective cohort studies differ in that both the exposure and the follow-up period have occurred prior to the onset of the study. These studies utilize data from existing records such as occupational records, professional registries, and death certificates to identify the cohort and conduct the follow-up. Studies of occupational groups are most often conducted using this approach. As with prospective studies, the cohort is first defined on the basis of exposure status. For example, the cohort may be defined as all the members of a particular occupation or all employees at Company X as of some specified time in the past. The subsequent occurrence of disease in the cohort (up to the time of the study) is then ascertained, generally by using death certificates. To reduce costs, an unexposed cohort is often not identified for comparison; instead, the mortality experience of the exposed group is usually compared to that experienced by the general population in the state, region or country from which the study population was derived.

The advantages of retrospective cohort studies include:

- Much less time and less cost is required to complete the study compared to a prospective study, since the disease outcome has already occurred.

- These studies are widely used in occupational settings, where personnel records, industrial hygiene data and other records can be used both to construct the cohort and establish some rough measures of exposure.

The limitations of retrospective cohort studies include:

- Past exposures cannot be defined as precisely as current exposures. For example, it may be difficult or impossible to estimate exposures to workers that occurred 40 years ago if no industrial hygiene data are available and work practices have changed over time.

- Little information may be available on confounding factors, such as smoking history.

- It may difficult to select a suitable population to which the cohort can be compared. Frequently, the study results will differ depending on whether national, regional, or local disease rates are used as the comparison. The problem of a suitable comparison population is avoided in large cohort studies in which internal comparisons can be made, i.e., a particular category of workers within the cohort can be compared to the complete cohort.

Some cohort studies involve both prospective and retrospective components. For example, a cohort may be defined through personnel and other records as everyone who worked at Company X at least one month between 1945 and 1985. The mortality experience of this population as of 1986 (the time the study is undertaken) can then be determined using state and national mortality records. Additional follow-up of this cohort might then be conducted in 1990 or 1995, for example.

Milham, 1988 is a cohort of amateur radio operators. Lund, 1985 is a modified cohort study in which electric worker union members were followed for six years to determine their leukemia risk. This study was designed only to be a screening tool however, and the rigorous methods generally used in cohort studies to ascertain and validate completeness of the cohort, cause of death, and exposure were not employed. Two case-control studies of electrical workers have been derived from large cohort studies that were not concerned specifically with persons working in electrical occupations (Stern et al., 1986 and Gilman et al., 1985).

Case-Control Studies

This is the most common study design used in epidemiology. As outlined above, cohort studies first identify the exposure status of non-diseased individuals, then determine the subsequent incidence of disease in the cohort. In contrast, case-control studies begin by first identifying individuals who have developed the disease under study (cases) and individuals without the disease (controls). Cases can be selected through hospitals, disease registries, health maintenance organizations, physician's practices, or even through death certificates. Controls may be selected from individuals who are "patients" at the same neighborhood as the cases, or who live in the same hospital as the cases, or from other sources. An attempt is then made to compare the previous exposure experience of the cases with that of the control subjects. Certain factors that can influence disease rates (e.g., age) must be taken into account in the design or analysis of these studies.

Case-control studies offer several advantages:

- They are generally much faster and less expensive to undertake than prospective cohort studies.
- Sample sizes can be much smaller than cohort studies, particularly in the case of relatively uncommon diseases. Whereas a cohort size of tens or hundred of thousands might be required to demonstrate some cancer risk, several hundred or even fewer subjects in a case-control study might be sufficient to reveal the risk. For very rare diseases, the only practicable study design is a case-control study.
- A variety of previous exposure variables can be (and usually are) examined in a single study.

Case-control studies have a number of limitations as well:

- The cases selected for inclusion in the study may not actually be representative of all those who develop the disease. For example, the selected cases may represent only those individuals who entered particular hospitals, and these cases may differ from non-hospitalized cases.
- It is often difficult to select an appropriate control group that is sufficiently comparable to the cases as well as representative of the general population from which the cases arise. Comparability and representativeness are both important yet sometimes mutually exclusive goals in selecting controls. In some studies, two different control groups have been utilized (e.g., hospital controls and neighborhood controls). Many of the controversies in epidemiology arise from case-control studies in which the appropriateness of the controls is questioned.
- It is difficult or impossible to ascertain accurate exposures that have occurred in the past.
- These studies are inefficient for studying rare exposures.

Many EMF studies are of case-control design, including Wertheimer and Leeper, 1979; Fulton et al., 1980; Gilman et al., 1985; Savitz et al., 1988; and Nasca et al., 1988.

Proportional Mortality Studies

This study design is frequently used in exploratory or "hypothesis-generating" investigations, usually in occupational settings. The entire study is most often based only on death certificate information: age, sex, race, cause of death, residence, and in most states, usual industry and occupation. Proportional mortality study is conducted, when only the numbers and cases of deaths among the exposed group can be ascertained, but the structure of the population from which the numbers and cases of deaths is unknown.

In a proportional mortality study, the proportion of deaths from a specified cause relative to all deaths among the exposed group is compared with the corresponding proportion in the non-exposed group or a general population. This comparison is done independently of any relationship to the incidence *rate* of the disease in the exposed and unexposed groups, i.e., only *numerator* data are used to make the comparison. For example, a researcher might wish to investigate the hypothesis that EMF exposure is related to leukemia occurrence. Assuming that the job title "power lineman" is an adequate surrogate for exposure to electric and magnetic fields on the job, the researcher could plan a study to find out whether leukemia mortality in these workers was elevated in 1970-79. A relatively quick way to do this would be to identify all power linemen (from death certificates) who died in that time interval, determine what proportion died of leukemia, and compare that proportion with the proportion of persons of similar age and sex in the general population of deaths due to leukemia. The quotient of the proportion in all power linemen divided by the proportion in the general population is called the proportional mortality ratio (PMR).

A similar type of study might also be done using incidence data from a disease registry such as a regional cancer registry. Such a study is referred to as a proportional incidence study, and a proportional incidence ratio (PIR) shows the observed-to-expected ratio of cases. The population of this type of study consists of those with cancers newly identified in a specified time period, and the study data is derived from the registry medical records. As with the mortality data, the proportions of cancers of different types can be compared among different occupational groups (if occupational data are available in the record).

PMR studies have the following advantages:

- They can be conducted very quickly and inexpensively, especially if the relevant data are already computerized (as they often are).
- Many different occupations and causes of death (or types of cancer) can be examined simultaneously.
- They can provide many useful leads for possibly relationships between disease and occupation that can be investigated by more powerful study methods.

PMR studies also have some severe limitations:

- Unlike a cohort study, no information is collected on the population "at risk"; only on those already deceased. Therefore, no disease rates can be calculated. An elevation in the PMR may be due either to an increase in mortality from the cause of concern *or* to a reduction in mortality from another cause. For example, a PMR for leukemia may be elevated in power linemen because they are actually at increased risk of leukemia, *or* because they have lower risk of some other common disease such as heart disease.

Information on confounding factors (such as smoking) is usually not available.

- Accuracy and completeness of information obtained from death certificates or medical records is variable (see below).
- Study results can sometimes differ quite significantly when compared to results of more definitive studies such as cohort studies, especially if the overall mortality rates differ substantially among the groups (occupations) being compared.

Some examples of EMF proportional mortality studies are Wright et al., 1982; Coleman et al., 1983; McDowall, 1983; Calle and Savitz, 1985; Milham, 1985; and Pearce et al., 1985.

Cluster Studies

A cluster of disease cases (e.g., leukemia) is generally considered to be an unusually high number of cases appearing in the same setting (e.g., neighborhood, town, work place) over a limited period of time. Considerable attention has been given to the study of disease clusters, particularly cancer clusters, and a number of statistical methods have been developed to analyze them. Nevertheless, no non-infectious agent has ever been consistently implicated in causation of any type of cancer by cluster analyses.

Cancer clustering is therefore generally thought to be the result of random (i.e., non-uniform) distribution of disease cases in a population. Thus, even when a significant elevation of a disease is noted for a specified time and place, it is very likely a statistical artifact and not the result of the cases' exposure to an agent in their environment. For example, three new cases of leukemia might occur in a community of 4,000 person in a five-year period, and this incidence might be significantly ($p = 0.04$) elevated relative to the incidence in a comparison population for the same time period. But such a cluster might not be unusual. The calculations used to determine the statistical significance of the increased incidence of leukemia imply that if there are 1,000 communities of 4,000 persons in the country, 20 or 40 communities throughout the country (depending on the type of statistical test used) might have an elevated incidence of leukemia due to random statistical variation alone. Thus, such a cluster, while "statistically significant," would not be all that rare. It is also unlikely that similar environmental agents, leukemia subtypes, or age or gender distributions of the cases would be found in these 20 or 40 communities.

It is possible that a cluster of cancer cases may be related to the presence of an environmental carcinogen. The fact that no such relationship has been established through cluster analysis may in apart be due to the fact that cancer clusters generally consist of so few cases that it is not possible to test a hypothesis relating an environmental carcinogen to cancer risk. Thus, the size of the population being studied is generally insufficient to yield statistically significant results.

An example of a cluster study is Aldrich et al., 1984.

B.2 Sources and Validity of Data

In any scientific study, careful attention must be given to the validity and reliability of the data. Unfortunately, all data collection methods involve some degree of inaccuracy and variability. These data quality problems are addressed in scientific studies by such means as full descriptions of data collection techniques, calculation of likely or potential measurement errors, validation procedures, and replication of measurements.

Because of the wide variety of epidemiologic data sources, professionals outside the field may find it difficult to judge the validity, utility, reliability, and limitations of these data. Data on exposure of study subjects, for example, may range from direct measurements of chemicals or their metabolites within the body to the relatively imprecise information on a decedent's exposure history taken from interviews with next-of-kin.

The following discussion briefly describes the major sources and limitations of epidemiologic data, with particular emphasis on determination of exposure and disease status. The overall consequences of data inaccuracies are also briefly considered.

Data Sources

Population Data. Census data are collected by the U.S. Department of Commerce, Bureau of the Census, every 10 years, and provide age, race, and sex-specific counts for persons living in the various geographic subdivisions of the U.S. plus certain additional demographic, socioeconomic, and household characteristics for those individuals. Census information is collected, analyzed, and presented for the country as a whole and for progressively smaller subdivisions such as states, counties, cities, and census tracts within cities. These published data supply the "denominator" (i.e., population at risk) for most commonly reported disease morbidity and mortality rates.

One of the major limitations of census data is that a count taken once every ten years will not provide the up-to-date information necessary to accurately describe a growing (or shrinking), highly mobile population. This problem is, to a degree, offset by the Current Population Survey (CPS), which consists of monthly sample assessments of about 50,000 homes. However, there are many areas in the county in which the population does not behave as expected and in which population projections are significantly in error by the end of the decade. Such errors in the denominator (population at risk) of a rate calculation can cause the rate to be significantly in error also. For example, if population growth has been higher than expected, morbidity or mortality rates may appear artificially elevated for that area.

Environmental Measurements. A variety of environmental measurements may be used to provide data on exposure levels either in the community or in the work place. Data

are sometimes available for specific industries from industrial hygiene surveys. These environmental measurements, coupled with detailed work histories (usually available from personnel records) are frequently used to establish exposure categories for individuals. Environmental levels can also be measured as part of the study.

The use of environmental measurements can involve several potential problems. Complete data may not be available on past exposure, particularly if it occurred many years ago as is often the case in occupational studies. Even when data are available on past or current exposures, the measurement errors associated with a particular sampling method must be considered.

Another problem with environmental measurements in their relevance to *personal* exposure levels. Different individuals who live in the same community or work at the same job may experience quite different exposure to the same agent. More relevant personal exposure measurements may be obtained by the use of personal dosimeters, such as radiation film badges. However, even these "personal" measurements are not always an accurate indication of the biologically-absorbed dose of an agent. In recent years, considerable attention has been given to identifying markers of exposure in individuals at the molecular or genetic level.

Thus, environmental measurements of an exposure variable are an indirect index of personal exposures. Personal dosimetry provides a more direct measure of exposure, but even here, some degree of error will result in classifying an individual's exposure. Fortunately, misclassification of a comparatively small proportion of individuals does not invalidate a study. Exposure can best be determined if some biological marker of exposure can be identified or if the agent (or an appropriate metabolite) can be measured in the individual. For example, the presence of antibodies to the Hepatitis B virus in the blood can serve as a biological marker of exposure to that virus. Lead levels in serum or in teeth can give a measure of either short-term or chronic exposure to lead, respectively.

State or Local Health Departments. Nearly all states have some form of infectious disease reporting law requiring physicians, hospitals, and/or schools to report cases of specific infectious diseases which are considered to be of significant public health importance to that state or to the Centers for Disease Control (CDC) in Atlanta, Georgia. A number of states also have some form of occupational disease reporting law and/or surveillance activities. However, the reporting of such communicable or occupational disease cases to the state or local health department is often neglected by many health professionals, and the reported cases for some diseases often represent only 10 percent or less of the actual cases occurring in that state.

Federal Agencies

Federal agencies, such as the CDC or the National Center for Health Statistics (NCHS), maintain active and/or passive surveillance on a wide variety of infectious and chronic diseases and health status parameters for the various geographic areas of the U.S.

Medical Records. Hospital or clinical records are a frequent source of information for identification or confirmation of study subjects. These records can also provide information about a person's age, sex, race, address and additional relevant medical data.

The information contained in medical records is highly variable in accessibility, accuracy and completeness. Access to medical records, even for scientific research, has been restricted due to privacy and legal concerns in many situations. Another practical problem involves the many judgments that must be made in reviewing and abstracting the data from medical records. Also important in many cases is the considerable variation in the definition and diagnosis of certain diseases. While some diseases can be routinely diagnosed with a higher degree of certainty (e.g., acute leukemia), others are not readily or consistently diagnosed (e.g., Alzheimer's disease). Diagnostic criteria can vary according to the physician, the hospital, and the geographic region.

Both diagnostic criteria and acumen for a particular disease can vary significantly over time. One common procedure for achieving some degree of standardization is to identify and code diseases according to the diagnostic classifications found in the International Classification of Diseases (ICD). Since major revisions of the ICD occur about every ten years, it is important to specify which revision is followed (the 9th revision of the ICD was published in 1978, the 10th in 1990). When medical records are utilized in a study, diagnostic criteria should be explicitly established at the study outset, and these criteria should be clearly reported.

Although hospital medial records or hospital disease indexes occasionally provide valuable sources of disease morbidity data, information based upon hospital admissions is likely to contain significant biases. Many diseases require no medical intervention or the individuals are treated by physicians on an outpatient basis. Consequently, these cases will not appear in any incidence or prevalence data derived from hospital records. Additionally, many selective factors are operative in any hospital admission. Therefore, the population base associated with particular hospitals or with all the hospitals in a given area may be undefined. Finally, hospital-generated statistics are often difficult to collect, in part because of the lack of computerized retrieval systems.

Sources and Limitations of Mortality Data. The most routinely collected and commonly used source of data for surveillance of disease has been mortality data (Kelsey, Thompson and Evans, 1986). Advantages include the fact that these data are readily accessible and inexpensive to use. Since death certificates are required by law in the U.S. and many other countries as well, very nearly all deaths in these countries are reported to the authorities and death certificates are filed. Finally, mortality data have been collected, tabulated, and published annually for many decades and for many different countries of the world so that both temporal and geographical trends may be studied. Few other data bases exist which allow such comparisons.

There are a number of problems and limitations associated with the use of mortality data for epidemiologic studies or as an indicator of frequency of disease. Some of these involve biases in mortality reporting which are dependent on the particular disease. For example, the mortality rates for diseases which have high case fatality rates are more likely to accurately represent the status for that disease than the mortality rates for a disease that less often results in death. In addition, those diseases which are easily diagnosed may be over-represented on the death certificates relative to diseases for which the diagnosis is more difficult.

The cause of death may be inaccurately reported on the death certificate for a number of reasons, including unfamiliarity of the physician with the past medical history of the case. Causes of death which bear some social stigma, such as suicide, sexually transmitted diseases, or abortion-related deaths, may be significantly under-reported on the death certificates. Failure to perform an autopsy may result in totally missing the underlying cause of death. Revisions in the International Classification of Diseases ICD codes or changes in the way diseases are grouped together may lead to apparent sudden changes in the mortality rate for a particular cause of death code. Occasionally, the cause of death is recorded correctly but is then miscoded on the certificate. Sometimes, a diagnostic "label" is more heavily used in one place than in another or diagnostic "fads" may occur which result in the disproportionate assignment of death to a few particular disease codes.

Variations in the quality of medical care over time or from place to place may cause deceptive differences in mortality rates. For example, improvements in diagnostic procedures for a certain disease may result in an apparent increase in the mortality for that disease when it is only the ratio of diagnosed cases to undiagnosed cases that has changed.

Lastly, elderly people may have several active disease processes at time of death, and selection of the underlying cause of death may not be possible or feasible. For this last reason, more and more authorities are recommending the use of multiple-cause coding for death certificates (Kelsey, Thompson and Evans, 1986).

In conclusion, mortality data can, unquestionably, help an epidemiologist to understand fundamental disease trends and relationships and to help generate hypotheses about risk factors and etiologic agents. However, because of the potential problems with reliability, caution should be used in the interpretation of the results of any mortality data analysis. Such findings should be considered preliminary suggesting further exploration through more definitive methods (Kelsey, Thompson and Evans, 1986).

Death certificate data are used frequently in epidemiologic studies not only to ascertain the cause of death, but also it identify the decedent's occupation (a possible indicator of occupational exposures) and certain other demographic data (e.g., age at death, date of death, sex). Several studies have shown that death certificate data vary considerably in accuracy and reliability. Certain causes-of-death are more accurately or more reliably reported on death certificates than are other causes. This variability is due to factors such as uncertain diagnostic criteria for some diseases, the existence of multiple diseases, whether the death occurred in a hospital, and whether an autopsy was performed.

Occupational data from death certificates have even greater variability. Death certificates generally list the decedent's "usual occupation," as reported by family members or other persons. Just as there is no routine confirmation of cause-of-death (i.e., autopsy), there is no verification of occupational information. Studies show that certain occupations are systematically over- or under-represented. For individuals with a multiple-job history, the most recent occupation may be listed, rather than the usual occupation. Thus, except for a decedent who held a single, well-defined occupation and for whom this information is accurately entered on the death certificate, the occupation shown on the death certificate may represent an incomplete and inaccurate characterization of a person's actual occupational history.

Disease Registries. In some areas, disease registries have been established for the surveillance of diseases which are of major concern to public health. Cancer is one such disease entity. In 1972, the National Cancer Institute (NCI) established the Surveillance, Epidemiology, and End Result (SEER) Program which consists of a number of population-based cancer registries from different geographical areas across the country. These SEER registries systematically collect demographic, diagnostic, treatment, survival, and follow-up information, on all patients in the area who are diagnosed as having any of the various forms of cancer.

The term "population-based," as used above, means that the registry has made every effort to enroll every case of cancer that occurred among the residents of a particular geographical area such as a city, county, region, or state. When all (or very nearly all) cases from the geographical area have been ascertained, the "population at risk" is the population of that area, and only then is it possible to calculate a cancer incidence rates. This is in contrast to a "hospital-base" cancer registry which may have enrolled every case of cancer that was diagnosed in (or admitted to) a particular hospital but which has insufficient information to generate cancer incidence rates because the "population at risk" is undefined.

Registries, particularly those for cancer, are becoming a widely-used resource for occupational and environmental studies. The approximately 45 population-based cancer registries in the United States collect data on cancer cases in prescribed geographic areas. Some collect additional data on treatment and follow-up. These systems can be used to identify unusual clusters of cancer cases around a particular environmental exposure, to study occupational hazards, to assess the magnitude of and trends in cancer rates, to identify cases for case-control studies, and to facilitate the ascertainment of cancer among members of a study cohort.

Despite the obvious usefulness of registries, the completeness, timeliness and accuracy of registry data vary substantially from one registry to another, and these can be factors of concern in epidemiologic studies. In addition, limitations on access to personal identities reduces the utility of these data for epidemiologic studies requiring follow-up or record linkage.

Special Disease Surveys or Epidemiologic Studies. With the best of intentions, routinely collected data on illness from hospitals, registries, and other sources do not yield a complete picture of the illness and disability picture of a defined region. More comprehensive data for monitoring the health status of a region are provided by sample surveys, known as morbidity surveys. Such surveys may consist of a single, cross-sectional examination or of long-term (longitudinal) studies in which respondents are revisited periodically. Although the most ambitious of these, the National Health Survey, collects data on all diseases, specific disease states may be surveyed. The NCI has conducted cancer surveys which have yielded basic data on the incidence of cancer by primary site, histologic type, and state of disease at diagnosis. Both leukemias and brain cancers are included in these surveys.

Data on personal factors, exposures, and even disease status are often obtained from in-person or telephone interviews of study subjects or their relatives. The validity and reliability of these data are affected by many factors such as the training and experience of the interviewer(s), the length of the interview, and recency of the events questioned. In short, the quality of data obtained from interviews depends on how carefully the interviews are designed and administered, as well as on the type of information being sought. The information obtained from interviews is frequently confirmed by other data sources (e.g., medical records) to improve its validity.

Mailed questionnaires are another source of data on demographic factors, exposures and health status. As with interviews, the quality of questionnaire data is influenced by many factors including length of the questionnaire, specific wording of the questions, types of questions, motivation of the study subjects, and the perceived importance of the study. Questionnaire data are also frequently confirmed (validated) by other data sources such as medical records.

Impact of Data Errors

As indicated in the previous discussion, the data sources used by epidemiologists are each characterized by potential inaccuracies. These inaccuracies are usually well-recognized by epidemiologists, and efforts are made to limit and/or quantify their extent and magnitude. Inevitably, however, some error remains and must be examined in terms of its impact on overall study validity.

Epidemiologic studies usually involve the comparison of large groups of subjects, often hundreds or thousands of individuals. Study subjects are generally classified according to whether or not they are exposed to the agent in question, as well as according to their disease status. An error in assessing an individual's degree of exposure may affect his relative ranking in the exposed group, but will not necessarily remove him from the "exposed" category. Even if an occasional individual is completely misclassified on exposure, the overall findings are not necessarily invalidated. As long as the exposed *group* has on average a significantly higher exposure level than the non-exposed group, a comparison can still be made and a correct conclusion reached even though the precise exposure-response effect will be somewhat in error.

In general, occasional and random misclassification is likely to reduce the strength of, but not eliminate or reverse, a significant association between exposure and disease. Frequent or systematic misclassification, on the other hand, can obscure or even change the direction of an association, or create an association where none exists.

Sound epidemiologic research strives to identify, assess, and reduce the inevitable inaccuracies in data collection. It is particularly important that frequent or systematic errors be recognized. This is accomplished through the usual scientific means of providing detailed descriptions of data sources, observing rigorous methodologic standards, and confirming data whenever possible.

B.3 Comparability and Bias

A serious threat to the validity of any epidemiologic study is the possibility that its subject selection and data are biased. In epidemiology, "bias" does not imply any prejudice or prejudgment on the part of the study investigators. Rather, "bias" generally refers to systematic errors, i.e., errors other than sampling variability that prevent the true value of a disease rate or other production variable from being obtained. The introduction of bias renders study groups noncomparable in some important way.

To understand how a study can become biased, it is useful to recall the degree to which the laboratory scientist strives to achieve comparability between exposed and unexposed organisms in his/her experiments. This is accomplished by such means as using a single strain of test organism, randomly assigning each organism to an exposure group, maintaining uniform environmental and dietary conditions during the course of the study, and using a consistent protocol for examination. The examination is performed with the investigator "blinded" to the subject's previous exposure history. Failure to achieve any of these major comparability elements can bias a study, and its conclusions must be considered suspect.

In epidemiologic research, utilizing an observational methodology, an equivalent degree of comparability cannot be achieved. The goal of the epidemiologist is to select from an existing population exposed and non-exposed (or diseased and non-diseased) groups that are fundamentally comparable and from which equivalent data can be obtained. Bias can be introduced in numerous ways, some of which cannot be known or controlled by the investigator. The following discussion provides representative examples of biases that can occur in epidemiologic studies.

Biases

Bias can occur in virtually every aspect of epidemiologic research. However, the following examples illustrate only those biases that can arise (1) in the process used to specify or select study participants (selection bias), (2) in the process of collecting data on study participants (observation or information bias), and (3) due to the existence of factors that are associated both with the exposure and the disease (confounding bias). Some types of bias can only occur in a particular study design, while others must be considered a possibility with any design.

Non-Response Bias. Some portion of those who are selected or identified as study subjects cannot or will not participate in the study. Bias can occur when this group of non-respondents differs systematically from respondents with respect to exposure or disease status. For example, non-respondents may have more serious health problems. To minimize this bias, considerable effort must be expended to achieve a high participation rate (e.g., 90 percent or better), or at least to obtain a sample of non-respondents to determine if, or how, they differ.

Lost-To-Follow-Up-Bias. A similar type of bias can occur when study participants are "lost-to- follow-up" in cohort studies. Those who are "lost" may differ in their disease outcome, removing from the study, for example, those who had more serious health problems. Significant efforts must be made in cohort studies to keep this proportion as low as possible. It is important to choose a proper study population, such as a group of electrical workers in a company. The workers are more easily located and followed-up.

Detection Bias. This bias refers to the situation in which a disease (such as a brain tumor) is more frequently diagnosed and ascertained in a particular population (such as an occupational group) than in the general population. This may result from better access to medical care. If the general population rates are used as a basis for comparison, it will appear that members of the particular population are at increased risk of the disease. In reality, they are at increased risk only of being diagnosed with the disease. Widespread publicity about some agent may prompt exposed persons to seek medical examination, again increasing the possibility of detection among members of that group.

Healthy Worker Effect. Overall, the working population is healthier than the general population. Less healthy peopled are less likely to become or remain employed; thus employment serves as a selective actor. In occupational studies, therefore, a clear possibility of bias arises if the general population is used as the basis for obtaining expected disease rates as is often done in retrospective cohort studies. The use of general population rates can create the false appearance that employment in an industry actually affords protection against mortality, or at least that there is no excess mortality. This effect is more evident for some diseases than others. For example, it does not appear that overall cancer mortality is typically lower than expected in occupational cohorts when compared to the general population. Cardiovascular disease on the other hand, is typically found to be lower in an occupational cohort than would be expected based on general population rates (McMichael, 1976).

Incidence-Prevalence Bias. Newly diagnosed ("incident") cases of disease may differ in certain characteristics from all existing ("prevalent") cases of the disease. Studies that use prevalent cases are more likely to include longer duration cases and exclude both rapidly fatal and readily cured cases. Consequently, prevalence studies are more likely to yield information relating to disease duration, rather than disease development.

Observation and Measurement Bias. Numerous biases involve non-comparable data or data collection procedures. For example, exposure data obtained from interviews will not be comparable to data obtained from environmental measurements.

Observation bias can also arise when interviews are used to obtain health outcome data. If the interviewer knows a subject's disease status as well as they hypothesis under study, he or she may subconsciously probe harder concerning past exposure. Furthermore, a subject who has been advised of a study's purpose may attempt to provide responses that are perceived as "favorable" or "helpful" to the interviewer. Thus interviews are frequently conducted in a "double-blind" fashion where neither the interviewer nor the subject is aware of the specific hypothesis under investigation.

Disease diagnosis may be influenced by the physician's knowledge of a subject's exposure history. This bias, which applies mainly to cohort studies, will tend to increase the association between exposure and disease.

Recall Bias. A person who has developed a particular disease may be better able to recall previous exposures, compared to control subjects. The mother of a child born with a malformation may better recall (or perhaps exaggerate) exposures experienced during pregnancy, compared to the mother or a healthy child. This is a serious potential basis in case-control studies.

Misclassification Bias. This does not refer to random misclassification of some small proportion of the study population, but to systematic misclassification of disease or exposure status. This could happen if, for example, the job title "electrician" is used to identify subjects occupationally exposed to EMF, and a large portion of these electricians work only on dead circuits, where EMF exposure is low. On the contrary, some other workers, who are identified as "non-electricians", might be exposed to EMF.

Berksonian Bias. This bias, first described by Berkson in 1946, can arise when controls are selected from hospitals (usually the same hospitals from which the cases have been selected). Hospitalized controls are generally not representative of the overall population with respect to certain characteristics; e.g., smoking, alcohol or coffee consumption. In order to detect and prevent Berksonian bias, multiple controls are suggested. Therefore, some case-control studies have used both hospital and neighborhood controls at the same time to delete this bias.

Confounding Bias. Confounding bias occurs when there is a third variable which is not of interest to the study, but it is related both to the exposure and the disease under study. A study of lung cancer, for example, will find a significant association between alcohol consumption and the development of lung cancer. In such a study smoking would be considered a confounding variable since it is associated both with alcohol consumption and lung cancer. If the effect of smoking is removed in the study (by design strategies such as matching, or analytic techniques such as stratification or adjustment), the association between drinking and lung cancer might not remain.

Most epidemiologic studies consider at least several well-established confounding variables such as age, sex, race, and socioeconomic class. Other variables may be examined in a particular study. However, not all variables can be examined; confounding bias is probably present in all data.

Conclusions

Given the difficulty in recognizing and controlling all potential sources of bias, no study should be considered completely free of it. For example, rarely does a study attain 100% follow-up of subjects. Critics can always attribute study findings to some form of bias since there are indeed so many potential sources of bias. However, it is difficult to actually demonstrate that some bias accounts for or even materially affects the study's findings. Strict adherence to established procedures and standards can reduce many, but not all, possibilities for bias. In many well-reported studies, the authors frequently discuss the possible sources of bias in their study and attempt to show, through logic and/or data, that their findings are not likely to be due to some bias. But there still remains the possibility that some unknown bias is operating.

B.4 Association or Causation?

In laboratory research, a well-designed experiment that results in a statistically significant effect (i.e., one not due to chance variation) is usually interpreted as demonstrating a cause-and-effect relationship. The existence of a cause-and-effect relationship cannot be so readily inferred from

observational epidemiologic studies. The epidemiologist, at best, can show that some association or relationship exists between an exposure (e.g., chemical, radiation) and a physiological or health-related effect (e.g., blood chemistry, disease, death). Typically, the epidemiologist further attempts to demonstrate that the association is unlikely to be due to chance and is not due to some third (confounding) variable.

Judging Positive Associations

Scientific "proof" of a cause-and-effect relationship cannot be obtained from an observational study. However, as a practical matter, explicit or implicit judgments of causality are frequently derived from such studies, and strongly influence public health policy. Therefore, it is important to consider epidemiologic findings from a variety of perspectives, such that a reasonable assessment can be made. Epidemiologists have not established hard and fast rules for determining when a positive association should be considered a cause-and-effect relationship. Different experts stress different factors in evaluating associations, and not all agree that certain items are particularly useful. However, certain guidelines arise frequently in discussions of causal relationships, and these are discussed below.

Strength of Association. The more strongly an exposure is associated with a disease, the more likely it is that the exposure causes the disease. Many different measures of association are utilized in epidemiologic studies, depending in part on the type of study conducted. Most are expressed as some ratio comparing or estimating disease risk in the exposed to disease risk in the unexposed. For example, the "relative risk" may be defined as:

- Risk of disease among those exposed
- Risk of disease among those not exposed

The "strength" of the association refers to the magnitude of the risk ratio. Generally, the larger the magnitude of the relative risk, the stronger the association. As an example, smokers are ten times more likely to develop lung cancer than non-smokers (relative risk = 10). This greatly elevated relative risk makes it much less likely that some other variable (confounder) overlooked by the investigator(s) is actually responsible for the association. A very low relative risk, e.g., less than 2.0, would have a greater probability of being due to some study bias or confounding factor.

Although a strong association is very suggestive of a causal relationship, it cannot be argued that a weak association is not causal. It might also be noted here that the strength of an association does not by itself reflect the overall public health impact or importance due to that risk factor.

Other crucial variables are the frequency of the disease associated with the risk factor and the number of people commonly exposed to the risk factor. A risk factor associated with a high relative risk for a relatively rare disease may have less public health impact than a risk factor associated with a lower relative risk for a more common disease. For example, occupational exposure to asbestos has caused many more deaths through lung cancer than through mesothelioma (a rare disease) although the relative risk for mesothelioma is much higher than the risk for lung cancer. And, of course, a risk factor commonly encountered by many people may result in more illness even though it is associated with a low relative risk for disease, than a rarely experienced risk factor with a high relative risk for disease.

Consistency. An association consistently found by different investigators, in different populations, and/or in different geographical areas is more likely to be causal. Although the many studies that have examined lung cancer and smoking have involved many different investigators, study populations, locations, and study designs, all have shown a very strong positive association. It is extremely unlikely that such consistent findings can be the result of some overlooked bias or can occur by chance alone. Some investigators attach special significance to consistent associations found in both retrospective and prospective studies.

Temporal Relationship. Obviously, an exposure must precede a disease if it is even to be considered a possible causative agent. Prospective cohort studies most firmly establish this time sequence. In contrast, cross-sectional (prevalence) studies do not generally permit determination of whether exposures preceded disease development. It may also be difficult to establish the time sequence in some case-control studies in which, for example, a disease may have a very long pre-clinical (non-symptomatic) phase (e.g., asbestos and lung cancer).

Dose-Response Relationship. The existence of a dose-response relationship between exposure level and disease incidence supports a causal interpretation. In other words, those who have the highest exposures should also have the highest disease risks. It has been clearly demonstrated that the number of cigarettes smoked correlates directly with the degree of lung cancer risk.

The absence of an apparent dose-response effect is not considered evidence against causality. Exposures may not have been ascertained accurately enough in studies, leading to misclassification and bias that can obscure a risk gradient. It is also possible that some threshold of exposure is necessary for a given agent before an effect is observed. There is only weak evidence, for example, of a dose-response relationship between occupational asbestos exposure and mesothelioma risk, although there is no doubt about the causal nature of the relationship.

Coherence/Plausibility. A causal hypothesis is supported when an association is consistent with or supported by other known facts and observations. For example, a causative hypothesis is favored if there is some demonstrated or potential biological mechanism by which the effect can be explained. The cellular effects of ionizing radiation have long been recognized and offer a clear explanation for the health hazards of radiation. In the case of cigarette smoking, laboratory studies have identified a variety of organic compounds in inhaled smoke; a number of these compounds have been shown to cause cancer in animal studies. These findings are thus consistent with the human epidemiologic evidence.

The absence of a recognized biological mechanism does not necessarily contradict a causative interpretation. The lack of an apparent mechanism may only reflect an early stage of investigation, a situation well illustrated by the outbreak of toxic shock syndrome. Early epidemiologic findings clearly indicated that the highest risk group consisted of young, menstruating women who used a high-absorbency brand of tampon. However, it was found that some non-menstruating women and some men were also disease victims. Thus, the use of high-absorbency tampons alone obviously could not account for all cases, and there was considerable doubt by some (including the manufacturers) that the tampons could be causally related to the disease. However, the absence of an explanation or recognized mechanism did not prevent withdrawal of the tampons from the market. Some time later an explanation was found: the disease was actually caused by a toxin from a relatively common bacterium. The toxin is only produced under certain physical and biological conditions, conditions which are more likely to occur in young women using high-absorbency tampons.

Specificity. When an association links exposure to a single disease rather than to a broad spectrum of diseases, a causal interpretation is favored. An example of high specificity is the association between occupational exposures to vinyl chloride and angiosarcoma (a rare form of liver cancer). The high specificity, as well as the strength of this association leaves little doubt as to its causative nature.

A lack of specificity, however, does not necessarily argue against causality. For example, cigarette smoking has been associated with a wide range of diseases. In fact, the smoking history of study subjects is almost always considered in well-designed studies of other diseases. This lack of specificity, although still sometimes raised in arguments by the tobacco industry, is not particularly troublesome to epidemiologists since a great many components have been identified in tobacco smoke, and many of these components can be transported through the body to different sites. This rather broad exception to the concept of specificity has led some epidemiologists to consider this guideline useless in determining whether an association is likely to be causal or not.

Conclusions

It is important to emphasize that none of the above factors is sufficient either to prove or disprove that an association represents a true cause-and-effect relationship. They do, however, offer some reasonable guidelines with which both epidemiologists and non-epidemiologists may judge whether a positive association is likely to represent a true cause-and-effect relationship.

B.5 Statistics: Risk Estimates

The following discussion addresses how rates and ratios are used to provide estimates of *risk*, with emphasis on the measures of risk derived from two major study designs: the cohort study and the case-control study.

Risk Measures from a Cohort Study

A cohort study is similar to a laboratory study in terms of the time sequence of events. A study group (cohort) of healthy people is identified and each individual is then classified according to whether he/she is exposed or not exposed to the agent under study. At some later point in time, which may be many years later, the cohort is re-checked (the "follow-up") to identify those study participants how have occurred when the study is initiated depending on the study design. Two risk measures from cohort studies will be described: the relative risk and the standardized mortality ratio.

Relative Risk. From the follow-up data, an actual disease rate can be tabulated separately for both the exposed and non-exposed groups. Depending on the specific disease in question, the rate may be either a morbidity or a mortality rate. As an example, consider that the exposure under study is cigarette smoking and the disease in question is lung cancer. Data from an actual study showed that the lung cancer mortality rate for a particular age-group of non-smokers was 19 deaths per 100,000 per year. In contrast, the rate for smokers in this same age-group was approximately 190 per 100,000 per year.

These rates can be compared in several ways such that a quantified expression of risk can be obtained. The most common measure of risk in this type of study is the *relative risk* (RR). The relative risk indicates the increased (or decreased) degree of risk of disease among the exposed compared to the non-exposed. It provides a measure of the causative importance of the exposure under study. A relative risk with a value of one (1.0) indicates no association between the exposure and the disease.

The relative risk is calculated as follows:

$$\text{Relative Risk (RR)} = \frac{\text{rate in the exposed}}{\text{rate in the non-exposed}}$$

For smokers, the relative risk is:

$$RR = \frac{190/100000/\text{year}}{19/100000/\text{year}} = \frac{190}{19} = 10$$

This indicates that smokers have ten times the risk of dying from lung cancer compared with non-smokers.

Confidence limits can (and should) be computed for relative risks to determine if the risk is statistically significant, that is, not due to chance. Confidence limits are the range of the risk estimate which takes into account sample size and variability. If the range of the estimate does not include 1.0, it is recognized as being statistically significant.

Standardized Mortality/Morbidity Ratios (SMR).

Standardized mortality ratios (SMR) are used for adjusting mortality rates in order to compare health outcomes between populations that may have different distributions of important variables such as age, sex, or race. Indirect standardization (adjustment) involves applying mortality rates from some selected reference population, adjusted for age and possibly other factors, to the study population. This procedure generates the number of deaths that would be "expected" if the study population had experienced the same disease incidence as the reference population. Then, a common way to compare this expected number with the actual observed number is to compute the standardized mortality ratio (SMR). This is done by dividing the observed number of deaths by the expected number, and then multiplying the quotient by 100 to eliminate decimals:

$$SMR = \frac{\text{Observed deaths}}{\text{Expected deaths}} \times 100$$

An SMR of 100, then, means that the expected and observed deaths are essentially equal in number, and no excess risk is evident. An SMR of 120 means that there 20 percent more deaths than expected, while an SMR of 80 would mean that the observed deaths were only 80 percent of the deaths expected based on the reference population. SMRs are used frequently in occupational studies.

In a typical SMR occupational study, the investigator has collected extensive information on who has worked in the industry, when, for how long, in what jobs, and if deceased, the cause of death. Thus both numerator data (deaths) and denominator data (person-years or persons at risk) are collected, and an actual mortality rate for each disease can be determined. This serves as the basis for the observed number of deaths.

A similar ratio can be calculated using morbidity data. For example, a standardized incidence ratio (SIR) can be determined using only incident cases.

Proportional Mortality Ratio

An entirely different ratio, which appears frequently and almost exclusively in occupational studies, is the *proportional mortality ratio* (PMR). As previously described, proportional mortality expresses the proportion of all deaths that are due to one cause. For example, of those who worked in a particular industry, 20 percent of the deaths may have been due to cancer, whereas heart disease may have accounted for 35 percent of the deaths.

In a PMR study, on the other hand, the data are often obtained completely from death certificates. Consequently, the investigator only has data on people who have already died. Recall that death certificates also list the usual occupation and other personal data such as age, race, and sex. The investigator does not (and perhaps cannot) obtain denominator data, i.e., the total person-years or persons at risk (most of whom may even still be living). Thus, a mortality rate cannot be determined; all that can be done is to compare, for example, the proportion of all deaths that were due to leukemia in one occupation with that proportion in another (reference) group.

Although the PMR and SMR appear superficially similar, they are quite different and are derived from different types of data. Because they are both widely used in occupational epidemiology, the distinctions need to be underscored here.

Risk Measures from a Case-Control Study

In a contrast to cohort studies which determine subsequent disease rates between exposed and non-exposed people, case-control studies first identify diseased and non-diseased persons, then ascertain their previous exposure history. This approach does not permit determination of actual disease rates. Thus, a relative risk cannot be determined. One can, however, compare "exposure ratios" between diseased and non-diseased groups. Under certain conditions, these exposure ratios can be used to estimate the relative risk by calculating an *odds-ratio.*

To illustrate the odds-ratio calculation, it is first useful to categorize case-control study data in a two-by-two table according to disease and exposure status:

	Exposed	Unexposed
Deceased persons (cases)	a	c
Controls	b	d

The letters represent the number of study subjects who fall into the four categories. Omitting its derivation, the odds-ratio (OR) is then calculated as:

$$OR = \frac{a \times d}{b \times c}$$

As an example, consider that the following data are obtained from a case-control study:

	Exposed	Unexposed
Deceased persons (cases)	85	15
Controls	40	60

The odds-ratio is then calculated as:

$$OR = \frac{85 \times 60}{15 \times 40} = 8.5$$

The odds-ratio will be a reasonable estimate of the relative risk if the disease in question is relatively rare (e.g., cancers), the exposure is relatively common, and, of course, there are no serious study biases.

The odds-ratio is interpreted exactly the same as the relative risk. If equal to one (1.0), it suggests no association between the exposure and disease. If greater than one, it indicates a positive association, and if less than one, a negative association or a protective effect. As with relative risks, confidence limits can be computed to determine if the odds-ratio is significantly different from a value of one.

In some case-control studies, the controls are individually "matched" to the cases during the selection process. For each case identified, a systematic approach is used to select a control who is in the same age bracket, of the same sex and race, etc. This matching process avoids having to account for these variables later in the analysis. When this type of matching is used in a study, the odds-ratio is calculated differently than above.

Analytic Control of Confounders

As previously described, epidemiologic studies involve examination of many different variables in addition to exposure and disease since there are other factors that may be related to the exposure and/or disease under study. The challenge then is to tease out the effect of the exposure of interest in the presence of these other factors or co-variates. In practice, analysis and interpretation of epidemiologic studies involves much more than a single 2x2 table. If confounding variables are not controlled for in the design of a study, then they must be controlled for in the analysis. Two approaches for the analytic control of co-variates or confounding are stratification and mathematical modeling.

Stratification. If the number of variables to be controlled for is not too large, and the range of values for these variables is not too wide, then stratification provides a simple and powerful analytic technique. In stratification, the investigator looks at the relationship between exposure and disease among subsets of the study population which have been categorized according to the level of some other co-variate. In a study of breast cancer, for example, it may be found that a late age at first birth has a positive association with breast cancer, and also low parity has a positive association. The investigation may suspect that age at first birth and parity are themselves related and that one is a confounder. Instead of a single 2x2 table, the investigator might construct a series of 2x2 tables showing the association of breast cancer and age at first birth for different parity levels (e.g., one child, two children, and three or more children). In other words, the investigator "stratifies" on the variable parity. The investigator might also look at breast cancer and parity, stratifying on age at first birth (e.g., under 30 years, and 30 years and older). The investigator would then find that the late age at first birth shows an increased risk ratio regardless of parity level. Stratifying on age at first birth, the investigator would find that parity is no longer associated with breast cancer risk. Stratifying has thus eliminated the confounding of parity and age at first birth by examining each variable separately.

Where several 2x2 tables and risk ratios are constructed in an analysis, a summary odds ratio can still be calculated. The usual technique for calculating a summary odds ratio is the Mantel- Haenszel procedure. This summary odds ratio can be thought of as a weighted average of the individual odds ratios from the separate 2x2 tables. Actual techniques for calculating the summary odds ratio and its confidence limits an be found in basic epidemiology or biostatistics texts.

Mathematical Modeling. Until relatively recently, stratification was the main approach to analysis in epidemiologic research. The limitation, however, is that if more than a few variables are controlled for at one time, too few subjects fall into each stratum, and the resulting risk estimates become unreliable. In this situation, the addition or deletion of even one subject in a stratum could change the risk estimate dramatically. Mathematical modeling overcomes this limitation. Many different mathematical models are available today, some of which are available on personal computers. The most commonly used model is logistic regression. Although developed originally for use with cohort studies, logistic regression is commonly employed in case-control studies. Discussion of the assumptions, use, and limitations of logistic regression and other models can be found in most recent epidemiology and statistics texts.

Attributable Risk Measures

Simple Attributable Risk. Disease rates can also be compared in another fashion: by looking at the difference in the rates between exposed and non-exposed groups. This measure is referred to as a simple attributable risk. The simple attributable risk is used to quantify the risk of disease in the exposed group that can be considered attributed to the exposure. Using the smoking data presented above,

Rate difference = (190/100000/year) - (19/100000/year)
= 171/100000/year

For this age group, the excess lung cancer rate among smokers attributable to smoking is 171/100000/year. Expressed as a percentage (171/190 x 100%), it would be said that 90 percent of lung cancer among smokers can be attributable to the fact they smoked and 90 percent lung cancer among smokers could be eliminated if they did not smoke.

Population Attributable Risk. Another more useful measure of attributable risk is referred to as the population attributable risk. It provides a useful measure of the proportion of disease which can be explained by the exposure under study. The population attributable risk has important public health implications since it provides an estimate of the potential impact of a preventive program. For example, if a population attributable risk of a disease is 40 percent for a factor, it is implicated that 40 percent of the disease can be attributed to the factor, then eradication of that factor should result in the eventual elimination of 40 percent of the disease.

Although a number of methods have been proposed for calculating the population attributable risk, the most useful ("Levin's formula for the population attributable risk") is as follows:

$$PAR = \frac{P(R-1)}{P(R-1)+1}$$

where, P = the proportion of the population exposed to the factor, and R = the relative risk (or odds-ratio if derived from a case-control study).

As an example, assume that 40 percent of the population is exposed to some agent (this is approximately the proportion of smokers in the U.S.) in which the relative risk (or odds-ratio) has been determined to be ten (10). Then:

$$PAR = \frac{0.40(10-1)}{0.40(10-1)+1} \times 100\% = 78\%$$

Thus, by eliminating this particular exposure, 78 percent of the disease could potentially be eliminated.

B.6 Statistics: p-Values, Confidence Intervals and Significance

The epidemiologist can use a variety of approaches and sources of information to obtain data on exposures and other factors that may be related to the development of disease. These data are then used to calculate rates which are compared between groups. In the case-control study, for example, the investigator identifies a group of people with the disease under study (cases) and another, presumably comparable group without the disease (controls). The investigator then seeks to assess and compare the exposure history of the cases and controls. The goal is to determine whether there is a higher proportion of those who are exposed among the cases than among the controls. The goal is to determine whether there is a higher proportion of those who are exposed among the cases than among the controls. If such a difference is found, its significance must then be evaluated.

A difference might be found for several reasons:

- There may actually be an association between the exposure and the disease;
- The difference (association) may be the result of bias in the study;
- The difference may be due to confounding; or
- The difference may be the result of random variation.

Unfortunately, it can never be proven that confounding and bias do not exist in a study. The best that can be done is to consider the potential sources of confounding and bias, and attempt to show that they are unlikely to exist or to have strongly influenced the study results.

An association between some exposure and a disease does not automatically demonstrate that the exposure causes the disease. It may be that the disease causes the exposure or that some other unknown factor causes both the exposure and the disease.

Before one attempts to judge the causal nature of an association, it is necessary first to determine whether the difference in rates (indicating an association) is likely to be real or just due to chance. Because of random variations that arise among population samples, the case and control groups are unlikely to have *exactly* the same proportion of exposed and non-exposed persons, even when there is no association between the exposure and the disease. The question, then, is how large must a difference be to show convincingly that it is real and not due to chance. Two approaches are commonly used in epidemiology to determine whether a difference is likely to be the result of random chance: use of significance testing by the calculation of *p*-values, and use of confidence intervals. Both will be briefly described and an example shown.

Significance testing

The vast majority of published epidemiologic studies have statements declaring that the differences observed between the comparison groups are (or are not) "statistically significant." Unfortunately, much confusion exists, particularly in the non-scientific community, about the meaning of a "statistically significant" result. Such a finding is one that, according to certain assumptions and based on a mathematical probability, has a low likelihood of being due to random sampling variation (chance).

The probability of this difference being due to chance is expressed as a "p-value" and may be given in either decimal or percentage form. Its magnitude will depend on a number of factors including the size of the difference observed, the size of the groups being compared, and sometimes, the data variability.

In practice, the most common p-value used to label a finding as statistically significant is $p < .05$. If a difference in a particular study is large enough that there is less than a five percent chance that it is the result of random variation, then this finding is considered significant. Another commonly cited threshold of significance is $p < .01$, less than a one percent chance that a difference is due to random variation.

In some published reports, an exact p-value (e.g., $p = .03$) is provided, while in others, the investigator only states that "$p < .05$," or that the findings are significant at the .05 level. Exact values are, of course, more informative and allow the reader to apply his or her own standard of statistical significance.

The level of significance selected depends on how strongly the investigator wishes to avoid the error of concluding that there is a real difference when none may actually exist. This is referred to as a "Type I" error. The smaller the p-value, the smaller the chance that a Type I error exists.

Calculation of p-value

There are a number of procedures for calculating p-values depending on whether one is considering, for example, the difference between the means of a continuous variable (e.g., age, years of employment) or a categorical variable, such as the difference between the proportions of those in each group who have some characteristic (e.g., residence near high-current distribution lines). These formulae and their applications can be found in great detail in any statistics text. Only one common example is provided below.

Consider a case-control study which is investigating whether the proportion of those with a specific exposure differs significantly between the case group and the control group. The common statistical method for comparing proportions (or percentages) is the X^2 (chi square) test. To apply the X^2 test, it is helpful to arrange the data in the form of a 2x2 table. To demonstrate this, assume that the study involved 100 cases and 125 controls. Thirty-five (35) of the cases were exposed to the agent, while 25 of the controls were exposed. The table would then be constructed as follows:

	Cases	Controls	Totals
Exposed	35	25	60
Not Exposed	65	100	165
Totals	100	125	225

The X^2 test statistic is defined as:

$$X^2 = \frac{(O-E)^2}{E}$$

where O = observed number and E = expected number, and the summation is over all cells of the table. Usually, a correction for continuity is made by subtracting 0.5 from |O-E| as shown below:

$$X^2 = \frac{(|O-E|-0.5)^2}{E}$$

To calculate the X^2 statistic, the "expected" number for each cell in the table must be found. This is done by assuming that there is no association between exposure and disease, and making use of the marginal totals in the table. The expected value can then be calculated with the following equation:

$$E = \frac{\text{(row total)x(column total)}}{\text{grand total}}$$

To illustrate, consider the upper-left cell of the 2x2 table shown above. The row table is 60, the column total is 100, and the grand total is 225. Thus the expected number of exposed cases is E = (60 x 100)/225 = 26.7. This calculation can be applied to each of the other cells of the table to obtain the other expected values. The expected (E) numbers thus obtained are shown in parentheses below:

	Cases	Controls	Totals
Exposed	35 (26.7)	25 (33.3)	60
Not Exposed	65 (73.3)	100 (91.7)	165
Totals	100	125	225

Using the simple formula for X^2 gives: $X^2 = 6.39$. Using the corrected formula gives a value of: $X^2 = 5.65$.

Once this statistic has been calculated, the investigator can then refer to a table of X^2 distribution, found in most statistics texts. These tables show the probability of obtaining a given X^2 statistic (the larger the value, the lower its probability or *p*-value). In this case, with a simple 2x2 table with one degree of freedom, our corrected X^2, which value is 5.65, yields a *p*-value of approximately 0.0175.

Confidence Intervals

A second, but related, approach for assessing the significance of epidemiologic results is the use of confidence intervals. The principle of confidence intervals is very straightforward. A certain degree of chance variability occurs in sample data. The amount of this variability depends on such factors as the sample size, the inherent subject-to-subject variability in a measured characteristic, and/or the prevalence of a characteristic. Therefore, the observed value of some characteristic of the sample (e.g., means, risk ratio) is only an estimate of the "true" value. However, more credence can be placed in some estimates than in others; i.e., estimates range--in the vernacular--from a "ball-park figure" to a "gnat's eyebrow."

One way to express the precision of a sample estimate is to calculate boundaries between which the true value is most likely to fall. These upper and lower limits, which bracket the estimated value, are referred to as *confidence interval* is the range of values from the lower confidence limit to the upper confidence limit. Confidence intervals are very useful in showing the precision of sample estimates. The larger the confidence interval the less precise the estimate is.

In epidemiologic studies, confidence limits are frequently calculated for risk ratios. A major purpose is to determine whether the interval around an estimate of the relative risk includes unity (1.0). Recall that a relative risk of value "x" is interpreted as meaning that subjects with the exposure are x times more likely to have the disease than those without the exposure. If the disease and the exposure are not associated with each other, the risk will be unity. Values less than 1.0 indicate a negative association (protective effects), while values greater than 1.0 indicate a positive association. If the confidence interval for a relative risk includes the value of 1.0, then no association is considered to exist between the exposure and the disease.

As an example, consider the same following data from a case-control study:

	Cases	Controls	Totals
Exposed	35	25	60
Not Exposed	65	100	165
Totals	100	125	225

In a case-control study, the odds ratio (OR) quantifies the strength of the association as an approximation of the relative risk. In this example, it is calculated as follows:

$$OR = \frac{35 \times 100}{25 \times 65} = 2.2$$

Thus, the *point estimate* of the relative risk is 2.2.

The calculation of confidence limits will then show the precision of this estimate. Commonly, 95 percent confidence limits are used. This means that there will be a 95 percent chance that the true risk will be contained in the interval. The first step of the procedure is the calculation of the variance and the standard error of the risk ratio. For the above data, a number of different formulas can be used. The standard error is then used in calculating the lower (LL) and upper (UL) confidence limits. In practice, some of the simpler formulas provide results quite similar to the more complex formulas. A complete description of these calculations can be found in any standard epidemiology textbook.

In this example, the variance for the natural logarithm (ln) of the odds ratio will be calculated as the sum of the reciprocals of the cells in the 2x2 table.

Variance of ln OR =

$$\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}$$

$$= \frac{1}{35} + \frac{1}{25} + \frac{1}{65} + \frac{1}{100}$$

$$= 0.09396$$

Standard Error (SE) = variance = 0.09396 = 0.3065

The logarithm of the lower and upper 95 percent confidence limits is then:

$$\ln LL = \ln OR - (1.96 \times SE) = 0.1877$$

$$\ln UL = \ln OR + (1.96 \times SE) = 1.3892$$

Converting from natural logs of these exponential values to obtain the actual lower and upper limits can easily be done on most scientific calculators:

$$LL = e^{0.1877} = 1.21$$

$$UL = e^{1.3892} = 4.01$$

Thus, the 95 percent confidence interval for the odds ratio is 1.2-4.0. This interval shows several things. One is that the observed odds ratio (2.2) is not a highly precise estimate. The actual risk could range from a very weak 1.2 to a moderately high 4.0. All we know is that there is a 95 percent chance that the real risk ratio falls within this interval.

Another important aspect of this interval is that it does not include one (1.0). This is expected since the significance test (X^2 test) had already revealed that an association exists between the exposure and disease.

Many epidemiologists believe that a confidence interval conveys more information than a significance test because it indicates the lowest and highest likely true relative risk (or other parameter). It also reveals something about the precision of an estimate. An extremely wide confidence interval, whether or not it includes a risk ratio of 1.0, suggests caution in interpreting the results of a study.

B.7 Statistics: Type II Errors and Power

The discussion in the previous section only considered techniques to avoid a mistaken conclusion regarding the presence of an association (Type I error). Less frequently discussed is another type of error that may be equally important: type II error is the chance of producing a conclusion of no association when one actually does exist. Just as chance can operate to produce an apparent association when none actually exists, chance can also obscure a difference that does exist. Failing to detect a true association is referred to as a Type II error. The possible combinations of correct and incorrect conclusions are:

Study Conclusion vs. True Relationship

	Association	No Association
Association	Correct	Type I Error
No Association	Type II Error	Correct

A relationship exists between Type I and Type II errors in that the more closely one guards against a Type I error, the more likely a Type II error will occur. In other words, the greater the difference required for a conclusion of a real association, the greater the chance that a real association will not be detected.

The probability that a real association will be detected in a study is referred to as the *power* of the study. It is determined by subtracting the probability of a Type II error, expressed as ß(beta), from 1.0. Although not as commonly discussed in study reports, the power of a study to detect a particular level of risk is extremely important both in the planning of a study and in the evaluation of "negative" studies. Most recent epidemiologic and statistical texts provide detailed discussions of power and Type II errors for various types of studies. Rather than review these methods for calculating power or sample size, this section will only briefly outline the major factors that determine power and then show one example.

Four factors affect the probability of a Type II error and, therefore, the power. The first is the level of confidence used to reduce the chance of a Type I error. If one demands an extremely high level of confidence (i.e., a very small *p*-value), a greater chance exists that a true association will not be recognized.

Another factor that affects the power of a case-control study is the prevalence of the exposure among the controls. Power is reduced where the exposure is either very rare or very common among the controls. In a cohort or cross-sectional study, power is mainly dependent on the "expected" number of diseased cases in the unexposed population, which is in turn related to sample size. (Sample size is discussed below.)

Obviously a study has a greater probability (power) to detect large relative risks (or large differences in means or proportions) than small risks. A particular study may have a 90% chance of detecting a relative risk of 3, but less than a 25% chance of detecting a risk of 1.5.

Another factor that affects the power of a study is the sample size of the study -- the number of cases and controls in a case-control study, or the number of people and period of follow-up (person-years) in a cohort study. Obviously, the larger the study, the greater its power to detect a particular level of risk. Sample size is also quite important in Type I errors. Only by increasing sample size can the investigator simultaneously reduce the chance of both types of error. Because of the relationship of sample size to the probability of these errors, and because sample size is one of the conditions that is under some control of the investigator, considerable emphasis is placed on sample size in the design of studies.

Unfortunately, sample size questions cannot be answered without consideration of many of the factors discussed above. For example, an appropriate sample size will depend on: how small a difference (or how small a relative risk) the investigator wants to be able to detect, the desired confidence level (*p*-value) to be used in significance testing, the power desired to detect a given difference or risk, and the expected prevalence of the exposure in the general population.

In many situations, sample size may not be readily under the control of the investigator. In an historical cohort study, for example, the sample size may be fixed by the number of individuals employed and the years of follow-up. In a case-control study, sample size may be determined by the number of new cases diagnosed over a set period of time at a hospital or through a disease registry. Time and costs are always practical constraints. Power calculations can be important in these situations by showing, for example, the power of a proposed study or a completed study to detect specified levels of risk.

To illustrate some of these interrelationships, the following example is taken from an actual study proposal. The proposed project would be a case-control study to examine the possible association between leukemia and residential exposure to magnetic fields. Based on the population of a study area, expected cooperation rates, leukemia rates, etc., the investigators estimated that they ultimately would be able to compare 163 leukemia cases with 163 controls. Significance testing would be done at the 95 percent confidence level ($p < .05$). The investigators then determined the minimum detectable relative risks (odds ratios) that they would have an 80 percent chance of detecting (i.e., power = .80). Since they did not have reliable data on the prevalence of magnetic field exposure (however defined) in the general population, several estimates were considered based on the findings of an earlier study. The following estimated minimum detectable risks were presented corresponding to exposure prevalence:

Prevalence of Exposure	0.10	0.15	0.20	0.25	0.30
Minimum of Detectable Risk	2.41	2.15	2.02	1.95	1.90

Thus, depending on sample size, the exposure prevalence estimates, and use of 95 percent confidence level for significance testing, an 80 percent chance exists that this study would detect a relative risk as low as 1.9 to 2.4. If the true risk were higher than 2.0, the power would be higher than 0.80. However, if the true risk were actually small (e.g., 1.5), the power would be much less than 0.80.

If the investigator considered it important to detect a risk of 1.5 with high probability, the study size would have to be increased. If the number of cases could not be further increased due to cost or availability, sample size and power could be increased by increasing the number of controls. For each case, 2, 3, or even 4 controls might be selected. Little further improvement in efficiency, however, can be gained beyond a ratio of about 4 to 1, controls to cases.

The above calculations could have been determined for a power of 0.70 or 0.90 or any other desired level. Conversely, one could have been selected various relative risks (e.g., 1.5, 2.0, 5.0, 10.0), and then determined the power to detect that risk.

An understanding of the relationships between power, sample size, significance tests, etc., is quite important both to the design and evaluation of epidemiologic research. If a proposed study design requires a higher power to detect a certain magnitude risk which is considered important, then a larger sample size should be sought. Of course, the power of a study should always be taken into account in evaluating a report of negative findings, i.e. was the study sufficiently powerful to give the reader confidence that the author's claim of a negative study is valid?

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APPENDIX C - RESULTS OF EMF SURVEY

C.1 Siting

No.	Utility	Case/Project Description	Status
1.	Allegheny Power System (Potomac Edison Company)	Walkersville Loop 138-kV Line	Siting approved.
2.	Appalachian Power Co.	Culloden-Gavin 765-kV Line	Court found that there are no known adverse biological effects associated with the fields from this 765-kV line.
3.	Arizona Public Service Company	Altadena 69-kV Substation	Site was approved by both Scottsdale Planning Board and Scottsdale City Council.
4.	Arizona Public Service	SDG&D 500-kV Interconnection	No direct ruling on EMF issue but Committee granted Certificate of Environmental Compatibility.
5.	Associated Electric Coop.	Missouri, Iowa, Nebraska Transmission Project (MINT), 345-kV Line (scheduled completion 1992)	Project received "Finding of No Significant Impact" from licensing authority; EMF issues were raised by landowners in public hearings; subsequently acquired 94% of ROW through negotiation, remaining 6% through condemnation; EMF not an issue in condemnation hearings.
6.	Atlantic Electric Co.	Application to Construct and Operate a 230-kV Transmission Line and Related Substation Facilities (1984)	Landowners raised issue of EMF health effects; AEC submitted reports on EMF health effects; landowners dropped EMF claims and the 230 kV line was approved when a new route was agreed upon.
7.	Atlantic Electric Co.	Mickleton 230-kV Line	Line approved; Board found that fields from this line would be similar to fields from existing lines of same voltage class and that field levels from this line fall within field standards in New Jersey and other states.
8.	Atlantic Electric Co.	Millville-Maurice River 138-kV Line	Line approved; Board found that the line "will not unduly affect the quality of the environment or the health of the public."
9.	Atlantic Electric Co.	Cardiff-New Freedom 230-kV Line	EMF issue raised; no specific findings re EMF; alternate route proposed.
10.	Central Ill. Pub. Service	Certification for 138-kV Line	Site approved and request that utility provide indemnification denied.
11.	Central Main Power Company	State Board of Environmental Protection	Utility filed written report on EMF issue; line was built.
12.	Central Power & Light Company	Walker–Matagorda 400-kV Line, No. 5023	Commission directed utility to provide more information on possible health effects of DC air ions; utility withdrew the application.

Siting (Continued)

No.	Utility	Case/Project Description	Status
13.	Central Power & Light Co.	Application for Lon Hill - Coleto Creek 345-kV Line	EMF issues raised; case pending; no trial date set pending resolution of endangered species issues.
14.	Cheyenne Light, Fuel & Power Co.	Corlette 115-kV Line	Commission found no evidence of adverse health effects. Landowners appealed decision to Wyoming S. Ct., S. Ct found sufficient record of no health risks.
15.	Cleveland Electric Illuminating Co.	Chester Township v. Power Siting Comm'n (1977)	Opposition presented EMF testimony through engineer; utility produced company engineer; line approved; S. Ct. of Ohio upheld.
16.	Cleveland Electric Illuminating Company	Ohio Power Siting Board: No. 02-00022	EMF issue was presented; Board made no finding regarding EMF but denied certificate on other grounds; amended application filed; certification granted in February, 1991.
17.	Commonwealth Electric Company	Commonwealth Electric Company v. Energy Facilities Siting Council: EFSC 85-4A	Issues raised in this proceeding were resolved in Cape Howitch - Dennis proceeding before the DPU, discussed below.
18.	Commonwealth Electric Company	Application for 345-kV Substation: No. DPU 86-257	Dept. of Public Utilities found no evidence that EMF from the substation would increase health risk.
19.	Commonwealth Electric Company	115-kV Transmission Line Cape Howitch-Dennis	Line approved on September 28, 1990; Department of Public Utilities found that "[t]he evidence presented by the intervenors does not demonstrate that the EMFs produced by electric power lines cause adverse effects."
20.	Connecticut Light & Power	Braun V. CP&L	Line approved; court found that there was not "anything close to proof of a reasonable likelihood that defendants' intended actions will harm one or more of the plaintiffs"; permanent injunction denied; landowners filed notice of intent to appeal on May 29, 1991; further hearing on damages possible.
21.	Florida Power Corporation	Application for Certification of Lake Tarpon 500-kV Line, No. 85-1411	Siting Board denied certification based on failure of DER to provide standards; EMF regulations were adopted & line approved on remand.
22.	Florida Power Corporation	Application for Certification	Board found that fields from the line would have essentially no biological effect.
23.	Florida Power Corporation	Piedmont-Sorento 230-kV Line, No. 81-1856	Board found that EMF from this line would have no impact.
24.	Hawaii Electric Light Company, Inc.	Puna-Pohoiki Certification for two 69-kV Lines	Commission found insufficient evidence to conclude that a health risk exists and approved line.
25.	Kauai Electric Co.	1989 Kauai Line Siting	Action involving state conservation lands; Hearings held by Board of Land and Natural Resources Conservation with experts on issue of EMF health effects; found insufficient evidence of adverse health effects.

Siting (Continued)

No.	Utility	Case/Project Description	Status
26.	Jersey Central Power & Light Co.	Manitou-Whiting 230-kV Line	EMF issues raised; line approved; opposition motion to stay pending appeal denied April, 1990.
27.	Jersey Central Power & Light Co.	Aberdeen-Red Bank	Application withdrawn by utility after reassessment of need for line.
28.	Lower Colorado River Authority	Application for 345-kV Transmission Line and Associated Substation (1979)	Commission adopted Hearing Examiner's ruling that there were no proven health effects and added provision that the commission could amend or revoke certificate if future research shows that exposure to electric fields causes adverse health effects.
29.	Minnesota Power Co.	Application for Exemption From Siting Requirements for Duluth Area	Application approved; Board found that proposed upgrade would result in lower magnetic field levels and that there is "no definitive evidence" that EMF causes health problems.
30.	Minnkota Power Coop. Inc.	Center-Maple River 230-kV to 345-kV Upgrade (1980)	EMF witnesses appeared; Application granted.
31.	Mississippi Power Company	Application for CPCN: U-4128	Commission found no evidence of health effects from 500-kV line.
32.	Montana Power Company	Application for Certification of Laurel-Bridger 100-kV Line	State agency found field levels acceptable.
33.	Nashville Electric Service	Sharondale 161-kV Substation	Project has been placed on hold pending results of independent engineering study of system-wide electricity needs.
34.	Nashville Electric Service	Hendersonville 161-kV Substation	Line approved; construction subsequently opposed by Sierra Club. Utility met with local citizens group and proposed engineering alternatives to delay construction of project; alternatives adopted and project delayed indefinitely.
35.	Nebraska Public Power District	Application for Certification of Corridor Compatibility: No. 9942	Application granted. Utility decided not to build line.
36.	Nebraska Public Power District	Application for Permit to Construct and Operate: No. F-3371	Application granted. Utility decided not to build line.
37.	Nevada Power Company	Warm Springs Eastern Line	EMF raised; witnesses appeared; approval granted; appealed to County Planning Commission; lost approval for certification; utility rerouted line.
38.	New England Electric System	Petition for Permission to Build 345-kV Line, No. DPU 19559	Department of Public Utilities found that health hazards were conjecture and had not been established. Supreme Judicial Court affirmed this finding and remanded the case on other issues.

Siting (Continued)

No.	Utility	Case/Project Description	Status
39.	New England Electric System	Certificate to Install 450-kV Line. No. DSF81-349	Commission found that effects on public health, if any, fall within acceptable range.
40.	New England Power Company	Costello v. Department of Public Utilities (1984)	Dept. of Public Utilities approved 345-kV line; Costello challenged approval; court affirmed decision to allow construction of line and accepted utility testimony that no adverse health effects would be associated with line.
41.	New York Power Authority; Niagara Mohawk Power Corp.; New York State Gas & Electric Corp.	Common Record Hearings before the New York Public Service Commission. No. 26529	Pending; utilities required to fund research on the EMF Issue.
42.	Northeast Utilities	Farmington-North Bloomfield 115-kV Line	Site approved but decision did not address the EMF issue.
43.	Northern states Power Co.	Applications to Modify and Upgrade Transmission Lines	Applications approved in May 1991; Board found that there is "no evidence that the increased magnetic fields associated with the increased power flow in 500-kV line will present a risk to human health."
44.	Pacific Gas and Electric	Geyser Project, No. 79 AFC-5	Commission found that there is no persuasive evidence that adverse health effects result from high voltage EMFs.
45.	Pacific Power & Light	Eugene-Medford 500-kV Line	Application granted; "COPE" group subsequently raised EMF issue prior to construction; site certificate amendments sought for 4 route changes; EFSC approved August 29, 1990. PP&L will use "Delta" Line configuration for EMF mitigation.
46.	Philadelphia Electric Company	230-kV Line; No. E-81768003	Court found that the proposed line is not dangerous to humans or animals.
47.	Philadelphia Electric company	Horsham-Middletown 230-kV Line Certification	In May, 1991, State Court ordered PUC to reopen its hearings to take evidence on EMF issues.
48.	Potomac Edison Company	Brighton-High Ridge 500-kV Line	Commission found no basis to conclude that power line fields cause adverse health effects. Rejected proposals for field standards which have no scientific basis. Staff will monitor ongoing EMF research and report on semi-annual basis.
49.	Public Service Company of Colorado	Daniels Park Transmission Line	Board of Commissioners held that undergrounding did not constitute "Prudent Avoidance" under the circumstances. Overhead line approved with conditions offered by Utility. State Court overturned decision on grounds unrelated to the merits of the EMF claim.
50.	Public Service Company of Colorado	Sidney-North Yuma 230-kV Line	Pending.

Siting (Continued)

No.	Utility	Case/Project Description	Status
51.	Puget Sound Power & Light Company	Canadian Tie-in	Pending.
52.	Salt River Project	Pinnacle Peak-Papago Buttes 230-kV line.	Certificate denied at least in part on basis of potential for EMF health effects.
53.	San Diego Gas & Electric Co.	Application for Certification: Decision #93785	Commission found that available information did not indicate that EMF causes adverse health effects. Ordered utility to continue to fund EPRI studies and inform Commission of results.
54.	Southern Cal. Edison Co.	Kramer-Victor 230-kV Line	CPUC granted approval to construct transmission line; required utility to "minimize" magnetic fields associated with the line.
55.	Tucson Electric Power Company	Bel Air Ranch Estates v. TEPC; No. C458986	Court found that plaintiff had failed to prove adverse health effects by a preponderance of the evidence.
56.	Union Electric	Apache Flats 161-kV Line	Line approved; decision made no reference to EMF.
57.	United Power Association	Bento-Milaca 230-kV Line: Docket No. UPA-TR-1	Board found that evidence to date did not indicate transmission lines as a health hazard.
58.	United Power Association	Coal Creek-Stanton 230-kV: Docket No. 9593	Commission found that designated route would have acceptable health and environmental impacts.
59.	United Power Association	Wilmarth 345-kV Line: Docket No. CU-TR-2	Council found no substantial showing of adverse biological effects.
60.	United Power Association	Certificate of Site Compatibility; Docket 9459	Commission found no evidence of adverse health effects.
61.	United Power Association	Route Permit 400-kV DC Line: Case No. 9370	Commission found no detriment to human health from the line.
62.	United Power Association	Construction Permit 400-kV DC Line: Docket No. CU-FR-1	Council found the line would have no adverse health effects.
63.	United Power Association	Corridor Designation: Wilmarth 345-kV Line, No. CU-TC1	Council found no reports of adverse health effects from EMF.
64.	United Power Association	Corridor Designation: 400-kV DC, No. CU-TC-1	Council found that proposed line would have no adverse health effects.
65.	Vermont Electric Power Company	450-kV DC Interconnection. 4763	Board found that potential for adverse health effects was minimal or nonexistent.
66.	Virginia Power	Loudoun- Gainsville 230-kV Line	State Corporation Commission decided to monitor the EMF health effects issue.
67.	Virginia Power	Ox-Possum Plant 500-kV Line	State Corporation Commission decided to monitor the EMF health effects issue.
68.	Virginia Power Co.	Elmont-Chickahominy 230-kV Line (1990)	EMF experts appeared; Hearing examiner found no EMF health effects; line approved.

Siting (Continued)

No.	Utility	Case/Project Description	Status
69.	Virginia Power Co.	Clifton-Cannon Branen 230-kV Line (1990)	EMF witnesses appeared; Hearing examiner found no EMF health effects.
70.	Waverly Municipal Electric Utility (Iowa)	Application of City of Waverly for Certificate of Necessity to Construct 69-kV Transmission Line Docket No. E-20990	State Utilities Board held hearing; objectors presented oral testimony and submitted written materials, primarily popular publications, on issue of EMF health effects; no cross examination; no experts were called. Line being built as proposed.
71.	Wisconsin Public Service Corporation (WPSC)	Bayport-Mason Street upgrade (69-kV double circuit 138-kV Line and Substation)	Approved by PSC-magnetic fields not likely to adversely affect human health; condition: magnetic field measurements before and after project.
72.	WPSC; Madison Gas & Electric Co.; and Sun Prairie Water & Light	Dane County 69-kV Transmission Line & Substation	Approved by PSC-magnetic fields not likely to adversely affect human health; condition: magnetic field measurements before and after project.

C.2 Zoning

No.	Utility	Case/Project Description	Status
1.	Boston Edison	115-kV New Substation in Norfolk, MA	Hearing before zoning board; central issue EMF; experts testified for utility, none for objectors; second hearing scheduled mid-October 1990 on EMF health effects.
2.	Bonneville Power Administration	Eugene Springfield Planning Project (500-kV Line)	Hearing re use of ROW; EMF issues raised; use of existing ROW for 500-kV line pending.
3.	Central Hudson G&E	Substation Matter	EMF issue raised by Planning Board; approval pending.
4.	Con. Edison	40th St. Substation Upgrade	Pending.
5.	Dominion Resources	Georgetown Cogeneration Project 69-kV Lines	Hearing before D. C. Board of Zoning Appeals included EMF testimony; zoning approval granted.
6.	Idaho Power	Sun Valley Transmission Line Siting (1989)	Planning and Zoning Council, citing EMF concerns, adopted "informal" standard that the ROW must be more than 150 feet from nearest structure.
7.	Independence P&L	161-kV Line Project	Public concern raised in informal hearings; utility voluntarily rerouted.
8.	Long Island Light Co.	Great Neck Substation Extension	EMF issues raised; approval pending.
9.	Long Island Light Co.	Shelter Island, Southold-Buel Cable	EMF issues raised; Shelter Island zoning Board imposed magnetic field limit to underground cable.
10.	Massachusetts Electric Co.	Application to Construct a Transformer in Milbury, MA	Withdrawn without prejudice after hearings during the zoning process were held on EMF health effects; company is reconsidering design and other issues.
11.	Orange & Rockland Utilities, Inc.	Montvale-Grand Ave. Substation	Approved. EMF testimony presented. No mention of EMF in Final Order.

Zoning (Continued)

No.	Utility	Case/Project Description	Status
12.	Pacific Power & Light Company	China Hat-south Loop 69/115-kV Line	Public hearing re line including EMF and property value issues. Hearing Officer found that causal relationship between EMF and health had not been demonstrated, and that transmission line would have minimal if any impact on property values. Line approved in late 1990.
13.	PEPCO	Brighton-High Ridge 500-kV Line	Howard and Montgomery County Boards are preempted from setting EMF standards once State PSC has authorized line.
14.	Public Service Gas & Electric	Eagle Point 230-kV Feed to N.U.G.	Hearing before Westville Environmental Planning Board; EMF witnesses; utility modified route; zoning approved.
15.	Public Service Co. of New Mexico	115-kV Line in Santa Fe	EMF raised; approval pending.
16.	Sierra Pacific Power Company	Carson City 120-kV Line	Approved. EMF testimony presented. No mention of EMF in Final Order.
17.	Tri-State G&T	Newton, Johnson & Kasnyski v. Grand Co. Commis. & Mtn. Parks Electric Inc., No. 86-CV-225	Utility withdrew application after District Court ordered new examination of the EMF issue. Utility built distribution line.

C.3 Condemnation

No.	Utility	Case Name	Status
1.	Allegheny Power System (Potomac Edison Co.)	Allegheny v. Ramsburg (138-kV) Line	EMF raised by landowner in condemnation proceeding; case settled.
2.	Arizona Public Service	APS v. Sheppard; No. C-444340 (500 kV)	No recovery; utility presented brief testimony on the EMF issue; jury did not award any compensation for fear of adverse health effects.
3.	Arizona Public Service	APS v. Selective Resources	Court held that testimony on EMF is irrelevant to a condemnation action and therefore inadmissible.
4.	Bluebonnet Electric Cooperative (BBEC) Texas	BBEC v. C. A. Colhoun 138-kV Line	Discovery controversies have delayed trial. Hearing June 1992 to resolve discovery issues.
5.	Brazos Electric Power Cooperative, Inc.	Brazos Electric v. Thelma Ray	Utility offered $42,000 for 4.2 acres. Landowner claimed damages of $1,000,000 to remaining property. Jury awarded $77,000 for 4.2 acres. No mention of EMF in final order.
6.	Brazos Electric Power Cooperative, Inc. (BEPC)	BEPC v. Maddle 138-kV Line R.O.W.	EMF issues raised; Commissioner's Court awarded landowner $11,800. On appeal, Jury awarded landowner $10,000. No mention of EMF in Final Order.
7.	Brazos Electric Power Cooperative, Inc. (BPEC)	BEPC. v. McAllum 138-kV Line R-O-W	EMF issues raised; Commissioner's Court awarded landowner $6,900. On appeal, jury awarded landowner $3,325. No mention of EMF in Final Order.

Condemnation (Continued)

No.	Utility	Case Name	Status
8.	Central Electric Power Coop.	Condemnation Case	Appraiser report raised EMF and fear issues; case settled out of court.
9.	Central Kansas Electric Coop., Inc.	Petition of Central Kansas Electric Coop. Inc. (1978)	Supreme Court of Kansas ruled parties' electrical engineering testimony of EMF health effects should have been excluded; ordered new trial consistent with opinion.
10.	City Public Service, San Antonio	Stone Oak condemnation; 345-kV Line	Lower Court found that property was worth $100,000. On appeal landowner raised the EMF issue. Appeals Court awarded $97,000 for the property.
11–17.	City Public Service, San Antonio	Seven (7) other Condemnation Cases	Settled out of court.
18.	Colorado-Ute Electric Assn.	Lamour v. Colorado-Ute (1986)	EMF issue raised by Lamour, but never argued in court; no witnesses appeared; settlement reached between parties on issue of valuation.
19.	Duke Power Co.	Duke Power v. Elizabeth Granger. Condemnation	EMF witnesses appeared; no EMF findings; proceeding settled by consent judgment.
20.	Florida Power & Light Co.	Fla. P&L v. Jennings	Court ruled that health effects testimony is irrelevant in condemnation action and therefore inadmissible.
21.	Georgia Power Company	Georgia Power v. Jimmy C. Barrett	Landowner has raised EMF as an issue with respect to land values of parcel being acquired; pending; no trial date scheduled.
22.	Georgia Power Company	Mystery Valley Subdivision v. Georgia Power	EMF health effects issues raised by landowners around the substation; condemnation case pending but no health experts have been identified; EMF claim not being actively pursued.
23.	Gulf States Utilities Company	Courtney v. Gulf State, No. 11058	Settled for amount much less than that originally claimed.
24.	Houston Lighting & Power Company	Klein v. HL&P, No. 395-755	Utility required to pay $104,275 in damages.
25.	Idaho Power Company	IPC v. Lettunich, No. 6828 (230-kV Line)	Landowner claimed $230,000 in damages; Utility offered $14,700. Jury awarded $15,000. No special findings, unable to determine whether the EMF issue affected award.

Condemnation (Continued)

No.	Utility	Case Name	Status
26.	Indiana & Michigan Electric Company	I&MEC v. Pounds, No. C-790235 (765-kV Line)	No recovery; court refused to decide the EMF issue.
27.	Interstate Power Co. (Iowa)	Condemnation Action 345-kV Rock Creek Transmission Line (1985)	Landowner raised adverse health effects; hearing before Iowa Board of Public Utilities; EMF experts appeared on both sides; case was settled and voluntary easement granted before opinion was issued by board.
28.	Iowa Power and Light Company	IP&L v. Stortenbecker, et al.	No recovery; court excluded expert testimony claiming EMF health effects because there was insufficient data to reach a conclusion that the line would cause health hazards.
29.	LaPlata Electricity Association	LaPlata Elec. Ass'n v. Cummins (1986)	Landowners submitted public opinion survey re desire to live near power lines due to health hazards of EMF; appellate ruled that admission was not reversible error since no weight given to it in trial judge's award.
30.	Los Angeles Department of Water & Power	City of LA v. Fink, LA Superior Ct. No. C307309	Jury made special finding that there was no diminution in value of property due to adverse biological effects of the 500-kV line.
31.	Los Angeles Department of Water & Power	City of LA v. Van Dooremoien, No. C606776	No special findings; unable to determine whether the EMF issue affected award.
32.	Louisiana Power & Light	Louisiana Power & Light Co. v. Mobley (1986)	Court of Appeal of LA held it was permissible for trial judge to force LP&L to pay for damage to land if damage was caused by fear of EMF adverse health effects.
33.	Louisiana Power & Light	LP&LC v. Zeringue, No. 53, 164-E	Court did not decide issue of EMF health effects but noted the landowners fear of such effects.
34.	Louisiana Power & Light	LP&LC v. Churchill Farms & Marcello, No. 184-546	No special findings; unable to determine whether the EMF issue affected award.
35–45.	Lower Colorado River Authority	Eleven Condemnation Actions	Involved EMF-related issues; three cases actually went to trial; LCRA prevailed in each; testimony was taken in each regarding EMF issues, but no EMF/health effects findings were made in the final orders. Others eight cases settled out of court.

Condemnation (Continued)

No.	Utility	Case Name	Status
46.	Mississippi Power & Light	MP&L v. Thomas, No. 3823 (500-kV Line)	No recovery; court found no convincing evidence of harmful effects on dairy cows.
47.	Missouri Public Service	Condemnation Case (131-kV Transmission Line)	EMF issues raised in discovery; landowners are pursuing theory that fear of EMF will reduce the income flow of the property; case pending.
48.	Montana Power Co.	161-kV Line Related Condemnation Case	EMF issues raised informally; case pending.
49.	New York Power Authority	Zappavigna v. PASNY, No. 74085	No recovery; court held there was no reasonable basis for fear of health effects; both sides appealed; appeal pending.
50.	New York Power Authority	Jonas Condemnation	Related case to Zappavigna condemnation; landowner attempted to call Dr. David Carpenter as EMF witness; Power Authority successfully objected to introduction of his testimony.
51.	Northern Virginia Electric Cooperative	Cedar Grove-Evergreen 115-kV Line Condemnation	EMF "fear" issues have been raised; no trial date set.
52.	Northern States Power Company	Hennepin County District Ct. No. CD-2007	EMF issues raised in condemnation but subsequently were dropped by landowners.
53.	Philadelphia Electric Company	Goodby v. PEC	No recovery; plaintiff's claims could not be substantiated.
54.	Potomac Electric Power Co. (PEPCO)	Brighton-High Ridge Condemnation Cases	Condemnation cases have begun; to date courts have excluded evidence of EMF or fear of EMF.
55.	Potomac Edison Co.	Beddington-W.C. Reid Line	EMF issues raised by landowner in condemnation action; case settled.
56.	Public Service Co. of Colorado	PSCo v. Ackerman	Ackerman Case settled when PSCo agreed to upgrade from 115-kV to 230-kV instead of 345-kV eliminating need to require additional ROW.
57.	Public Service Co. of Colorado	PSCo. v. MaHoney (1985)	Award in Mahoney did not address EMF though it was raised by landowners.
58.	Public Service Co. of Colorado	Linnebur v. PSCo (1986)	Landowner sought to introduce testimony of health effects experts to support claim of damages; court ruled health effects testimony inadmissible; no damages due to EMF.

Condemnation (Continued)

No.	Utility	Case Name	Status
59.	Public Service Company of Colorado	PSCo v. Judge	Despite testimony on the EMF issue, decision did not address the EMF issue.
60.	Public Service Company of Colorado	PSCo v. Higgs	Pending.
61.	Public Service Company of Indiana	Unknown.	No recovery; EMF evidence was excluded by trial judge.
62.	Public Service Co. of New Mexico	1980 Condemnation Case	Electric field issues raised; judge did not allow plaintiffs' witness to testify as EMF expert; no specific findings re EMF.
63.	Public Service Co. of Oklahoma	Burl Clanton Condemnation (345-kV) (April 1990)	EMF raised through appraiser; landowner claimed $500,000; jury awarded $34,000; no mention of EMF in decision landowner appealed, but later dropped the appeal.
64.	San Diego Gas & Electric Company	SDG&E v. V&V Development Company, No. 484042	Testimony on EMF was presented; no special findings and no method of determining whether EMF affected amount of compensation.
65.	San Diego Gas & Electric Company	SDG&E v. Anderson, No. 487321	No recovery; court ruled that EMF health effects are too speculative for the jury to consider in a damage award.
66.	San Diego Gas & Electric	SDG&E v. Tallaferro, No. 489761	No specific findings; unable to determine whether the EMF issue affected award.
67.	San Diego Gas & Electric	SDG&E v. Daley, No. 483834	The Court ruled that the utility could not present testimony on the EMF issue because it is irrelevant in a condemnation action.
68.	Santee Cooper	Myrtle Beach Condemnation Case	No EMF witnesses; EMF first raised in closing argument by landowners; appeal pending.
69.	Southern Cal. Edison Company	So. Cal. Edison v. Stafford, et al, No. INDIO 28701	No recovery; jury found no proof that property values had been diminished by fear of health effects.
70.	Southwest Arkansas Utility Corporation	SWAUC v. Black, No. E-83-8-G	No recovery; court found that 161-kV line would not create a health hazard.

Condemnation (Continued)

No.	Utility	Case Name	Status
71.	Southwestern Public Service Company	Matador Cattle Co. v. SWPSC	No explicit ruling on health effects of EMF; court ruled that no trespass damage had been caused by EMF.
72.	Southwestern Public Service Company	Tuco-Oklaunion 345-kV Line	EMF health effects issue raised but no expert witness testimony presented.
73.	Tennessee Valley Authority	TVA v. An Easement	No recovery; court ruled that EMF testimony is not relevant in a condemnation action.
74.	Texas Utilities Electric Company	TESCO v. Berger, No. 85A-216	No recovery; opposing attorney failed in attempt to introduce EMF testimony.
75	Tucson Electric Power Company	TEPC v. Shepis, No. 188972	No specific findings; unable to determine whether EMF affected award.
76.	United Power Association	CPA/UPA v. Aasand, No. C-1474	No specific findings regarding the EMF issue, unable to determine whether EMF affected award.
77.	Virginia Power Co.	Virginia Power Co. v. Fendley (1982)	Commissioners ruled landowner's expert witness did not qualify as an expert on EMF; circuit court affirmed decision following landowner's filing of formal exception to ruling.
78.	Wisconsin Public Service Corp.	Sturgeon-Bay Condemnation Cases	EMF raised; No finding of increase due to EMF; one appeal settled out of court.

C.4 Tort

No.	Utility	Case Name	Status
1.	Clark Co. P.U.D. No. 1 (Washington State)	Sheila Anderson v. P.U.D. Clark Co.	Personal injury and wrongful death action by mother of deceased child (leukemia); fields in school measured; case dismissed without prejudice.
2.	Florida Power & Light	Chaney v. FP&L, Palm Beach Circuit Court	Adverse health effects and nuisance from EMF claimed; plaintiff recently filed motion to delay trial; no decision on motion or trial date.
3.	Florida Power & Light	Fantigrassi v. FP&L, Broward County Circuit Court	Adverse health effects, trespass, nuisance claimed; action is pending in discovery phase.
4.	Florida Power & Light	Mocciola v. FP&L	Voluntary dismissal of case.
5.	Houston Lighting & Power Company	Scott v. HL&P, No. 87-058967	Dismissed.

Tort (Continued)

No.	Utility	Case Name	Status
6.	Houston Lighting & Power Company	Klein v. HL&P	Court found that utility cannot be held for tort of trespass because it had acquired property in a legal manner.
7.	Indiana & Michigan Electric Co.	Runge v. Indiana Michigan Power, No. 20D02-90005-CP-351	Suits alleges personal injuries from EMF and shocks caused by power lines on property; suit filed May 24, 1990; discovery procedures currently being litigated.
8.	Mississippi Power Company	Shaw v. MPC; No. S87-0329(s)	Pending.
9.	Philadelphia Electric Power Co.	Hoch v. Philadelphia Electric Power Co. (1985)	Landowner claimed trespass and nuisance as a result of EMF; trial court dismissed complaint stating Public Utility Commission was proper forum; on appeal, Hoch succeeded in having nuisance and trespass claims reinstated; the case settled with no final ruling on EMF.
10.	Utah Power & Light	Gerald Hanson v. Utah P&L (farm in Idaho)	Alleged interference with farm animal/dairy cattle production; $8 million claimed; case dismissed.
11.	Kansas City Power & Light	Overland Park Substation	Utility found new site for proposed substation after local residents expressed concern over proximity to local high school.
12.	Alabama Power Co. (APC)	Allen v. APC (Civil Action 91-321); Circuit Court, Jefferson Co. Alabama.	Pending

C.5 Other

No.	Utility	Case/Project Description	Status
1.	Arizona Public Service	Century Substation	School Board examined health effects issue prior to building school near 69-kV substation and proceeded with construction of school.
2.	Baltimore Gas & Electric Company	Oakland Mills Road-Wilde Lake 230-kV Line	PSC held-line would not be undergrounded on basis of health effects.
3.	City of Austin	345-kV Loop Around City to Import Power	City Council denied original plan and required utility to study alternatives that would minimize exposure; study is pending.
4.	City of Cleveland	Inland - Lakeshore Approval Hearing	City of Cleveland had hearing before the Cleveland City Council, including EMF testimony. Council voted 18-4 to approve line in city. Subsequent appeal to state court denied in May, 1991.
5.	Central Maine Power Co.	Hydro-Quebec Tie-In	EMF was discussed in Environmental Impact Statement; line was built.
6.	Consolidated Edison	Resolution to Halt Construction: 40th St. Substation	City Council heard testimony on the EMF issue but did not render decision; substation was energized in 1985.

Other (Continued)

No.	Utility	Case/Project Description	Status
7.	El Paso Electric Company	Springville-El Paso 345-kV Line	EMF was discussed in Environmental Impact Statement; line was built.
8.	Florida Power & Light Company	Rausch v. School Board of Palm Beach	Limited access to playground.
9.	Houston Lighting & Power Company	Rainwater v. HL&P, No. 87-7058968	The case has been dismissed.
10.	Jacksonville Electric Authority	Sable Palms Elementary School (school located near 230-kV Line)	School Board held hearings; local cancer doctor asked by Board to testify; testimony that no connection between EMF and adverse health effects; no further action taken by School Board or parents.
11.	Kansas City Power & Light	Overland Park Substation	Utility found new site for proposed substation after local residents expressed concern over proximity to local high school.
12.	LADWP	Citizens for a Better Henderson v. Hodel (1985)	Citizens challenged adequacy of EIS for proposed transmission line; federal judge found that EIS provided sufficient discussion of health effects; appeals court upheld this ruling.
13.	Louisiana Power & Light	Jefferson Parish Council resolution to limit EMF exposures in transmission line ROW's & from substations	Electric fields within ROW limited to 8 kV/m and at edge of ROW 1 kV/m; magnetic exposure in ROW maximum of 30 mG for 5 hours per day. Resolution passed and will remain in effect until after 1991 session of Louisiana Legislature.
14.	Massachusetts Electric Co.	Planning construction of a 345-kV line in the town of East Greenwich	Town of East Greenwich considering moratorium on the construction of any new power lines above 115 kV; hearings have been held; more may be held; no scheduled decision yet on the moratorium.
15.	Narragansett Electric Co.	Warwick, R.I.	Town Ordinance passed to place three year moratorium on facilities 60 kV and over; Narragansett Electric will ask PUC to overturn.
16.	Nevada Power Company	Warm Springs-Eastern 138-kV Line Approval Hearing	County Board of Commissioners heard testimony on EMF and approved line.
17.	Public Service Co. of New Mexico	1984 ROW Width Hearings	EMF raised re width of ROWs; utility's ROW width request granted.
18.	Puget Sound Power & Light	Watcom Co. Wash. Initiative 4-90	Initiative to prohibit construction of transmission lines above 115 kV in urban areas: Initiative 4-90 passed by 2 to 1 majority.
19.	Salt River Project	Apache Junction School District	School Built.
20.	Wisconsin Public Service Corp.	Wisconsin Public Service Commission Case No. 9327-EI-100	Township ordinance declared void that would have required all lines above 20 kV to "reduce to the extent possible" electromagnetic field effects.
21.	Wisconsin Public Service Corp.	Hiking Trail Ordinance	City ordinance to declare deed for hiking trail under line void; PSC declared ordinance invalid.
22.	Wisconsin Public Service Corp.	Biannual Planning Hearing Before the Wisconsin PSC	Pending; Hearing on the EMF issue complete, but report not yet issued by Commission.