Epidemiology of Health Effects and Exposure to EMF

Leading Causes of Death in the U.S.

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

U.S. Life Expectancy at Birth

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.
   • 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.

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
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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...
Experimental Studies

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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 inconsistencies 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., ornithine 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
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(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 insufficient 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). Still 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 Schmit (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 stimulus for rats. In a saccharin-flavored water experiment, Creim et al. (1984) concluded that exposure of moderate duration to 60-Hz electric fields (153 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 negative 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
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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 such 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.

In Vitro Studies. 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 in vitro to EMF, depending on amplitude, frequency and exposure duration (Byus and Adely, 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., 6OCo 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 in vitro 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, Adolphc 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 (HLOG) 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 (s) 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 offspring. 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; Maffco 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 chick embryos exposed during the first two days of development, to magnetic fields with the same set of characteristics, and effects occur, they are manifested in the malformation of the offspring. Various in vivo studies using different test animals have been performed to determine if teratogenic effects occur due to EMF exposure.
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 Cherrioff (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 offspring 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

Carmacci et al. (1977, as cited in Carstensen, 1987) reported that initial increases in the adrenal hormones epinephrine and norepinephrine (which control vasoconstriction 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.
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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-hypophysial-adrenal system (affecting behavior, metabolism, maintenance of body temperature, etc.) in rats. Levels of steroids and adreno cortieotrophic 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 hypothalamic-hypophysial-adrenal system in exposed rats. Although, they did observe a statistically significant increase in growth hormone production. Michaelson and Lu (1988) showed that rates 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 aclimatized (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 experimental 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 organism's 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 affected 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 melatonin 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...
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 effects 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 Staphylococcus 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 cell-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 bimodal 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
Health Effects of Exposure to Powerline Frequency Electric and Magnetic Fields

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/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...
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(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

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stern et al (1983) &amp; Stern and Laties (1985)</td>
<td>Detection of electric fields by rats.</td>
<td>Rats detected electric fields as low as 3.0 kV/m and as high as 10 kV/m.</td>
</tr>
<tr>
<td>Kato et al (1989)</td>
<td>Exposure of rodents to electric fields to determine animals ability to detect field.</td>
<td>Body hair and whiskers of rodents vibrated when rodents were exposed to electric fields.</td>
</tr>
<tr>
<td>Stell and Adcy (1988)</td>
<td>Detection of 60-HZ electric fields by rodents as a function of circadian rhythm activity.</td>
<td>Rats exhibited no differences in detection performance during high/low activity periods, up to 25 kV/m exposure.</td>
</tr>
<tr>
<td>Smith et al (1979)</td>
<td>Exposure to power-frequency electric fields to determine effects on general activity of animals.</td>
<td>No observed effect of power frequency electric fields on general activity of animals tested.</td>
</tr>
<tr>
<td>Graves et al (1985)</td>
<td>Exposure to power frequency electric fields to determine effects on general activity of chicks.</td>
<td>General activity not affected by power frequency electric fields.</td>
</tr>
<tr>
<td>Smith and Justesen (1977)</td>
<td>Exposure of mice to 60-HZ magnetic fields to determine effects on motor behavior.</td>
<td>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.</td>
</tr>
<tr>
<td>Hjersen et al (1982)</td>
<td>Determination of avoidance of electric fields by pigs.</td>
<td>Female pigs avoided electric fields of 30 kV/m during their sleep/rest period.</td>
</tr>
<tr>
<td>Crelin et al (1982)</td>
<td>Avoidance of electric fields by rodents.</td>
<td>No avoidance in rat exposed to 100 kV/m.</td>
</tr>
<tr>
<td>Crelin et al (1984)</td>
<td>Avoidance of 60-HZ electric fields by rodents.</td>
<td>Exposure of moderate duration to 60-HZ electric fields (133 kV/m or less) did not produce taste aversion in rats.</td>
</tr>
<tr>
<td>Stern and Laties (1987)</td>
<td>Exposure to 60-HZ electric fields to determine avoidance behavior by rodents.</td>
<td>Under many conditions, fields as high as 100 kV/m were not a very aversive stimulus for rats.</td>
</tr>
<tr>
<td>Hackman and Graves (1981) Rosenberg et al (1981)</td>
<td>Exposure of rodents to electric fields to determine avoidance behavior.</td>
<td>Reactions to electric fields, sometimes lasting only a few minutes; response attributed to recognition of environmental change, to which the animal quickly adjusts.</td>
</tr>
</tbody>
</table>
### Health Effects of Exposure to Powerline Frequency Electric and Magnetic Fields

#### Table 4.1 (Continued)

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Davis et al (1984)</td>
<td>Effect on general activity level of rodents.</td>
<td>No changes in mice activity levels in the presence of DC or AC magnetic fields.</td>
</tr>
<tr>
<td>Grob et al (1988)</td>
<td>Effect on general activity level of rodents as controlled by circadian rhythms and physiochemical regulators.</td>
<td>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 35 kV/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.</td>
</tr>
<tr>
<td>Rogers et al (1988)</td>
<td>Activity/behavior patterns of baboons usually exposed to 60-HZ fields.</td>
<td>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, &quot;learning&quot; after some time that there was no danger, and returning to normal patterns. Re-exposure produced no effects.</td>
</tr>
<tr>
<td>Orr et al (1987)</td>
<td>Performance patterns of baboons exposed to 30 kV/m and 60 kV/m electric fields.</td>
<td>Responses to food reward affected by electric fields upon initial exposure; responses returned to normal within a few days.</td>
</tr>
<tr>
<td>Salzinger et al (1987)</td>
<td>Performance of rats exposed to electric and magnetic fields.</td>
<td>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.</td>
</tr>
</tbody>
</table>

#### HUMANS

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stern et al (1983)</td>
<td>Detection of electric fields.</td>
<td>Humans were able to detect electric fields between 5 kV/m and 15 kV/m.</td>
</tr>
<tr>
<td>Graham and Cohen (1985)</td>
<td>Detection of magnetic and electric fields.</td>
<td>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.</td>
</tr>
<tr>
<td>Gamberale et al (1987)</td>
<td>Performance of 26 utility linemen exposed to 60-HZ EMF in the laboratory over two days.</td>
<td>Measurements of behavioral performance, EEG, mood scales, subjective symptoms and various blood chemistry parameters revealed no statistical differences in exposed vs. control groups.</td>
</tr>
<tr>
<td>Graham et al (1988)</td>
<td>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.</td>
<td>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 &quot;windows&quot; of stimulation, i.e., for a particular frequency, some field intensities produce effects, and those intensities above/below the &quot;window&quot; don't.</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CANCER INITIATION</strong></td>
<td></td>
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</tr>
<tr>
<td>Cohen (1986); Cohen et al. (1986); Livingston et al. (1986)</td>
<td>Exposure of human lymphocytes (white blood cells) to 60-HZ EMF fields.</td>
<td>Exposed cells did not show any change or mutation in the DNA material, i.e., no evidence of cancer initiation.</td>
</tr>
<tr>
<td>Carstensen (1987)</td>
<td>Exposure of mouse bone-marrow cells to 60-HZ fields.</td>
<td>Exposed cells did not exhibit any change or mutation in the DNA material.</td>
</tr>
<tr>
<td>Reese et al. (1988)</td>
<td>Exposure of Chinese hamster ovary cells to 60-HZ fields.</td>
<td>No changes or mutations in DNA material were observed.</td>
</tr>
<tr>
<td>Nordenzon &amp; Hansson (1987)</td>
<td>Examination of human amniotic cells, exposed to sinusoidal and sawtooth magnetic fields.</td>
<td>Researchers reported chromosome damage due to magnetic exposure.</td>
</tr>
<tr>
<td>Bauchinger et al. (1981)</td>
<td>Examination of switchyard workers exposed occupationally to EMF.</td>
<td>Researchers reported no chromosome damage due to EMF exposure.</td>
</tr>
<tr>
<td>d’Ambrosio et al. (1985)</td>
<td>Exposure of bovine white blood cells to 50-HZ fields.</td>
<td>Increased percentage of chromosome aberrations in bovine peripheral lymphocytes exposed for 72 hours.</td>
</tr>
<tr>
<td>El Nahas &amp; Oraby (1989)</td>
<td>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).</td>
<td>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.</td>
</tr>
<tr>
<td><strong>CANCER PROMOTION IN VITRO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Byus and Adey (1988)</td>
<td>Exposure of cells in-vitro to EMF, to examine changes in hormone production.</td>
<td>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.</td>
</tr>
<tr>
<td>Frazier et al. (1989)</td>
<td>Tested the hypothesis that magnetic fields can promote transformation of initiated cells.</td>
<td>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.</td>
</tr>
<tr>
<td>Cain et al. (1987)</td>
<td>Exposure of cells in-vitro to EMF to determine changes in enzyme activity.</td>
<td>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)).</td>
</tr>
<tr>
<td>Fletcher et al. (1987)</td>
<td>Exposure of cells in-vitro to EMF to detect changes in cell-to-cell communication.</td>
<td>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).</td>
</tr>
<tr>
<td>Goodman et al. (1989)</td>
<td>Exposed human cells to sinusoidal with repetition rates of 60 Hz and 72 Hz.</td>
<td>Observed induced quantitative changes in messenger RNA and proteins.</td>
</tr>
<tr>
<td><strong>CANCER PROMOTION IN VIVO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leung et al. (1988a)</td>
<td>Exposure of rats to 7, 12-dimethyl benzene (x) anthracene and 60 Hz, 40 kV/m electric field compared to rats exposed to the chemical only.</td>
<td>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 rat.</td>
</tr>
</tbody>
</table>
Table 4.2 (Continued)

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

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

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graves et al (1985)</td>
<td>Exposure of more than 20,000 chick embryos to 60-HZ electric fields from 0.1 to 100 kV/m to detect effects on incubation and development at and after hatching.</td>
<td>No observed significant change in growth, development, or overall health of the exposed chick embryos.</td>
</tr>
<tr>
<td>Sikov et al (1987)</td>
<td>Exposed Hanford miniature swine to EMF.</td>
<td>Observed malformations in offspring of sows exposed to EMF.</td>
</tr>
<tr>
<td>Durfee et al (1975)</td>
<td>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.</td>
<td>No observed effects on chicken fertility, hatchability, survivability, weight gain, and behavior.</td>
</tr>
<tr>
<td>Sandstrom et al (1987)</td>
<td>Exposed fertilized hen eggs to magnetic fields with an asymmetrical saw-tooth waveform.</td>
<td>No significant increases in abnormalities were observed in fertilized hen eggs, which were exposed during their first two days of development.</td>
</tr>
<tr>
<td>Delgado et al (1982)</td>
<td>Exposure of chick embryos to low-frequency pulsed magnetic fields during early development.</td>
<td>Abnormalities reported in chicken embryos exposed to low-frequency pulsed magnetic fields. (Note: pulsed magnetic fields are not normally associated with transmission lines).</td>
</tr>
<tr>
<td>Ubeda et al (1983)</td>
<td>Exposed fertilized chick embryos to pulsed electric and magnetic fields.</td>
<td>Observed effects in chick embryos exposed during the first 48 hours of development.</td>
</tr>
<tr>
<td>Berman et al (1988a 1988b)</td>
<td>&quot;Henhouse Project&quot; 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.</td>
<td>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).</td>
</tr>
<tr>
<td>Martin (1988)</td>
<td>Exposure of chick embryos to pulsed EMF to detect effects during early development.</td>
<td>Effects observed when exposure occurred during the first 24 hours of incubation, but no effects if embryos exposed later in their development.</td>
</tr>
<tr>
<td>Martin (1989)</td>
<td>Exposure of two different chicken strains to pulsed fields.</td>
<td>Effects were observed in the White Leghorn strain, but not in the Arbor Acre strain.</td>
</tr>
</tbody>
</table>
### Table 4.3 (Continued)

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
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<tbody>
<tr>
<td><strong>REPRODUCTIVE EFFECTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seto et al (1983)</td>
<td>Exposure of rats to electric fields for three generations to detect malformations and changes in growth/development.</td>
<td>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.</td>
</tr>
<tr>
<td>Stuchly et al (1987)</td>
<td>Exposure of rats to unsymmetrical sawtooth magnetic fields to detect reproductive effects.</td>
<td>No statistical differences between rats exposed and those not exposed.</td>
</tr>
<tr>
<td>Sikov et al (1978; 1984)</td>
<td>Exposure of rats prior to mating; exposure of pregnant female rats to detect effects on fetal development, birth rates, etc.</td>
<td>No effects on fetal length and weight or on internal/external malformations; more stillbirths in one of the exposed groups.</td>
</tr>
<tr>
<td>Rommerein et al (1984)</td>
<td>Exposure of rats to an electric field to detect changes in incidence of malformed offspring.</td>
<td>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.</td>
</tr>
<tr>
<td>Lotz and Saxon (1984)</td>
<td>Exposure of Rhesus monkeys to EMF.</td>
<td>Observed reduced weight loss in males chronically exposed to EMF, but not in females.</td>
</tr>
<tr>
<td>Smith et al (1981)</td>
<td>Exposure of mice to very low electric fields to detect changes in growth and development of over 1,400 mice in 128 litters.</td>
<td>Neither fertility, litter size, stillborn/live born ratios, nor sex ratio were affected.</td>
</tr>
<tr>
<td>Benz et al (1987)</td>
<td>Exposure of 3,000 mice to EMF over 3 generations to detect reproductive/developmental effects.</td>
<td>No effects observed.</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
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<tbody>
<tr>
<td><strong>HORMONE EFFECTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carmaci et al (1977)</td>
<td>Exposure of rats to 200-kV/m electric field for six to 72 hours to detect changes in hormone levels.</td>
<td>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 neuroendocrine changes correlated with increased hormonal secretions. Elevated neuroendocrine secretions induced by exposure were within normal response experience for test animals.</td>
</tr>
<tr>
<td>Free et al (1981)</td>
<td>Prolonged exposure of rats to strong 60-HZ electric fields to determine effect(s) on hormone levels.</td>
<td>Observed slightly lowered plasma corticosterone levels, together with slightly lower testosterone and prolactin levels. Changes which may be related to alterations in episodic rhythms.</td>
</tr>
<tr>
<td>Udintsev et al (1986)</td>
<td>Exposure of rats to an alternating magnetic field (50 Hz; 200 gauss) to determine effects on hormonal balance.</td>
<td>Exposure activated hypothalamo-hypophysial-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.</td>
</tr>
<tr>
<td>Lymangrover et al (1987)</td>
<td>Exposure of rat adrenal cells to 60-HZ fields to detect changes in cellular response.</td>
<td>EMF exposure apparently stimulated cellular response to ACTH.</td>
</tr>
<tr>
<td>Kartashev &amp; Ivanovs (1983)</td>
<td>Exposure of mice to 60-HZ fields to determine effects on adrenal and thyroid systems.</td>
<td>Activation of the adrenal and thyroid system observed.</td>
</tr>
<tr>
<td>Quinlan et al (1985)</td>
<td>Exposure of rats to 60-HZ fields to detect changes in adrenal system function.</td>
<td>Failed to show any generalized activation of the hypothalamo-hypophysial-adrenal system, but an increase in growth hormone production was observed.</td>
</tr>
</tbody>
</table>
Table 4.4 (Continued)

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michaelson &amp; Lu (1988)</td>
<td>Exposure of rats to an electric field of 80 kV/m for four hours at 71-hour intervals to detect changes in adrenal gland function.</td>
<td>Rats exhibited no persistent changes in adrenal gland function, and no indication of physiologic or neuroendocrine stress.</td>
</tr>
<tr>
<td>Leung et al (1988a)</td>
<td>Exposure of rats to electric fields to detect indications of stress.</td>
<td>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.</td>
</tr>
<tr>
<td>Michaelson (1987)</td>
<td>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.</td>
<td>Sustained and intermittent 80 kV/m exposure may elicit subtle regulatory adjustment 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.</td>
</tr>
<tr>
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</tr>
<tr>
<td>CIRCADIAN RHYTHMS</td>
<td></td>
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</tr>
<tr>
<td>Reiter et al (1988)</td>
<td>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.</td>
<td>Reduced peak nighttime pineal melatonin levels and shifts in circadian rhythms. No dose-dependent relationships was observed.</td>
</tr>
<tr>
<td>Anderson et al (1987)</td>
<td>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 hormonal levels.</td>
<td>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 &quot;All or None&quot; response. Changes also noted in pineal serotonin and N-acetyl serotonin.</td>
</tr>
<tr>
<td>Groh et al (1987)</td>
<td>Exposure of rodents to 60-HZ electric fields to detect changes in circadian rhythms as evidenced by changes in hormonal production.</td>
<td>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.</td>
</tr>
<tr>
<td>Wilson et al (1981; 1986)</td>
<td>Prolonged exposure of rats to electric fields to detect field-induced changes in circadian rhythms.</td>
<td>Significantly reduced the nighttime rise in melatonin with recovery observed in less than three days after exposure cessation.</td>
</tr>
<tr>
<td>OTHER BIOLOGICAL FUNCTIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cerretelli et al (1979)</td>
<td>Long-term exposure (i.e., two months) to an electric field of 100 kV/m to detect changes in fertility.</td>
<td>No effects on rat fertility.</td>
</tr>
<tr>
<td>Sikov et al (1984); Benz et al (1987)</td>
<td>Exposure of rats and swine to identical electric fields prior to and during gestation to detect field-induced changes in mating and fertility.</td>
<td>No changes in rat or swine mating performance or fertility.</td>
</tr>
<tr>
<td>Albert et al (1984)</td>
<td>Exposure of developing rats to EMF to determine effects, if any, on growth and development.</td>
<td>Unable to demonstrate any differences between exposed and unexposed developing rats.</td>
</tr>
<tr>
<td>Fam (1980)</td>
<td>Exposure of mice to an electric field of 240 kV/m to determine field-induced effects on development.</td>
<td>Observed reduced growth in female mice, but not in males, no effect on number of offspring or surviving progenies.</td>
</tr>
<tr>
<td>Sikov et al (1984); Kooserman and Monig (1980); Hilton and Phillips (1981)</td>
<td>Prolonged exposure of various laboratory animals to electric fields to detect field-induced effects on development.</td>
<td>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).</td>
</tr>
<tr>
<td>IMMUNE SYSTEM EFFECTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hackman and Graves (1981)</td>
<td>Exposure of test animals to electric fields to detect changes in blood hormone levels.</td>
<td>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.</td>
</tr>
</tbody>
</table>
Table 4.4 (Continued)

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerretelli et al (1979)</td>
<td>Exposure of mice to 25 kV/m electric fields for up to 42 days, followed by injection with the bacterium Staphylococcus pyogenes to determine field-induced effects on immune system.</td>
<td>No differences in mortality for exposed and unexposed groups of mice.</td>
</tr>
<tr>
<td>Krueger &amp; Reed (1975)</td>
<td>Exposure of mice to 100 kV/m electric field for 21 days, and injected with influenza virus to detect effects on mouse immune defenses.</td>
<td>No differences in mortality between control and exposed mice.</td>
</tr>
<tr>
<td>Stopps and Janiszewsky (1979)</td>
<td>Examination of general health and blood chemistry of workers maintaining high-voltage equipment and transmission lines to detect field-induced effects.</td>
<td>No differences in the general health or in levels of lymphocytes (white blood cells) and other blood cells.</td>
</tr>
<tr>
<td>Morris et al (1979, 1982, 1983, and 1988)</td>
<td>Exposure of mice to 60-HZ EMF for two hours/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.</td>
<td>No observable changes in either mouse T or B lymphocyte cells.</td>
</tr>
<tr>
<td>Hellman et al (1985); Emilie et al (1985); Cantini et al (1986); Franceschi et al (1986); Cadossi et al (1986)</td>
<td>Exposure of human lymphocytes to pulsed EMF to determine any field-induced changes in cellular response to mitogens.</td>
<td>Exposure to pulsed EMF stimulated lymphocyte response to mitogens such as phytohemagglutinin, as measured by DNA synthesis.</td>
</tr>
<tr>
<td>Conti et al (1983)</td>
<td>Exposure of human lymphocytes to square-wave pulsed electric fields (not found associated with transmission lines) to evaluate field-induced effects.</td>
<td>Lectin-stimulated mitogenesis (cell division) of human lymphocytes was inhibited.</td>
</tr>
<tr>
<td>Phillips (1986)</td>
<td>Exposure of irradiated bacterial cells to 60-HZ magnetic or combined electric/magnetic fields to determine cellular immune response.</td>
<td>60-Hz magnetic fields alone, or combined EMF inhibited natural killer cell-induced cytolyosis of irradiated coliform bacteria in vitro.</td>
</tr>
<tr>
<td>Lyle et al (1988)</td>
<td>Exposure of white blood cells to 60-Hz sinusoidal electric fields to detect inhibition of the allogenic cytotoxicity of the cells.</td>
<td>Inhibition of the allogenic cytotoxicity of a normal white blood cell line was observed in the exposed cells.</td>
</tr>
<tr>
<td>Winters (1986)</td>
<td>Exposure of human and dog blood cells to extremely low-frequency EMF to determine effects on molecular binding, immune responses or protein synthesis.</td>
<td>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.</td>
</tr>
<tr>
<td>Cadossi et al (1986)</td>
<td>Exposure of cells to low-frequency pulsed EMF to examine for inhibition/stimulation of cellular responses.</td>
<td>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 &quot;window effect&quot; for specific intensities of EMF.</td>
</tr>
<tr>
<td>Franceschi et al (1986)</td>
<td>Exposure of red blood cells to pure and combined electric and magnetic fields to examine stimulative/inhibitory cellular responses.</td>
<td>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.</td>
</tr>
</tbody>
</table>
Health Effects of Exposure to Powerline Frequency Electric and Magnetic Fields

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

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Experiment</th>
<th>Observations/Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMF-CELLULAR INTERACTION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bawin and Adey (1976)</td>
<td>Exposure of chick brain tissue to EMF at varying frequencies and amplitudes</td>
<td>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.</td>
</tr>
<tr>
<td>Bellorai (1986)</td>
<td>Exposure of chick brain tissue to static magnetic fields in an attempt to replicate efflux experiments.</td>
<td>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.</td>
</tr>
</tbody>
</table>
References


Health Effects of Exposure to Powerline Frequency Electric and Magnetic Fields


Leung, P.C.; Rommerem, D.N.; Stevens, R.G.; Wilson, B.W.; Buschbom, R.L.; Anderson, L.E. 1988b. Effects of electric fields on rat mammary tumor development induced by 7, 12-dimethylbenzene (A) anthracene.
Health Effects of Exposure to Powerline Frequency Electric and Magnetic Fields


Reiter, R.J.; et al. 1988. Reduction of the nocturnal rise in pineal melatonin levels in rats exposed to 60-Hz electric fields in utero and for 23 days after birth. Science 43:2203-2206.


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 (PURAct). (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

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Final</th>
<th>Pending</th>
<th>% of Total Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siting</td>
<td>72</td>
<td>64</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td>Zoning</td>
<td>17</td>
<td>11</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Condemnation</td>
<td>78</td>
<td>67</td>
<td>11</td>
<td>39</td>
</tr>
<tr>
<td>Tort</td>
<td>12</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>22</td>
<td>19</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>201</td>
<td>168</td>
<td>33</td>
<td>100</td>
</tr>
</tbody>
</table>

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)

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, 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 sicions, 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

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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
did not know 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 Company1 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-Oklahoma 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 nearby 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 judgments 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 neither 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 permissible 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>
<thead>
<tr>
<th>Standard</th>
<th>Electric Field</th>
<th>Magnetic Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRPA (public)</td>
<td>5 kV/m</td>
<td>1000 mG</td>
</tr>
<tr>
<td>IRPA (occupational)</td>
<td>10 kV/m</td>
<td>5000 mG</td>
</tr>
<tr>
<td>United Kingdom (all)</td>
<td>10.233 kV/m</td>
<td>1630 A/m (20 G*)</td>
</tr>
<tr>
<td>Australia (public—all day)</td>
<td>5 kV/m</td>
<td>0.1 mT</td>
</tr>
<tr>
<td>Australia (public—limited day)</td>
<td>10 kV/m</td>
<td>1 mT</td>
</tr>
<tr>
<td>Australia (occupational—all day)</td>
<td>10 kV/m</td>
<td>0.5 mT</td>
</tr>
<tr>
<td>Australia (occupational limited day)</td>
<td>30 kV/m</td>
<td>5 mT**</td>
</tr>
</tbody>
</table>

* Flux density in tissue
** Maximum 2 hours per day
Exposures to electric fields below 10 kV/m, no conclusions on the existing studies. For intermittent reviewed the existing worldwide research and reached Freaucncy c. The World not unduly within the population-based and occupational epidemiologie studies, they conclude that if the risks are real, they are proves 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 epidemiologie studies, they conclude that if the risks are real, they are within the range regarded as "tolerable" and "should not unduly concern individuals." (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 epidemiologie 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)

8.5.2. 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