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Health Effects of Low Frequency Electric and Magnetic Fields

Executive Summary
June 1992

Prepared by
An Oak Ridge Associated Universities Panel
for
The Committee on Interagency Radiation Research and Policy Coordination

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ORAU Panel on Health Effects of Low Frequency Electric and Magnetic Fields

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HEALTH EFFECTS OF LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS

Executive Summary

In October 1989, the U.S. Department of Labor (DOL) requested the assistance of the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC) in evaluating a series of articles in the popular press reporting various health effects from exposure to electric and magnetic fields. The DOL was concerned particularly about reports of cancers resulting from transmission lines and household appliances and reproductive problems attributed to video display terminals. In response to the DOL request, CIRRPC asked Oak Ridge Associated Universities (ORAU) to establish a panel and conduct an independent scientific review and evaluation of the reported health hazards of exposure to extremely low frequency electric and magnetic fields (ELF-EMF),* especially those related to cancer and to reproductive and neurophysiological effects. The ORAU panel was then selected to include members from the scientific disciplines required to perform a comprehensive review of the exposure data and reported biological and health effects. The panel was asked to focus on the fields at power frequencies (15-180 Hertz [Hz or cycles per second]) and video display terminal frequencies (10-30 kilohertz [kHz]), the frequencies that appeared to be of greatest public concern. The panel was not asked to review the scientific literature, guidance, and standards relative to higher frequencies in the electromagnetic spectrum above 30 kHz, which would have included radio, microwave, and radar frequencies.

The panel reviewed about 1,000 journal articles published within the last 15 years. The statement of work specifically asked the panel to evaluate the literature with regard to (1) the strength of the evidence that electric and magnetic fields cause the particular

*By international convention the frequency range of 30 to 300 Hz is described as "extremely" low frequency (ELF) and the range of 3 to 30 kHz as "very" low frequency (VLF). For convenience, this report uses the acronym ELF-EMF to designate the electromagnetic fields (EMF) associated with both the extremely low and very low frequency ranges.

phenomena being reported; (2) the biological basis for potential adverse human health effects; (3) the dose-effect relationship between the fields and adverse human health effects; (4) the uncertainties involved in the epidemiological studies; (5) the strengths and limitations of laboratory and theoretical studies; and (6) the adequacy of available data upon which to base reasonable quantitative risk assessments. In addition, although the panel's work statement did not expressly ask the panel to identify research needs, it did request that the panel identify what additional information is needed to develop such assessments.

The panel met seven times between September 1991 and May 1992 to hear tutorials on specific issues, discuss input for topical chapters, and develop overall conclusions and recommendations. In addition, the panel members worked individually, in small groups, and with other independent consultants, as required. While the particular expertise of the panel members was utilized to draft chapters on specific topics, the final report represents the collective views of the members.

This Executive Summary and the panel's complete report first describe electric and magnetic fields and how health problems in a population are studied. They then consider the reported effects of electric and magnetic fields on cell growth, cancer, reproduction, and neurobehavioral responses. The panel's conclusions and recommendations, based on the details developed in each chapter, are given at the end of the Executive Summary and in the final chapter of the complete report.

ELECTRIC AND MAGNETIC FIELDS

We live our lives immersed in electric and magnetic fields, both internally and externally, from natural and man-made sources. Natural sources include those associated with the normal physiologic functions of the body and the magnetic field around the Earth. Man-made electric fields and magnetic fields are produced, for example, in the generation, distribution, and consumption of electric power. We tend to take the services and conveniences provided by electric power for granted. Neither the natural fields produced by the magnetized Earth, nor the man-made electric and magnetic fields are visible, although their presence is observable with appropriate devices, e.g., a radio or TV receiver or a magnetic compass. This section describes the fields, indicates the strengths of typical fields in various situations, and outlines the coupling of fields outside the human body to sites inside the body.

There is a large variation in the frequencies produced by different sources and appliances we utilize: powerline frequencies are 50 or 60 Hz; video display terminals (VDTs) and television receivers produce time-varying (alternating) electric fields and magnetic fields that are about 15 kHz and multiples thereof; and radio frequencies are around one million Hz for AM radio and about 100 times higher for FM radio. As noted earlier, this review does not cover these higher frequencies.

At powerline and VDT frequencies, the electric field and the magnetic field can be considered separately. The electric field is related to the voltage on the line relative to ground. Voltages are either 110 or 220 volts (V) in homes, about 12,000 V on distribution lines, and much higher on major transmission lines. The magnetic field is related to the flow of current, i.e., electrons, in the line and is measured in amperes (A). A circuit in a home is usually fused for 15 or 20 A, which limits the current in the circuit. A small household appliance such as a toaster may draw 10 A or less. The currents in distribution lines and transmission lines are higher, since they serve progressively more customers.

Table 1 presents the range of typical values of electric and magnetic fields encountered in daily life. The range clearly illustrates the orders of magnitude differences in the electric and magnetic fields associated with various sources of exposure. Substantially higher fields may be encountered in industrial and laboratory situations. The strengths of these electric and magnetic fields decrease rapidly with distance from the source.

A person can be shielded relatively easily from external electric fields by a conducting box (screen room), a house, or an office, but not easily from magnetic fields. In addition, wiring configurations often can be arranged to minimize both the electric and magnetic fields produced by these common sources.

The penetrations of electric fields and of magnetic fields into and through the human body are very different. The ambient electric field unperturbed by the presence of the human body can be measured or calculated with some precision. However, the body is a complicated conductive dielectric with different tissues having different conductivities and permittivities. Such a conducting medium distorts the original electric field so as to reduce it by enormous (typically, a hundred million at powerline frequencies) factors inside the body. At the same time, the field external to the body can be increased by factors of 10 to 100 by the body itself acting as a conductor. The result is that only estimates of the internal fields are available, and these estimates vary from about one millionth to one-hundred millionth of the original, unperturbed external electric field.

Table 1. Typical Electric and Magnetic Fields Encountered in Daily Life Produced at Powerline Frequencies

Situation	Electric Field (volts/meter)	Magnetic Field (milligauss)
Home wiring	1-10	1 - 5
At electrical appliances	30-300	5-3000
Under distribution lines serving homes	10-60	1-10
Inside railroad cars on electrified lines	---	10-200
Under high-voltage transmission lines	1000-7000	25-100

Note: The static background is about 120 volts/meter from the Earth's electric field and about 500 milligauss from the Earth's magnetic field.

Because of this enormous attenuation, the electric fields listed in Table 1 are reduced to levels which are negligibly small compared to the normal background electric fields in the body generated by thermal fluctuations. For a representative cell diameter of 20 microns (micrometers) having a resistivity typical of body tissue (about 2 ohm-meters), these unavoidable thermal fields amount to about 0.02 volt/meter (V/m) at body temperature in a bandwidth of 100 Hz. Hence, electric fields of the order of a million V/m would be required outside the body to produce fields across a cell that are of the same order of magnitude as the unavoidable thermal fields.

In contrast to the external electric field situation, magnetic fields are unperturbed by the human body and penetrate without attenuation. This transparency of the body to magnetic fields comes about because the body contains almost no magnetic material. Internal electric fields are generated within the body by these time-varying magnetic fields through a well-known mechanism called the Faraday effect. For magnetic fields in the range shown in Table 1, these induced electric fields are also very much smaller than the unavoidable thermal electric fields across the cell.

Even the highest magnetic fields in Table 1 (3000 milligauss [mG] from a spiral hot plate) would not induce current densities comparable to those naturally occurring in the body. Moreover, order-of-magnitude reductions of these and other magnetic fields produced by electrical appliances and distribution lines can often be achieved by simple changes in wiring configurations that reduce the distance between wires carrying oppositely flowing currents. For example, the magnetic fields from electrified railroads have been substantially reduced by the adoption of out-of-phase feeder lines to provide current to the system in opposing directions at frequent intervals along the route; the use of twisted pair wiring in armored cable ("BX cable") can reduce background fields from house wiring well below the 1 mG level; and the magnetic fields from spiral hot plates can be reduced by an order of magnitude by the adoption of bifilar windings. Although there is no firm evidence to indicate that magnetic fields associated with common household appliances are biologically harmful, the use of minimum-field wiring configurations would be prudent and would also minimize interference with other electronic devices.

The sections that follow deal with the issues of whether these fields produce effects in the body, whether the effects are harmful, and how solid the evidence is for these effects.

DISEASES IN HUMAN POPULATIONS

Most of the reported findings of associations between the occurrence of a disease and ELF-EMF are the results of epidemiologic studies and, therefore, depend on an understanding of the scientific principles involved. In brief, epidemiology is the study of how disease is distributed and how various factors determine this distribution. The ideal way to look at the risks and causes of human disease is to study human beings themselves. Although the causation of human disease can also be studied in animals, no matter how well an animal study is conducted, at the end of the study the problem of applying the findings to human populations remains.

The objective of epidemiologic studies is to determine whether an association exists between a certain exposure, such as from an electric or magnetic field, and a certain disease or other health outcome, usually by estimating the relative risk. The relative risk is the ratio of the risk of disease in a population of exposed individuals to the risk of disease in a population of unexposed individuals, which is often referred to as a baseline or control population.

$$\text{Relative Risk} = \frac{\text{Risk in exposed individuals}}{\text{Risk in unexposed individuals}}$$

If the relative risk is significantly greater than one, is the association real or spurious, due to a bias in the study resulting from a defect in the design or conduct of the study? For example, an observed association may be spurious if it results from the fact that the data were not collected properly. Even when the observed association is real, is it because the exposure causes the disease, or because both the exposure and the disease are caused by, or are associated with, some third factor? Such an association due to other often unrecognized factors is not a spurious association; however, the association is a noncausal one. The reported findings of increased risk of cancer, in particular, resulting from ELF-EMF exposures must be considered in this light.

EFFECTS ON GROWTH CONTROL

The potential biological effects of electric and magnetic fields on cells and tissues, particularly with respect to cancer, reproductive effects, and developmental disorders, must be addressed systematically in terms of disturbances of growth control. The challenge is to identify and quantify the components in the regulatory processes controlling cells that could be influenced by electric or magnetic fields in a way that is related to these tissue disorders. This challenge includes pursuing experimental approaches using a broad spectrum of mammalian cells and tissues, including skeletal tissues (bone and cartilage). Examination of effects on biochemical and molecular parameters, as well as on cell shape and structure as related to cell function, must be considered.

Often, assessments of biological effects are initially made from studies on bacteria and lower eukaryotic (nucleated) cells. This has indeed been the case in the evaluation of electric and magnetic field exposures on cell proliferation and differentiation. However, caution must be exercised in extrapolating from such studies when assigning risk to humans from electric and magnetic field exposures. These systems exhibit structural and functional simplicity compared to mammalian cells.

It must be appreciated that bacteria and lower eukaryotes do not develop cancer, so that one must guard against concluding that induced mutations or perturbations in growth regulation in these systems are indicative of cancer risk in human cells. Cultured mammalian cells provide a system for experimentally addressing the influence of electric and magnetic field exposure. While it goes without saying that cultured mammalian cells cannot be accepted as the equivalent of cells within human tissues, they do provide an opportunity to observe systematically a spectrum of parameters associated with growth control and the relationship between proliferation and differentiation.

Based on the limited results that are available, it is speculative to propose mechanisms by which electric and magnetic fields may potentially influence cell growth. Cancer is a multistep process with three principal stages--induction, promotion, and progression--and each can be evaluated experimentally with respect to effects of EMF exposure. From the published studies, evidence is lacking to demonstrate that electric or magnetic fields act as cancer initiators by altering structural properties of DNA, function as cancer promoters by inducing or accelerating cell growth, or influence tumor progression.

That ELF-EMF exposure may influence cell proliferation is evident from the development of effective therapeutic applications of pulsed electromagnetic fields prompted by reports of EMF-promoted bone healing. The development of optimal conditions for the use of electromagnetic fields to repair nonunion fractures has necessitated the evaluation of an extensive series of field exposures. The reported results from both clinical and laboratory studies indicate that variations in pulse characteristics produce different responses. From the standpoint of risk assessment, patients have been monitored to date only over a short period of time following EMF exposures, and no aberrations with respect to cell structure or tissue organization have been observed. However, this finding should not detract from the importance of pursuing studies to elucidate long-term effects, since this is a key issue from a health risk perspective.

EPIDEMIOLOGIC STUDIES OF CANCER

The study of cancer in relation to extremely low frequency electric and magnetic field (ELF-EMF) exposures in humans began with the 1979 publication of a study of childhood cancer in Denver. Since that time, several other studies have explored associations between various measures of *residential* ELF-EMF exposures and cancer risk. A large number of studies have also examined cancer risk among adults with respect to *occupational* ELF-EMF exposures. In the occupational studies, exposure has been assessed for the most part by the identification of persons who have worked in "electrical" occupations and industries. Among both children and adults, the focus has narrowed to brain cancer, leukemia, and adult male breast cancer (in a small number of very recent studies).

The most cited studies of residential ELF-EMF exposures in relation to cancer are two studies of childhood cancer in Denver and a study of childhood leukemia in Los Angeles. High-current home wiring configurations were associated with the risk of childhood leukemia in all three studies and with the risk of brain cancer in the two Denver studies. However, measurements of in-home magnetic field strengths in the second Denver study and the Los Angeles study did not demonstrate the increase in strength of association that would have been expected from a more relevant measure of exposure.

Neither significant correlations between wiring codes and short-term magnetic field measurements nor other data such as national power consumption trends directly address the crucial question of how present short-term measurements compare with wiring codes as indicators of long-term magnetic field exposures. In the absence of evidence, wiring codes and short-term measurements should be treated not only as proxies of long-term exposure to ELF-EMF, but also as proxies of socioeconomic selection factors. However, it is not reasonable to dismiss the causal hypothesis on the basis of the essentially negative results based on actual measurements of ELF-EMF.

If the apparently consistent associations between high-current wiring configurations and childhood leukemia and brain cancer are not a result of an underlying causal effect of magnetic fields, some other explanation for these associations must exist. The only direct way to answer these questions is to conduct additional studies of childhood leukemia and brain cancer, gather information on additional potential risk factors for these cancers, and alter the methodologic approaches so that the potential for control selection bias is minimized.

Studies of adult brain cancer and leukemia in relation to residential ELF-EMF exposures do not show consistent associations with wiring configurations. It is a significant shortcoming of the literature on adult leukemia and brain cancer in relation to ELF-EMF exposures that no residential study includes any information on exposures from occupational sources, and vice versa.

With respect to occupational studies for all leukemia, the summary relative risk is of the order of 1.1 to 1.2 (the risk for exposed persons is 1.1 or 1.2 times the risk for the unexposed persons) with tight confidence intervals.

Occupational case-control studies of central nervous system or brain tumors indicate an estimated relative risk of 1.4. However, the aggregate results from cohort studies (which are frequently considered more reliable) showed a relative risk equal to 1.0 (no excess risk from exposure) with a tight confidence interval.

Three occupational studies had reported results on ELF-EMF exposure and breast cancer in men, a rare occurrence. A cohort study of telephone employees observed no cases of male breast cancer among the company's line workers, but an excess was found among the central office workers. Two other studies, one case-control and one cohort study, found an elevated relative risk of about 2.0 for breast cancer in men. Selective reporting is a concern about the literature on occupational studies and male breast cancer. For a rare cancer such as male breast cancer, it is likely that most occupational cohorts would not observe any cases and no reports would be available for an overall epidemiologic evaluation.

Investigators are in agreement that the ascertainment of true relevant exposure in ELF-EMF studies is subject to considerable misclassification which could generate systematic underestimation of the relative risk. Thus, it can be inferred that the relative risks linking ELF-EMF to childhood cancers, *if truly elevated*, should in fact be much higher than the empirically derived relative risks, unless they have been biased upward by other methodologic shortcomings such as control selection bias. Exposure to ELF-EMF is almost universal. Per capita electricity consumption increased exponentially in this century. If a rapidly increasing widespread exposure were indeed strongly associated with childhood cancers, and if no strong countervailing trends in other risk factors were occurring, we should be witnessing an observable epidemic of childhood cancers. However, there is little, if any, evidence of such an epidemic of childhood cancer.

REPRODUCTIVE EFFECTS

One of the most difficult and complicated areas of research is that of reproductive risks. Since all reproductive problems have multiple and frequently interrelated causes and putative causes, researchers must recognize that differences in the incidence of reproductive problems between exposed and unexposed groups may be due to the differences in the groups being evaluated and not to exposures to reproductive toxins.

One difficulty in predicting the effect that an environmental exposure, such as from electric and magnetic fields, may have on the developing embryo stems from the normally observed variation in the incidence of embryonic and fetal loss with the stage of gestation. A large proportion of embryos are lost in early pregnancy; 50% of the loss occurs within the first three weeks. Of the liveborn infants, 3-6% will be recognized as congenitally malformed.

Several factors affect the sensitivity of the developing embryo to environmental influences, including (1) the embryonic stage; (2) the dose or magnitude of the exposure; (3) threshold phenomena; and (4) species differences. Whether there is a variation in species susceptibility to electric and magnetic fields is a matter of conjecture, but it is evident that the actual exposure varies with the size of the organism being exposed. The dose-response relationship is extremely important when effects among different species are compared.

Support for the suggestion that ELF-EMF produces or has the potential for producing reproductive toxicity must be based on reliable and consistent evidence. The study of electric and magnetic field reproductive risks should also involve the development of plausible hypotheses.

Human reproductive studies involve three sources of electric and magnetic fields: (1) video display terminals; (2) powerlines and appliances; and (3) medical diagnostics.

Video display terminals (VDTs) expose the operator to magnetic fields. The strength of the fields vary with the manufacturer, and more recent models tend to have weaker fields. The fields are stronger just behind the terminal and at the sides than they are at the front, but are comparable to those from home TV sets. At the operator's position, magnetic field strengths are not very different from those in typical homes and offices without VDTs.

Several studies have dealt with reproductive risks from VDTs. The overall results do not indicate that pregnant women exposed to VDTs have an increased risk of birth defects or spontaneous abortions. Other reproductive problems were evaluated in only a few of the studies, but none of the other adverse outcomes were consistently more frequent in the exposed populations.

Compared to the epidemiological data on reproductive risks from VDTs, there is meager information concerning the reproductive risks from exposure to powerlines and electric home appliances and what findings are available need to be clarified. Users of certain appliances (hair dryers, motor-driven electric razors, coffee makers, or electric ranges) are exposed to higher fields because of their close proximity to the appliances.

The reported results have inconsistencies which do not permit conclusions on reproductive risks at this time.

Magnetic Resonance Imaging (MRI) diagnostic units expose humans to very strong magnetic fields. While the frequencies used in MRI are outside the range of this review, it should be noted that there are no epidemiological reproductive studies dealing with this type of exposure and no anecdotal reports of ill effects.

One approach in evaluating environmental hazards is to determine whether there is any correlation between the incidence of the disease or diseases in question and changes in exposure. The per capita electric power generation and the per capita residential consumption of power during this century have increased by nearly three orders of magnitude. It is obvious that a large proportion, probably approaching 100%, of the population is exposed to ELF-EMF from electric power generation and consumption. However, reliable data are not available for evaluating secular trends for all of the reproductive effects. The three outcomes that would be appropriate for a trend analysis are birth defects, spontaneous abortions, and stillbirths. Of these, data dealing with the occurrence of birth defects are the most accurate and, as noted earlier regarding the lack of an association between childhood cancer and electric power generation, do not show any increasing secular trend.

The study of reproductive effects in animals has involved the use of the chick embryo, chickens, cows, mice, rats, and Hanford miniature swine. The most frequently used animal model has been the chick embryo. While the chick embryo is useful for studying mechanisms, studies in whole mammalian organisms provide data that are more relevant in assessing possible reproductive effects in humans. There have been approximately 15 studies of chick embryos exposed to electric and magnetic fields, but they have not yielded consistent results and do not justify concerns about human reproductive problems.

In another animal study, pregnant cows were penned continuously for four months under a high-power transmission line. There were no changes in any of the reproductive parameters studied and no increase in the incidence of malformations in the offspring. The experiments with pregnant mice and rats varied in size, goals, quality, and reproductive effects studied. The results predominantly indicated normal reproductive performance in the exposed mice and rats even with a very high magnetic field exposure.

There are some studies that report a mutagenic effect, but the predominance of the reports indicate that electric and magnetic fields are not mutagenic agents, as are some reproductive toxins.

It has been suggested that many of the studies are negative because there is not only a threshold for some of these effects, but a ceiling as well. Thus, the concept has been introduced that ELF-EMF effects may have a narrow window of opportunity to produce biologic effects, but this aspect has not been adequately explored.

The suggested reproductive risks of electric and magnetic fields are not supported by the totality of the basic science and human studies that pertain to reproduction. However, the fact that a reproductive effect may not seem biologically plausible and that adequate documentation of an increased risk has not been demonstrated in human studies does not mean that these concerns should be summarily dismissed.

NEUROBEHAVIORAL EFFECTS

Changes in behavior may be the initial signs of nervous system problems, but performance, which is observable, represents more than just the action of the nervous system. It is often not possible to find structural damage under conditions that produce profound behavioral changes. The scientific literature has been evaluated with regard to possible ELF-EMF effects with measures of both behavioral interactions and central nervous system activities. Studies of electric and magnetic fields, and their possible effects on both behavior and the nervous system, have been conducted under a range of conditions, but the data on the relationship between measured effects in these two domains are extremely limited.

Although the detectability of an electric or magnetic field by the subject is neither a necessary nor a sufficient condition for health effects, an analysis of such stimulus functions could help elucidate mechanisms of action. Most of the literature involving human subjects shows that electric fields can be detected, but the mechanism or mechanisms of detection remain to be established. The results of several animal studies addressing the issue of avoidance of electric field exposure appear to support the conclusion that such effects, to the extent that they have been demonstrated, are small and of minor importance.

Studies based on the conditioned performance of laboratory animals have been prominently featured in the experimental literature on the learned-behavior effects of electric field exposure. The rather extensive research literature in this area, with few exceptions, provides little, if any, basis for concern regarding detrimental health effects of electric fields on learned-behavior interactions. Few firm conclusions can be drawn regarding learned-behavior effects, if any, attributable solely to electric field parameters.

Among the more controversial reports of electric field effects are those describing alterations in calcium ion exchange in brain tissue at certain field strengths and frequencies. Although more recent results appear to suggest both frequency and intensity windows for the inhibition of calcium flux from cerebral tissue, the results contrast with earlier reports that showed an increase. Regardless of the nature or direction of these changes in response to electric fields, it remains to be demonstrated that such effects represent a significant health hazard for exposed humans.

The results of a study with humans demonstrated that, when noise and vibration artifacts are eliminated, not a single subject in a population of 200 could reliably detect the presence of a magnetic field having a strength similar to that under a high voltage transmission line. However, patients exposed to intense magnetic fields (ten or more times those above) in the course of clinical MRI have reported detection of the fields.

Over the past two decades, several investigators have addressed the problem of magnetic field effects on general activity, with equivocal results. At the level of the laboratory primate and the human research subject, there is little or no indication that magnetic fields have any significant effect on general activity.

Unlike the attention directed toward observation of the avoidance of electric fields, magnetic field effects of this sort have only rarely been studied, resulting in the same conclusion found with electric fields--a general lack of avoidance, i.e., non-detection.

The literature on learned behavior in primates provides little basis for concern regarding the health effects of magnetic field exposure. Experiments with both squirrel monkeys and rhesus monkeys have involved a range of performance tasks and magnetic field parameters with negative results.

There are only a few studies that address the problem of structural changes in the central nervous system under conditions of exposure to magnetic fields. The results described remain unconfirmed and are inconsistent.

The research in this area suggests that magnetic fields may be more effective than electric fields in inducing currents capable of stimulating electrically excitable tissue. With exposures to a strong magnetic field, short-term changes in some components of the electroencephalogram (EEG) were recorded without any observable change in behavior. Several additional reports have described experiments with human subjects with no measurable effects on the EEG.

There is little evidence, one way or the other, with respect to the effects of combined electric and magnetic fields on general activity. While there are studies with animals indicating that either electric or magnetic fields alone may temporarily increase or decrease general activity levels, there would seem to be little cause for concern regarding adverse health effects of such activity changes.

Adult rats, pigeons, and monkeys were exposed to electric fields and to magnetic fields while performing a range of complex visual and temporal discrimination tasks. With field exposures limited to the periods when the animals were actually performing, no behavioral effects from the electric or magnetic fields could be discerned.

The effects of electric and magnetic field exposures with rats *in utero* plus the first eight days of life show that when these animals were subsequently trained in lever pressing for a food reward, the exposed animals showed a reduced rate of response compared to unexposed animals. The differences held up over a number of experimental conditions and persisted well beyond maturity into "old age". However, these persistent motor effects were of a small magnitude and appeared to pose little, if any, hazard to health.

The behavior of human subjects, as indicated by mood, daily life activities, reaction time, memory, time perception, and speeded addition, among other complex tasks, showed no systematic effects under various exposures.

The relationship of the pineal gland (a hormonal-secreting organ in the brain of man and other vertebrates) to circadian (day/night cycle) and seasonal rhythms is well documented. In mammals, including man, the gland responds to light impinging on the eye. The melatonin (a hormone) content of the pineal is closely correlated with the light:dark environment to which animals are exposed. Nighttime is associated with a rise in the content of melatonin in the pineal and also in the blood because the hormone is quickly released from the cells of the gland.

The ability of electric and/or magnetic fields to influence the nocturnal production of melatonin has been examined. Each of these exposures, under certain circumstances, has been shown to change the nighttime production and secretion of melatonin in mammals, including man. The magnitudes of the changes varied among the studies and have not been defined in reference to exposure parameters; nor have dose-response relationships been found.

The evidence linking alterations in cardiovascular physiology to the exposure of animals and man to either electric or magnetic fields has been inconsistent. Studies conducted in humans reported a slight increase in the interbeat interval of the heart after exposure to very high field strengths; that the reported changes significantly compromised the cardiovascular system of the exposed individuals seems doubtful.

Since electric fields are and magnetic fields may be detectable by animals, it has been suggested that the fields may constitute a stress. The most credible evidence suggests there may be a mild stress response when animals are initially exposed to the fields, but there seem to be no long-term stress responses that are a result of such exposures. Thus, functional changes of the hormone-producing glands, with the exception of the pineal, as a result of electric or magnetic field exposure are either minimal or nonexistent. On the other hand, changes in pineal melatonin production as a result of either electric or magnetic field exposure may be substantial.

CONCLUSIONS AND RECOMMENDATIONS

This review indicates that there is no convincing evidence in the published literature to support the contention that exposures to extremely low frequency electric and magnetic fields (ELF-EMF) generated by sources such as household appliances, video display terminals, and local powerlines are demonstrable health hazards.

Epidemiologic findings of an association between electric and magnetic fields and childhood leukemia or other childhood or adult cancers are inconsistent and inconclusive. No plausible biological mechanism is presented that would explain causality. Neither is there conclusive evidence that these fields initiate cancer, promote cancer, or influence tumor progression. Likewise, there is no convincing evidence to support suggestions that electric and magnetic fields result in birth defects or other reproductive problems. Furthermore, any neurobehavioral effects are likely to be temporary and do not appear to have health consequences.

The lack of converging epidemiological and biological support for the occasionally reported adverse health effects is consistent with calculations of quantities based on fundamental laws of physics for describing electric or magnetic fields. These calculations show that the electric and magnetic fields induced in the human body from external ELF-EMF sources are very weak and generally much weaker than intrinsic fields created by the normal, natural thermal movement of ions within the body. Given this lack of conclusive evidence, any assessment of a health risk associated with fields emitted by these sources would be speculative and seemingly unjustified.

Although exposure to ELF-EMF does not appear to constitute a public health problem, there is evidence that these fields may produce some biological effects, such as changes in the pattern of secretion of the hormone melatonin and enhancement of healing of bone fractures. These findings and those described elsewhere in this report suggest areas of some scientific interest and warrant consideration for further research. However, in considering such research, attention should be given to the discussion and suggestions outlined in the appropriate sections of this report.

This review does not provide justification for a major expansion of the national research effort to investigate the health effects of ELF-EMF. In the broad scope of research needs in basic science and health research, any health concerns over exposures to ELF-EMF should not receive a high priority.

Printed in the United States of America. Copies of the complete report are available from the National Technical Information Service (NTIS) and the U.S. Government Printing Office (GPO).

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