Supplemental Materials Submitted at April 3 Public Hearing

Petty 4/3
(32 Reports on studies)

SELECTED ARTICLES ON HAZARDS OF ELECTROMAGNETIC FIELDS

WITH ABSTRACTS

Adey, W.R.
EVIDENCE FOR TISSUE INTERACTIONS WITH MICROWAVE AND OTHER NONIONIZING ELECTROMAGNETIC FIELDS IN CANCER PROMOTION, IN "The Biophysics of Cancer," First International Seminar, Charles University, Prague, July 1987

Cell membranes have been identified as a prime site of athermal interaction with low frequency EM fields and with microwave fields amplitude-modulated at frequencies below 100 Hz. These fields modulate signals to the cell interior initiated at cell surface receptors by hormones, antibodies and neurotransmitters and by chemical cancer promoters. Cancer promotion may involve joint action of EM fields and cancer-promoting substances at cell membranes, with distorted inward signals from the membrane to the nucleus and to other intracellular organelles.

Adey, W.R.
HEARINGS ON HEALTH EFFECTS OF TRANSMISSION LINES, TESTIMONY OF DR. W. ROSS ADEY, presented to the U.S. House of Representatives, Subcommittee on Water and Power Resources, Oct. 6, 1987

Adey urges that much further research is needed in order to explore potential health hazards from exposure to environmental EM fields. Contrary to the theories behind present safety standards, he does not feel that "tissue heating," such as occurs with higher frequency fields, is necessarily the threshold for injury. Neither laboratory findings nor epidemiological studies can yet offer categoric evidence that major health problems from exposure to EM fields are probable. However, results from animal tissue and cellular research strongly suggest tissue interactions that would initiate pathological responses, including cancer promotion.

Adey, W.R.
TISSUE INTERACTIONS WITH NONIONIZING ELECTROMAGNETIC FIELDS. Physiological Reviews, 61:435-514, 1981.

In the last 50 years there has been an exponential growth of man-made electromagnetic fields, associated with communication systems that now blanket the earth and with a vast and ever-increasing network of electric power distribution systems. Yet, although many of the most important fundamental observations on physical effects of light and other nonionizing electromagnetic radiations were made more than 100 years ago, knowledge of their biological effects has remained minimal. The questions of adequate controls in experiments with low-level electromagnetic fields is often difficult to evaluate. Manipulation of the EM environment of tissues with nonionizing energy sources has disclosed new classes of molecular events of fundamental importance in cell biology. Familiar biological doctrines of excitatory processes based on ionic shifts toward or away from equilibrium conditions do not pertain in these models.

Bawin, S.M., L. Kaczmarek, and W.R. Adey
EFFECTS OF MODULATED VLF FIELDS ON THE CENTRAL NERVOUS SYSTEM, Annals of the New York Academy of Science, 247:74-81, 1975.

The existence of brief epochs in which electro-encephalographic and neuronal activities are strongly correlated has been repeatedly established in different areas of the brain.

Indeed, extremely weak vhf fields [147 MHz, 1 mW/cm^2], amplitude modulated at brain wave frequencies, have been shown to strongly influence spontaneous and conditioned EEG patterns in the cat. The hypothesis was offered that the weak electrical forces induced in the brain were modifying the excitability of the central neurons and that these changes were reflected in the recorded transient EEG episodes.

The chick forebrain, being so highly sensitive to small perturbations of the extracellular concentrations of either divalent cations, was therefore chosen for investigating, in vitro, the possible interactions between extracellular weak voltage gradients, induced by vhf radiations, and ionic movements in cerebral tissue.

Bibliography
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Becker, Robert O., and Adam J. Becker
AN ANALYSIS OF THE EFFECTIVENESS OF REGULATORY AGENCY RESPONSES TO A SITUATION INVOLVING PERCEIVED HEALTH EFFECTS FROM MICROWAVE RADIATION, Journal of Bioelectricity 5(2): 229-231 (1986)

The issue of whether exposure to electromagnetic radiation can have deleterious effects on human health has received widespread attention in both the popular and scientific press. Recent studies have shown that such effects can be derived even from fields of very small strengths. Given this concern, it might prove useful to examine the capacity of federal and state agencies concerned with the maintenance of public health to cope with this problem. Using the case of the Vernon Township, New Jersey as a primary example, the authors find that their effectiveness is apparently compromised by a variety of factors, raising questions concerning their capacity to deal with this particular case, and with their past and future performance on this issue as a whole.

Becker, Robert O. and Gary Selden
THE BODY ELECTRIC: ELECTROMAGNETISM AND THE FOUNDATION OF LIFE, Yew York, Wm. Morrow & Co. 1985

Chapter 14 discusses the various rhythms and cycles in nature that can be linked to fluctuations in the earth's electromagnetic fields. Some studies have demonstrated a link between human behavior and these fields. In Chapter 15, electromagnetic fields and electromagnetic radiation are explained and their prevalence in the human environment has increased exponentially. Early experiments with microwaves to determine their effect on human behavior found some disturbing results. Becker discusses his involvement with the Navy during the ELF program proposals, and the Navy's subsequent suppression of reports that expressed concern over potential health hazards from the project.

Blackman C.F., S.G. Benane, and D.E. House.
EFFECT OF AMBIENT LEVELS OF POWER-LINE-FREQUENCY ELECTRIC FIELDS ON A DEVELOPING VERTEBRATE, Bioelectromagnetics 9(2), 1988.

Fertilized eggs of domestic chickens were exposed continuously during their 21-day incubation period to either 50- or 60-Hz sinusoidal electric fields at an average intensity of 10 Vrms/m. Within 1.5 days after hatching, the chickens were removed from the apparatus and tested. The test consisted of examining the effect of 50- or 60-Hz electromagnetic fields on efflux of calcium ions from the

chicken brain. These results demonstrate that exposure of a developing organism to ambient power-line-frequency electric fields at levels typically found inside buildings can alter the response of brain tissue to field-induced calcium-ion efflux.

Bowman, J.D., D.H. Garabrant, E. Sobel and J.M. Peters
EXPOSURES TO EXTREMELY LOW FREQUENCY (ELF) ELECTROMAGNETIC FIELDS IN OCCUPATIONS WITH ELEVATED LEUKEMIA RATES, Applied Industrial Hygiene 3(6):189-194, 1988.

In previous epidemiological studies, elevated leukemia rates have been found in a collection of occupational categories of "electrical workers." In this study, spot measurements were taken of the Extremely Low Frequency (below 100 Hz) electric and magnetic field exposures of "electrical workers" at 114 work sites at an electric utility, an aerospace firm, a municipal government, motion picture theaters, and TV repair shops. For comparison, the fields were measured in 18 residences and 3 offices. For magnetic fields, the 95th percentile of the residential measurements was exceeded by 59 percent of the occupational measurements, covering all the "electrical worker" job categories with the exception of radio operators. The highest magnetic field encountered was on a battery-powered fork lift operator, which had not been considered an "electrical worker" occupation previously. Only 25 percent of the occupational electric fields were above the 95th percentile measured in residences, and these were all in the job categories for power line workers, power station operators, and TV repairers. This survey indicates that many "electrical workers" have some exposures to elevated fields. However, the wide variability in field exposures over time and between workers will necessitate better exposure measurements to assess more rigorously the association between leukemia rates and electromagnetic fields.

Brodeur, Paul
ANNALS OF RADIATION: THE HAZARDS OF ELECTROMAGNETIC FIELDS, New Yorker, (3-part series), Pt. 1 - June 12, 1989, p. 5; Pt. 2 - June 19, 1989, p. 47; Pt. 3 - June 26, 1989, p. 39.

The author presents an overview of the controversy over studies on harmful effects of overhead power lines and electromagnetic fields in our environment. These articles are adapted from his work, CURRENTS OF DEATH.

Calle E.E. and D.A. Savitz
LEUKEMIA IN OCCUPATIONAL GROUPS WITH PRESUMED EXPOSURE TO ELECTRIC AND MAGNETIC FIELDS. New England Journal of Medicine 313:1476-1477, 1983.

Recent reports have suggested an association between employment in occupations with presumed exposure to electrical and magnetic fields and an elevated risk of leukemia, particularly acute leukemia. To examine this hypothesis, we have analyzed mortality data from the state of Wisconsin for 10 "electrical" occupations. The occupational groups were those used by Milham and Wright, et al.

In general, recent reports on this topic do not show a consistent pattern of excess leukemia for individual occupational groups, with the possible exception of radio and telegraph operators.

The three occupational groups contributing the greatest numbers of excess deaths in Washington State (electricians, aluminum workers, and power-station operators) were not associated with an increased risk in any other study.

The available evidence concerning the possible association between occupational field exposure and leukemia risk should be viewed with caution until work-place exposures are more realistically considered and adequate epidemiologic studies are conducted on particular cohorts of interest.

Deadman, J.E., M. Camus, B.G. Armstrong, D. Cyr, G. Theriault, P. Heroux, and M. Plante
OCCUPATIONAL AND RESIDENTIAL 60-h ELECTROMAGNETIC FIELDS AND HIGH-FREQUENCY ELECTRIC TRANSIENTS: EXPOSURE ASSESSMENT USING A NEW DOSIMETER. Journal of the American Industrial Hygiene Association 49(8): 409-419, 1988.

One problem that has limited past epidemiologic studies of cancer and exposure to extremely low-frequency (0-100 Hz) electric and magnetic fields has been the lack of adequate methods for assessing personal exposure to these fields. A new 60-Hz electromagnetic field dosimeter was tested to assess occupational and residential exposures of a group of electrical utility workers and a comparison background group over a 7-day period. Comparing work periods only, utility workers' exposures were significantly higher than background levels by a factor of about 10 for electric (E) and magnetic (B) fields and by a factor of 171 for high-frequency transient electric (HFTE) fields. When overall weekly time-weighted averages combining work and non-work exposures were compared, ratios of the exposed to background groups were

lower. B and HFTE exposure ratios remained statistically significant, with values of 3.5 and 58, respectively, whereas the electric field exposure ratio was no longer significant, with a value of 1.7.E-field exposures of the background group were the highest during the non-work period, probably reflecting the use of electrical appliances at home. Residential E- and B-field exposures were in the same range as published results from other surveys, whereas occupational E-field exposures tended to be lower than exposures reported in other studies. The high variability associated with occupational exposures probably accounts for the latter discrepancy.

Easterly, C.E.
CANCER LINK TO MAGNETIC FIELD EXPOSURE: A HYPOTHESIS, American Journal of Epidemiology, 114(2): 169-174, Aug. 1981.

Methodology is compared between the Wertheimer/Leeper study in Denver and Fulton's Rhode Island study of childhood leukemia and power lines, in which each produced different results. The author indicates that there is a growing database re: increases and decreases in cellular reproductive rate and function consequent to magnetic field exposure. (See entries under Fulton and Wertheimer.)

Foster, Kenneth R. and Arthur W. Guy
THE MICROWAVE PROBLEM, Scientific American, 255(3): 32-39, Sept. 1986.

Authors discuss the issue of whether low levels of microwaves are a hazard and the controversy over acceptable exposure limits. No clear-cut damage to human beings from low level radiation has been demonstrated. On the other hand, exposure to low levels of microwaves cannot be proven free of hazards. Authors do not present a viewpoint as to whether low levels of microwaves can be hazardous. They do describe the process by which known hazards have been quantified. Guy helped to revise the 1982 revision of the ANSI standard re human exposure to microwaves; the authors review the development and rationale behind this standard.

Fulton, J.P., S. Cobb, L. Preble, L. Leone and E. Forman
ELECTRICAL WIRING CONFIGURATIONS AND CHILDHOOD LEUKEMIA IN RHODE ISLAND. American J. of Epidemiology 111:292-296, 1980.

The study of the relationship between childhood leukemia and electric power line configurations in the greater Denver,

Colorado, area by Wertheimer and Leeper (Am. J. Epidemiol 109:273-284, 1979) was repeated in Rhode Island, focusing on leukemia (age at onset, 0-20 years; year of onset, 1964-1978). The addresses of 119 leukemia patients and 240 controls were studied by mapping power lines within 50 yards (45.72 m) of each residence. The shortest distance between each power line and the point of the residence closest to it was found; the number and types of wires in each power line were noted. Exposure weights were assigned each type of wire using Wertheimer and Leeper's median field strength reading for each. Assuming that the strength of the field decreases with the square of the distance from its source, and that fields generated by different wires grouped in the same power line are simply additive, a summary value of relative exposure was calculated for each address. Quartile exposure values for controls were used to group patient exposures. Contrary to Wertheimer and Leeper's results, no relationship was found between leukemia and electric power line configurations. (See entries under Easterly and Wertheimer.)

Ghandi, Om P.
THE ANSI RADIO FREQUENCY SAFETY STANDARD: ITS RATIONALE AND SOME PROBLEMS, IEEE Engineering in Medicine and Biology Magazine, March 1987, 22-25.

The AMERICAN National Standards Institute (ANSI) Committee on Electromagnetic Radiation (C95.1) standard for safety levels with respect to human exposure to radiofrequency (RF) electromagnetic fields is 300 KHz to 100 GHz. In the absence of verified reports of injury to or adverse effects on the health of human beings who have been exposed to RF electromagnetic (EM) fields, the ANSI standard was based on the most sensitive measure of biological effects -- the behavioral effects on laboratory animals. Recent studies have pointed to several problems with this ANSI safety standard. These are itemized and discussed in this paper. (See related entry under Foster.)

Guy, Arthur W.
DOSIMETRY ASSOCIATED WITH EXPOSURE TO NON-IONIZING RADIATION: VERY LOW FREQUENCY TO MICROWAVES, Health Physics 53(6):569-584, Dec. 1987.

The interpretation of the effects in biological systems exposed to electromagnetic (EM) fields requires knowledge of the internal fields and absorbed energy. The quantification of the specific absorption rate (SAR) is called dosimetry. The SAR given in units of watts per kilogram is a complex function of the source configuration,

shape and size of the exposed subjects, orientation of the subject with respect to the source, and the frequency. The average and maximum SAR in the exposed subject may vary over many orders of magnitude for a given exposure level. In order to relate observed biological effects in exposed laboratory animals to safe exposure levels for man, both the fields within the environment and SAR within the exposed tissues must be determined. The environmental fields and the SAR can often be determined from EM theory, but in most cases one must rely on instrumentation such as field survey meters for quantifying the exposure fields and electric field probes, thermocouples, thermistors, fiber optic probes, thermography, and calorimetry for quantifying the SAR in the tissues of equivalent models. A combination of techniques, each valid for a particular model over a particular frequency range, have been used to determine average and peak SARs in humans and animals exposed to plane wave radiation. Though it has been considerably more difficult to quantify these quantities for near field and partial-body exposure conditions, progress is continually being made in this area.

Lin R.S., P.C. Dischinger, J. Conde and K.P. Farrell
ELECTROMAGNETIC FIELDS AND THE OCCURRENCE OF BRAIN TUMORS: AN ANALYSIS OF POSSIBLE ASSOCIATIONS. Journal of Occupational Medicine 27:413-415, 1985.

To explore the association between occupation and the occurrence of brain tumor, an epidemiologic study was conducted using data from the death certificates of 951 adult white male Maryland residents who died of brain tumor during the period 1969 through 1982. Compared with the controls, men employed in electricity-related occupations, such as electrician, electric or electronic engineer, and utility company serviceman, were found to experience a significantly higher proportion of primary brain tumors. An increase in the odds ratio for brain tumor was found to be positively related to electromagnetic (EM) field exposure levels. Furthermore, the mean age at death was found to be significantly younger among cases in the presumed high EM-exposure group. These findings suggest that EM exposure may be associated with the pathogenesis of brain tumors, particularly in the promoting stage.

McDowall, M.E.
LEUKAEMIA MORTALITY IN ELECTRICAL WORKERS IN ENGLAND AND WALES. Lancet 77:246, 1986.

Two reports from the United States have suggested an association between electrical occupations and mortality

from leukaemia, the greatest increased risk being from acute leukaemia, particularly acute myeloid leukaemia (AML) Two independent analyses on England and Wales mortality data have been used to examine this hypothesis.

These two analyses reinforce the U.S. findings. Two hypotheses to explain the leukaemia excess were suggested in the earlier reports -- exposure to electromagnetic fields (non-ionizing radiation) and exposure to chemicals and substances used in electrical components or assembly. Unfortunately, there is little consistency between the studies in the degree of risk for different electrical occupations, but the numbers are small and different occupation classifications were used.

It has been suggested that non-ionizing radiation, and mobility between occupations may make data for specific occupations difficult to interpret.

Milham, Samuel, Jr.
INCREASED MORTALITY IN AMATEUR RADIO OPERATORS DUE TO LYMPHATIC AND HEMATOPOIETIC MALIGNANCIES, American Journal of Epidemiology 127(1): 50-54, 1988

To search for potentially carcinogenic effects of electromagnetic field exposures, the author conducted a population-based study of mortality in US amateur radio operators. Ascertainment of Washington State and California amateur radio operators (67,829 persons) was done through the 1984 US Federal Communications Commission Amateur Radio Station and/or Operator License file. A total of 2,485 deaths were located for the period from January 1, 1979 through December 31, 1984, in a population of amateur radio operators which accumulated 232, 499 person-years at risk. The all-cause standardized mortality ratio (SMR) was 71, but a statistically significant increased mortality was seen for cancers of the other lymphatic tissues (SMR = 162), a rubric which includes multiple myeloma and non-Hodgkin's lymphomas. The all-leukemia standardized mortality ratio was slightly, but nonsignificantly, elevated (SMR = 124). However, mortality due to acute myeloid leukemia was significantly elevated (SMR = 176).

Milham, Samuel, Jr.
MORTALITY IN WORKERS EXPOSED TO ELECTROMAGNETIC FIELDS, Environmental Health Perspectives 62:297-300, 1985.

In an occupational mortality analysis of 486,000 adult male death records filed in Washington State in the years 1950-1982, leukemia and the non-Hodgkin's lymphomas show

increased proportionate mortality ratios (PMRs) in workers employed in occupations with intuitive exposures to electromagnetic fields. Nine occupations of 219 were considered to have electric or magnetic field exposures. These were: electrical and electronic technicians, radio and telegraph operators, radio and television repairmen, telephone and power linemen, power station operators, welders, aluminum reduction workers, motion picture projectionists and electricians. There were 12,714 total deaths in these occupations. Eight of the nine occupations had PMR increases for leukemia [International Classification of Diseases (ICD), seventh revision 204] and seven of the nine occupations had PMR increases for the other lymphoma category (7th ICD-100.2.202). The highest PMRs were seen for acute leukemia: (67 deaths observed, 41 deaths expected: PMR 162), and in the other lymphomas (51 deaths observed, 31 deaths expected: PMR 164). No increase in mortality was seen for Hodgkin's disease or multiple myeloma.

These findings offer some support for the hypothesis that electric and magnetic fields may be carcinogenic.

Milham, S.
SILENT KEYS: LEUKEMIA MORTALITY IN ELECTRICAL WORKERS. Lancet 1:812, 1985.

There is a strong association between employment in occupations with exposure to electromagnetic fields and membership in the American Radio Relay League. 97 of the 280 (35%) Washington State "silent key" death records listed occupations such as electronics technician, electrician, and radio operator, while these occupations account for only 3% of male deaths in the Washington State death file. The PMR due to leukaemia (ICD 204-207) in Washington State amateur radio operators was 264 (2 deaths observed, 0.76 expected) in those who worked in electrical-exposure occupations and 210 (3 deaths observed, 1.4 expected) in those who worked in all other occupations. Occupational exposure alone, therefore, probably does not explain the leukaemia excess in these men.

These findings offer some further support for the hypothesis that electromagnetic fields are carcinogenic.

Savitz D.A., H.A. Wachtel, F. Barnes, E.M. John and J.G. Tvrdik
CASE-CONTROL STUDY OF CHILDHOOD CANCER AND EXPOSURE TO 60-HERTZ MAGNETIC FIELDS. American Journal of Epidemiology 128(1):21-38, 1988.

Concern with health effects of extremely low frequency magnetic fields has been raised by epidemiologic studies of

childhood cancer in relation to proximity to electric power distribution lines. This case-control study was designed to assess the relation between residential exposure to magnetic fields and the development of childhood cancer. Eligible cases consisted of all 356 residents of the five-county 1970 Denver, Colorado Standard Metropolitan Statistical Area aged 0-14 years who were diagnosed with any form of cancer between 1976 and 1983. Exposure was characterized through in-home electric and magnetic field measurements under low and high power use conditions and wire configuration codes, a surrogate measure of long-term magnetic field levels. Measured magnetic fields under low power use conditions had a modest association with cancer incidence. In spite of these concerns, the results encourage further examination of the carcinogenic potential from this form of nonionizing radiation. (See related entry under Wertheimer.)

Savitz D.A. and E.E. Calle
LEUKEMIA AND OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS: REVIEW OF EPIDEMIOLOGICAL SURVEYS. Journal of Occupational Medicine 29:47-51, 1987.

Several recent surveys have presented data suggesting an increased risk of leukemia among men with occupational exposure to electromagnetic fields. Eleven pertinent data sets were compiled in order to assess the consistency of this pattern and to identify those occupations most deserving closer examination. Results for total leukemia show a modest excess risk for men in exposed occupations, with an enhanced risk elevation for acute leukemia and especially acute myelogenous leukemia. These studies are inherently limited regarding the effect of electromagnetic fields due to the absence of exposure characterization. Nonetheless, telegraph, radio, and radar operators, power and telephone linemen, and electrical and electronic engineers showed the most consistent results and warrant further study to ascertain potential occupational health hazards.

Stuchly, Maria A.
ENVIRONMENTAL AND OCCUPATIONAL EXPOSURE TO ELECTROMAGNETIC FIELDS, IEEE Engineering in Medicine and Biology Magazine, pp. 15-17, March 1987.

This paper presents general background information on exposures of the general public and workers to electromagnetic radiation from various sources. Environmentally encountered fields are generally low, the main sources of exposure being electricity distribution systems, electrical appliances, other electrical and electronic

devices, and radio and television broadcasting waves. Workers in some occupations are exposed to high-intensity fields. Unless adequate control measures are implemented, these exposure levels may exceed recommended limits.

Thomas T.L., P.D. Stolley, A. Stemhagen, E.T.H. Fontham, M.L. Bleecker, P.A. Stewart and R.N. Hoover
BRAIN TUMOR MORTALITY RISK AMONG MEN WITH ELECTRICAL AND ELECTRONICS JOBS: A CASE-CONTROL STUDY. Journal of the National Cancer Institute 79:233-236, 1987.

The authors' data suggest that certain jobs involving the design, manufacture, installation, or maintenance of electronics or electrical equipment involve exposures that are related to excess risk of astrocytic brain tumors. Because these jobs may involve a wide variety of exposures, a specific etiologic agent cannot be identified from the present data. Results should be interpreted with some degree of caution, because when risks were calculated for specific occupations and for individual strata by duration employed, numbers in single cells were very small. Despite this limitation, our findings suggest that further investigations of electronics jobs should be conducted, with particular attention to exposures to MW/RF radiation, soldering fumes, and solvents.

Weaver, James C. and R. Dean Astumian
THE RESPONSE OF LIVING CELLS TO VERY WEAK ELECTRIC FIELDS: THE THERMAL NOISE LIMIT, Science 247:459-462, January 26, 1990.

Significant biological effects due to the exposure of cells to electric fields have been reported, including in vitro experiments involving isolated cells that demonstrated responses (for example, altered synthesis or transcription) to very weak fields. Controversy concerning the validity of weak field responses has arisen because the very small field magnitudes sometimes reported appear to be lower than allowed by thermal noise that causes randomization of cellular processes. The estimates presented here argue that concerns related to possible biological effects due to very weak environmental electric fields cannot be dismissed on the grounds of being swamped by thermal fluctuation.

Wertheimer, N. and E. Leeper
ADULT CANCER RELATED TO ELECTRICAL WIRES NEAR THE HOME. International Journal of Epidemiology 11:345-355, 1982.

Like childhood cancer, adult cancer was found to be

associated with high-current electrical wiring configurations (HCCs) near the patient's residence. Such wiring can expose occupants of the residence to alternating magnetic fields (AMFs) at a level which, though very low, may produce physiological effects. Several patterns in the data suggest that HCCs and cancer may be causally linked: (1) a dose-relationship was found. (2) The association did not appear to be an artefact of age, urbanicity, neighbourhood, or socioeconomic level. (3) The association was most clearly demonstrable where cancer caused by urban/industrial factors was least apt to obscure the effect. (4) A distinct pattern of latency between first exposure to the HCC and cancer diagnosis was seen, which is consistent with a hypothesis of cancer promotion produced by AMF exposure.

Wertheimer, N. and E. Leeper
ELECTRICAL WIRING CONFIGURATIONS AND CHILDHOOD CANCER. American Journal of Epidemiology 109:273-284, 1979.

An excess of electrical wiring configurations suggestive of high current-flow was noted in Colorado in 1976-1977 near the homes of children who developed cancer, as compared to the homes of control children. The finding was strongest for children who had spent their entire lives at the same address, and it appeared to be dose-related. It did not seem to be an artifact of neighborhood, street congestion, social class, or family structure. The reason for the correlation is uncertain: possible effects of current in the water pipes or of AC magnetic fields are suggested.

Wright, W.E., J.M. Peters, and T.M. Mack
LEUKAEMIA IN WORKERS EXPOSED TO ELECTRICAL AND MAGNETIC FIELDS. The Lancet II(8303):1160-1161, 1982.

Two recent studies have suggested an increased risk for leukaemia with exposure to electrical and magnetic fields. To test this hypothesis the authors reviewed leukaemia cases in men who were listed as having jobs with exposure to electric or magnetic fields. The data base was the Cancer Surveillance Program, a population based registry that collects information on incidence cases of cancer in Los Angeles County, information on occupation being the occupation of the patient at the time when cancer was diagnosed.

Although the number of cases in these occupations in this registry is small, the findings are consistent with

Milham's and suggest that AML is the acute leukaemia for which risk is greatest.

The precise cause of the excess of leukaemia we have observed is not clear. The occupations grouped as sharing exposure to electric and magnetic fields undoubtedly share other exposures. While significant exposure to ionizing radiation is probably not present in most of these jobs, metal fume, solvents (including benzene), fluxes, chlorinated biphenyls, synthetic waxes, epoxy resins, and chlorinated naphthalenes are other exposures that may be shared. The hypothesis that electrical and magnetic fields or other shared exposures caused leukaemia deserves further study.

Bibliography
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INTRODUCTION

The people listed on the following pages are all recognized as leaders in the field of study generally referred to as "the effect of electromagnetic fields on living systems". Each of them have made major contributions to the field. The listing is not meant to be all inclusive for there are many others, both in the United States and abroad, that could easily be included on these pages. This listing is presented only for the purpose of allowing someone not actively engaged in work in the field the ability to contact "cutting edge" people. By making such a contact, it is hoped that a more accurate and clear picture of what is actually known about the effect of electromagnetic fields on all biological systems will be obtained. This may help to mitigate the two extremely polarized positions of "everything causes cancer" or of "there is nothing to worry about" that seem to occur when the general public forms opinions about the effects upon their lives from electromagnetic fields.

Two organizations are also given, along with the current Presidents (for 1990-1991). These two international societies represent more than 700 researchers from all over the world, and each of them holds one meeting a year where the latest research results are presented and discussed. If someone needs a clear look at what the latest science is in the field, attendance at one or both of the meetings is almost mandatory.

A brief reference list is also given, but again one that is far from complete. Most of the books or periodicals listed are commonly available, and, as such, one or more of them should be easy for almost anyone to obtain for reference reading. Some of the books listed are over ten years old, but were given to indicate in some small way just how long this field has been the focus of intense study. Others of the references are from symposia held in the past few years in which the major focus has been directly on the question "do electromagnetic fields pose a threat to human health?". The question has <u>not</u> been answered, but there is no doubt that the answer (or most probably answers) is likely to be found within the next few years. It is perhaps possible that, in some small way, this symposium will help us all to a greater understanding of the scientific, medical, and social aspects of how electromagnetic fields effect biological systems.

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SELECTED REFERENCES

1. Adey, W. R., Biological effects of radio frequency electromagnetic radiation, in Interaction of Electromagnetic Waves With Biological Systems, Ed. J. C. Lin, Plenum Press, New York, p 1-33 (1988)

2. Adey, W.R., Electromagnetic Fields and the Essence of Living Systems, in Modern Radio Science, Ed. J. Back Andersen, Oxford University Press, p 1-36, (1990)

3. Baranski, S. and Czerski, P.: Biological Effects of Microwaves, Dowden, Hutchinson & Ross, Inc., Stroudsburg, Penn. (1976)

4. Becker, R. O., and Marino, A. A., Electromagnetism and Life, State University of New York Press, Albany NY, (1982)

5. Becker, R. O., and Selden G.: The Body Electric, Electromagnetism and The Foundation of Life, Quill, William Morrow, New York, (1985)

6. Blank, M., and Findl, E., Eds.: Mechanistic Approaches to Interactions of Electric and Electromagnetic Fields with Living Systems, Plenum Press, New York, (1987)

7. Fitzgerald, K., Electromagnetic fields: the jury's still out, IEEE Spectrum, p 22-35, August (1990)

8. Konig, H. L., Krueger, A. P., Lang, S., and Sonning W.: Biologic Effects of Environmental Electromagnetism, Springer-Verlag New York (1981)

9. O'Connor M. E., Bentall R. H. C., and Monahan, J. C.: Emerging Electromagnetic Medicine, Springer-Verlag, New York, NY, (1990)

10. Polk, C., and Postow, E., Eds.: Handbook of Biological Effects of Electromagnetic Fields, CRC Press, Inc. Boca Raton, Florida, (1987)

11. Skomal E. N., Man-Made Radio Noise, Van Nostrand Reinhold Company New York, (1978)

12. Wertheimer, N., and Leeper E., Electrical Wiring Configurations and Childhood Cancer, American Journal of Epidemiology, Vol. 109, #3, p 273-284, (1979)

13. Wilson B. W., Stevens R. G., and Anderson L. E., Eds.: Extremely Low Frequency Electromagnetic Fields: The Question of Cancer, Battelle Press, Columbus, Ohio (1990)

14. International Utility Symposium **Health Effects of Electric and Magnetic Fields:** Research, Communication, Regulation, Sponsored By: Electric Power Research Institute, Canadian Electrical Assocation, Edison Electric Insitiute, National Rural Electric Cooperative Association, Bonneville Power Administration, Ontario Hydro, Tronto Canada, September 16-19, (1986)

15. Electrical and Biological Effects of Transmission Lines: A Review, Prepared by : J.M. Lee, A. Burns, G.E. Lee, G.L. Reiner, F.L. Shon, and R. Stearns, U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon, October, (1985)

Leukemia Mortality
In Men Occupationally Exposed to Electric and Magnetic Fields
Washington State White Male Deaths, 1950-1979

Code	ICD Number → Malignant Neoplasm → Occupation	204 All Leukemia Obs	Exp	PMR	204.3 Acute Leukemia Obs	Exp	PMR
083	Electrical Engineers	7	6	114	2	2	97
190	Electronic Technicians	6	4	149	3	2	162
352	Radio and Telegraph Operators	5	4	111	3	1	239
421	Electricians	51	37	138*	23	13	178**
453	Power and Telephone Linemen	15	9	159	6	3	183
474	Television and Radio Repairmen	5	3	157	4	1	291
493	Motion Picture Projectionists	4	2	234	1	1	111
526	Aluminum Workers	20	11	189**	11	4	258**
691	Streetcar and Subway Motormen	3	2	175	0	0	0
701	Power Station Operators	8	3	259*	3	1	282
721	Welders and Flame Cutters	12	18	67	4	7	56
	TOTAL	136	99	137*	60	35	160*

* P < .05; ** P < .01

TABLE 3

Mortality in Aluminum Workers
White males, 1950-1981
Washington State

Cause of Death	7th ICD CODE	Deaths Observed	SPMR†	SPMR§
Malignant neoplasm of brain	193.0	14	136	169*
All lymphatic and hematopoietic cancers	200-205	48	161**	191**
Multiple myeloma	203	8	182	219*
Leukemia	204	21	169*	191**
Acute leukemia	204.3	12	236**	268**

* $P < .05$, $X_1^2 > 3.84$

** $P < .01$, $X_1^2 > 6.64$

† Standardized Proportionate Mortality Ratio computed using all deaths, all occupations.

§ Standardized Proportionate Mortality Ratio computed using deaths in laborers.

7th ICD = Seventh revision, International Classification of Diseases.

LEUKEMIA IN ELECTRICAL WORKERS

DATA BASE	CAUSE OF DEATH	RATE	NUMBER OF CASES	REFERENCE
LOS ANGELES COUNTY TUMOR REGISTRY	ALL LEUKEMIA	PIR = 129	35	WRIGHT, W.E. ET AL LANCET 11-20-82
	ACUTE LEUKEMIA	PIR = 173	23	
	ACUTE MYELOGENOUS LEUKEMIA	PIR = 207	22	
ENGLAND AND WALES VITAL STATISTICS	ALL LEUKEMIA	PMR = 98	85	MC DOWALL, M.E. LANCET 1-29-83
	ACUTE MYELOGENOUS LEUKEMIA	R.R.= 2.3 (CASE-CONTROL)	36	
SOUTH THAMES TUMOR REGISTRY	ALL LEUKEMIA	PRR = 117	113	COLEMAN, M., ET AL LANCET 4-30-83
	ACUTE LYMPHATIC LEUKEMIA	PRR = 146	12	
	CHRONIC LYMPHATIC LEUKEMIA	PRR = 129	33	
	ACUTE MYELOGENOUS LEUKEMIA	PRR = 123	33	
	CHRONIC MYELOGENOUS LEUKEMIA	PRR = 91	16	

PIR = PROPORTIONATE INCIDENCE RATIO
PMR = PROPORTIONATE MORTALITY RATIO
R.R.= RELATIVE RISK
PRR = PROPORTIONATE REGISTRATION RATIO

INTERNATIONAL CLASSIFICATION OF DISEASES
9th REVISION, 8th REVISION, 7th REVISION CONVERSION TABLE

9th	8th	7th	
001	000	043	CHOLERA
002	001	040	TYPHOID FEVER
	002	041	PARATYPHOID FEVER
003	003	042	OTH.SLMNELA.INFECT.WOUT.FOOD AS VEH.INFT
004	004	045	FLXNR-BYD.GRP.-BACILARY DYSENTERY
005	005	049	FOOD POISONING
	0051	0491	BOTULISM
006	006	046	AMOBIASIS WOUT.LIVER ABSCESS
007	007	047	OTHER PROTOZOAL DYSENTERY
008	008	047	OTHER PROTOZOAL DYSENTERY
009	009	048	UNSPC.FORMS DYSENTERY
	010	001	RESP.TB W.OCCUP.DIS.OF LUNG
011	011	002	PULMONARY TB
010	012	007	OTHER RESPIRATORY TB
012	012	007	
013	013	010	TB OF MENINGES AND CENT.NERV.SYS.
014	014	011	TB OF INTESTNS.,PERTNM.,MESNTRC.GLANDS
015	015	012	ACT.OR UNSPC.TB OF VERT.COL.
	0150	0120	ACT.OR UNSPC.TB OF VERT.COL.
	0151	0121	ACT.OR UNSPC.TB OF HIP
	0152	0122	ACT.OR UNSPC.TB OF KNEE
	0158	0123	ACT.OR UNSPC.TB OTH.,UNSPC.BONES,JOINTS
	0159	0123	ACT.OR UNSPC.TB OTH.,UNSPC.BONES,JOINTS
016	016	016	TB OF GENITO-URINARY SYSTEM
017	017	018	TB OF EYE
	0170	0140	PRIM.TB OF SKIN
	0171	015	TB OF LYMPHATIC SYSTEM
	0172	0180	TB OF EYE
	0173	0181	TB OF EAR
	0179	0182	OTHER TB OF OTHER ORGANS
018	018	019	ACT.MLT.TB SPEC.NON-PULMONARY
	0180	0190	ACT.MLT.TB SPEC.NON-PULMONARY
	0181	0191	ACUT.MLT.TB.,UNSPEC.
	0189	0192	OTH.FORMS DISSEMINATED TB
137	019	018	TB OF EYE
020	020	058	PLAGUE
	0200	0580	BUBONIC PLAGUE
	0201	0581	PNEUMONIC PLAGUE
	0209	0582	OTHER PLAGUE

PROPORTIONATE MORTALITY RATIOS FROM ACCIDENTAL CAUSES FOR SELECTED OCCUPATIONS
WHITE MALES, AGE 20+, WASHINGTON STATE 1950-1979

OCCUPATION	CAUSE OF DEATH	7TH REV. ICD CODE	DEATHS		PMR*
			OBSERVED	EXPECTED	
AIRPLANE PILOTS AND NAVIGATORS	AIRCRAFT ACCIDENTS	860-866	171	7	2443
ELECTRICIANS	ACCIDENTAL DEATH DUE TO ELECTRIC CURRENT	914	17	4	425
LOGGERS	BLOW FROM FALLING OBJECT	910	448	42	1067
ROOFERS	ACCIDENTAL FALLS	900-904	19	8	250
FARMERS	MACHINERY ACCIDENTS	912	86	22	399

*PMR = $\frac{\text{DEATHS OBSERVED}}{\text{DEATHS EXPECTED}} \times 100$

Proportionate Mortality Ratios for Selected Occupations With Previously Reported Occupational Mortality Excesses or Deficits White Males, Age 20+, Washington State 1950-1979

Occupation	Cause of Death	7th Rev. ICD Code	Deaths Observed	Deaths Expected	PMR
Chemists	Cancer of pancreas	157	6	3	222*
Clergymen	Cancer of lung	160-165	38	85	45**
Dentists	Suicide	970-979	39	17	236**
Asbestos and insulation workers	Cancer of lung	160-165	43	13	325**
Miners	Silicosis	523.0	50	2	2500**

* P < .05
**P < .01

STRENGTHS

All types of cancer

Internal and external comparisons

Consistent job function code on all workers

LIMITATIONS

Short follow-up time

Race specific New York rates unavailable

Confounding variables unknown

Exposure category from job function code at one point in time (dose of exposure cannot be estimated)

STUDY POPULATION

50,582 active male employees of the New York Telephone Company

Followed from 1976 through 1980

86 percent white

Median age about 40 years

About one third worked over 20 years

Job Type	Number of Males	Person-Years
Cable Splicers	4,547	19,453
Central Office Technicians	9,561	42,761
Outside Plant Technicians	1,385	5,985
Installation/Maintenance/Repair	13,289	57,174
All Line (includes supervisory)	31,754	137,398
All Nonline	18,828	68,669
All Employees	50,582	206,067

THE STATISTICS

$$\text{Standardized Incidence Ratio} = \frac{\text{\# observed events in study group}}{\text{\# expected events based on standard}}$$

Two standards:

1. New York State cancer rates
2. New York Telephone Company nonlinemen cancer rates

Statistical significance is based on the Poisson distribution, 95% confidence limits, two tailed test

CANCER INCIDENCE IN NEW YORK TELEPHONE WORKERS

G.M. Matanoski, E.A. Elliott, and P.N. Breysse
Johns Hopkins University School of Hygiene and Public Health
Baltimore, MD

with the cooperation of Dr. William S. Burnett and colleagues
New York State Cancer Registry
Albany, NY

Supported by NIEHS
through the Johns Hopkins Environmental Health Sciences Center

and by the Electric Power Research Institute

November 1989

OCCUPATIONAL MORTALITY ASSOCIATIONS SUBSTANTIATED IN POPULATION-BASED STUDIES WHITE MALES, AGE 20+, WASHINGTON STATE, 1950–1971

Occupation	Cause of death	7th Rev. ICD Code	Deaths Observed	Deaths Expected	PMR
Atomic energy workers	Cancer of pancreas	157	19	8.76	217
	Multiple Myeloma	203	4	1.92	208
Copper smelter workers	Cancer of lung	162.1	30	18.52	162
Aluminum workers	Cancer of lung	162.1	26	19.12	136
	Malignancy of hema-topoietic system	200-204	21	12.35	170
	Cancer of pancreas	157	13	6.37	204
Pressmen and plate printers	Cirrhosis of liver without alcoholism	581.0	18	10.84	166
	Rectal cancer	154	17	9.09	187

EXPOSURE ASSESSMENT

Electric and magnetic field exposure assessment is being conducted in order to classify linework based on exposure. Jobs associated with telephone company linework have been divided into four basic categories: outside plant technicians (traditional linemen), cable splicing technicians, installation/maintenance/repair (IMR) technicians, and central office technicians. Various work tasks and locations are being evaluated for each of the four linework categories. These tasks and work locations were selected based on job descriptions utilized by AT&T prior to divestiture and information given through contact with telephone company employees during a three day preliminary exposure assessment workshop.

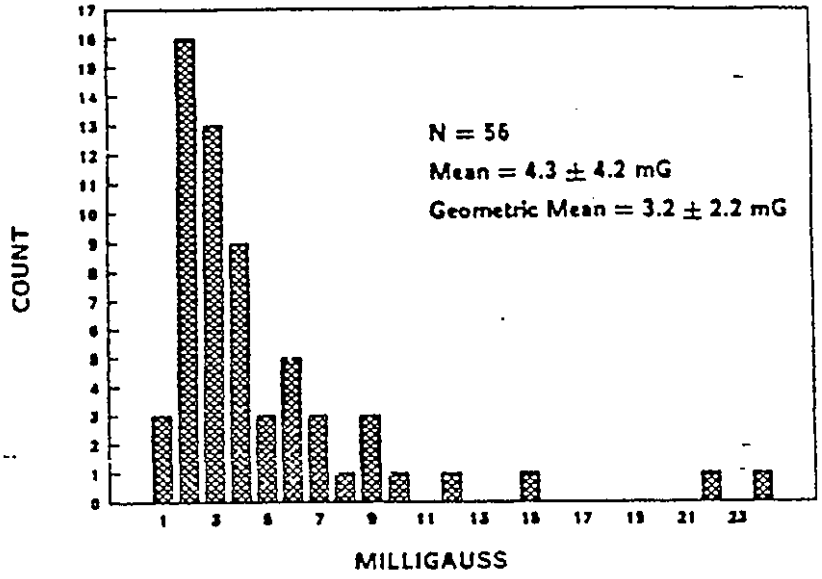
Two types of personal dosimeters are being used for this study: the EMDEX digital exposure meter and the AMEX. The EMDEX is a personal monitor equipped with a datalogger capable of measuring and recording 3-axis magnetic fields. The AMEX is a wrist-worn device which measures magnetic fields in a single axis and provides an integrated average estimate of the field strength. Data are being collected to see how the magnetic field exposure estimates for the two devices compare when used on a population of working linemen.

Full Shift Time-Weighted Average Magnetic Flux Density (mG)
by Telephone Company Job Category
1988-1989

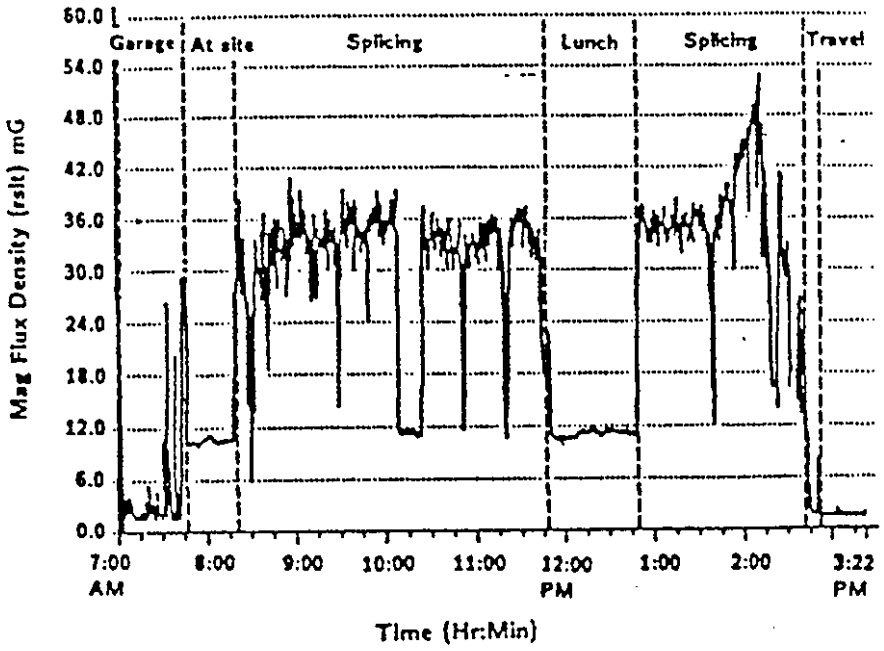
Job Category	N	Arithmetic Mean	Arithmetic Std.Dev.	Geometric Mean	Geometric Std. Dev.	Range
Cable Splicer	56	4.3	4.2	3.2	2.2	0.6 - 23.0
Central Office	34	2.7	2.4	2.1	2.0	0.6 - 10.9
Outside Plant	41	1.6	0.9	1.4	1.6	0.3 - 5.4
Install/Repair	15	1.7	0.6	1.6	1.4	0.9 - 3.1
Other*	43	1.6	1.2	1.2	2.0	0.3 - 5.1

* Nonline job titles such as supervisor, clerk, etc.

Frequency Distribution of Measures
for Cable Splicing Technicians
Full Shift Time-Weighted Average Magnetic Flux Density



Magnetic Flux Density For Cable Splicing in a Trench



Standardized Incidence Ratios (and Numbers of Cases)
for Specific Causes of Cancer by Type of Linework
New York Telephone Employees 1976-1980
Standard: Nonline Workers
Males

	Cable Splicer	Central Office	Outside Plant	Install Repair
All cancers	1.81*(40)	1.15(96)	1.15(9)	0.91(86)
All gastrointestinal	1.76(11)	1.02(20)	2.05(4)	0.84(24)
Oral	1.38(2)	2.45*(9)	2.31(1)	0.20(1)
Stomach	- (0)	# (4)	# (1)	# (4)
Colon	2.23(6)	0.54(6)	2.14(3)	0.55(6)
Lung	2.16(6)	1.26(19)	0.73(1)	1.41(23)
Leukemia	7.00*(3)	1.07(2)	- (0)	1.77(4)
Lymphoid	# (2)	# (1)	- (0)	# (3)
Myeloid	2.33(1)	0.53(1)	- (0)	0.89(2)
Brain	1.79(2)	0.90(4)	- (0)	- (0)
Lymphomas (200-202)	3.59*(5)	1.94(3)	- (0)	0.53(2)
Multiple myeloma	- (0)	# (1)	# (1)	# (2)
Breast	- (0)	# (2)	- (0)	- (0)
Prostate	4.38(3)	3.48*(9)	4.54(1)	1.02(3)
Bladder	0.60(1)	0.78(3)	- (0)	0.40(2)

* Statistically significant at the 95% level, two tail, Poisson distribution

No cases expected based on nonline rates

Standardized Incidence Ratios (and Numbers of Cases)
for Specific Causes of Cancer by Type of Work
New York Telephone Employees 1976-1980
Standard: New York State Male Rates
Males

	All men	All line	Cable Splicers	Central Office	Outside Plant	Install Repair
All cancers	0.81*(201)	0.83*(206)	1.27(40)	0.88(26)	0.86(9)	0.67(24)
Gastrointestinal	0.85(107)	0.83(66)	1.30(10)	1.19(14)	1.92(3)	0.60(20)
Oral	0.66(20)	0.71(14)	1.03(3)	1.36(3)	1.61(1)	0.12*(1)
Stomach	0.58(9)	0.88(9)	- (0)	1.13(4)	3.03(1)	0.97(4)
Colon	0.63(36)	0.77(30)	2.11(5)	0.65(4)	2.40(2)	0.50(6)
Lung	0.76*(66)	0.87(62)	1.20(8)	0.75(10)	0.44(1)	0.78(33)
Leukemia	0.77(13)	0.88(9)	2.65(3)	0.58(2)	- (0)	0.96(4)
Lymphoid	0.87(5)	1.34(5)	5.18(3)	0.79(1)	- (0)	1.32(3)
Acute & unspecified	1.16(3)	1.76(3)	7.14(1)	- (0)	- (0)	2.14(1)
Chronic	0.75(2)	1.15(2)	4.17(1)	1.11(1)	- (0)	0.95(1)
Myeloid	0.85(7)	0.74(4)	1.59(1)	0.56(1)	- (0)	0.90(2)
Brain	1.00(13)	0.70(6)	2.00(2)	1.42(4)	- (0)	- (0)
Lymphomas	0.79(25)	0.86(18)	1.96(5)	1.18(3)	- (0)	0.35(3)
Multiple myeloma	0.69(4)	1.07(4)	- (0)	0.78(1)	8.40(1)	1.30(2)
Breast	1.44(3)	- (0)	- (0)	6.48(2)	- (0)	- (0)
Prostate	0.85(31)	1.06(17)	2.45(3)	1.45(6)	1.95(1)	0.49(3)
Bladder	0.66(21)	0.53(11)	0.51(1)	0.70(3)	- (0)	0.36(3)

* Statistically significant at the 95% level, two tail, Poisson distribution

RATIONALE

Our case-control study of telephone linemen is designed only to evaluate the association of leukemia with electromagnetic field exposure. Most of the cases in that study occurred among retired workers. Two additional questions are of interest:

1. Do young workers have an increased risk of leukemia associated with electromagnetic field exposure?
2. Do linemen with electromagnetic field exposure have increased risks of any other types of cancer?

To address these questions we undertook this incidence study.

METHODOLOGY

We matched the subset of New York Telephone Company workers with the New York State Cancer Registry. Person years and events were counted if we could confirm that the person was still working for the telephone company within the study period.

Age specific New York cancer rates and rates of nonline telephone workers were applied to person years contributed by the telephone workers to determine the expected numbers of cancers. The ratios of observed to expected numbers are presented for all workers and for specific subsets of workers. Statistical significance at the 95 percent level was determined using the Poisson distribution.

RESULTS

Three observations are particularly remarkable.

1. There does appear to be an increased risk of leukemia in the young workers.
2. Cancer incidence ratios for cable splicers, the group with the highest EMF exposure, are high for almost every cancer site. Using nonline worker rates as the comparison, cable splicers have significantly high ratios for all cancers combined, leukemia, and lymphomas. These increased ratios are in keeping with a hypothesis of cancer promotion from EMF exposure.
3. Breast cancer ratios are high in central office technicians, a group with a different pattern of EMF exposure. Two cases were observed in the five year follow-up period and both occurred in central office technicians. In 1987, Stevens hypothesized that electric power use might lead to an increased risk of breast cancer (American Journal of Epidemiology 1987;125:556-561). The observed increased risk is in keeping with Stevens' hypothesis.

These data suggest that different exposures from line work appear to result in different patterns of cancer risk.

SECOND DRAFT
11 September 1987

ASSESSMENT OF OCCUPATIONAL EXPOSURES TO ELECTROMAGNETIC FIELDS

Electric Power Research Institute
Contract RP799-27

STUDY PROTOCOL

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OCCUPATIONAL MORTALITY IN WASHINGTON STATE

1950-1979

ABSTRACT

The occupational and cause-of-death information on 429,926 Washington State male deaths for 1950-1979 and 25,066 female deaths for 1974-1979 was analyzed using an age and year-of-death standardized proportionate mortality ratio program. A detailed cause-of-death analysis (160 causes) is published for each of 219 occupational categories for males and for each of 51 occupational categories for females.

The occupational mortality findings are compared with those of the Registrar General and with the published occupational mortality literature. The Washington State mortality pattern is, in general, consistent with both the Registrar General's results and with the published literature. Some of the new occupational mortality findings published in the 1950-1971 report and in this updated version have been confirmed. Others warrant follow-up. These include a lung cancer excess in workers at the ASARCO Tacoma copper smelter, increased mortality due to multiple myeloma and pancreatic cancer in workers at the Hanford atomic energy facility, and excess mortality due to cancer of the pancreas, lymphoma, leukemia, and emphysema in aluminum workers.

New findings in this report are a leukemia increase in workers exposed to electric and magnetic fields and a deficit of multiple sclerosis deaths among outdoor workers.

DHHS (NIOSH) Publication No. 83-116

Environmental Health Perspectives
Vol. 62, pp. 297-300, 1985

Mortality in Workers Exposed to Electromagnetic Fields

by Samuel Milham, Jr.*

In an occupational mortality analysis of 486,000 adult male death records filed in Washington State in the years 1950–1982, leukemia and the non-Hodgkin's lymphomas show increased proportionate mortality ratios (PMRs) in workers employed in occupations with intuitive exposures to electromagnetic fields. Nine occupations of 219 were considered to have electric or magnetic field exposures. These were: electrical and electronic technicians; radio and telegraph operators, radio and television repairmen, telephone and power linemen, power station operators, welders, aluminum reduction workers, motion picture projectionists and electricians. There were 12,714 total deaths in these occupations. Eight of the nine occupations had PMR increases for leukemia [International Classification of Diseases (ICD), seventh revision 204] and seven of the nine occupations had PMR increases for the other lymphoma category (7th ICD 200.2, 202). The highest PMRs were seen for acute leukemia: (67 deaths observed, 41 deaths expected; PMR 162), and in the other lymphomas (51 deaths observed, 31 deaths expected; PMR 164). No increase in mortality was seen for Hodgkin's disease or multiple myeloma.

These findings offer some support for the hypothesis that electric and magnetic fields may be carcinogenic.

In Washington State, all male death records for the years 1950–1982 have been coded to occupation. Analyses of the 1950–1971 data and of the 1950–1979 data have been published (*1,2*). In the 1950–1979 data set, men whose occupations were associated with electric or magnetic fields had more deaths due to leukemia than would be expected (*3*). This association has been supported in data from a Los Angeles County Cancer Registry (*4*), in Vital Statistics for England and Wales (*5*), and in a British Cancer Registry (*6*). Since three more years of data are now available, I examined the patterns of mortality in electrical workers in greater detail.

Methods

All deaths of Washington State resident men, age 20 years or older, from 1950 to 1982, were coded to occupation. This file contains 486,000 deaths. Proportionate mortality ratios (PMRs), standardized by age and year of deaths, were calculated for 158 cause-of-death groups in each of 219 occupational classes. For this analysis, the following occupations were considered to have electric or magnetic field exposures: electrical and electronic technicians, radio and telegraph operators, electricians, linemen (power and telephone), television and radio repairmen, power station operators, aluminum workers, welders and flame-cutters, and motion picture projectionists. Electrical engineers were not included, because their electrical exposures are infrequent and because of potential social class confounding of the mortality ratios. Streetcar and subway motormen were not included because of too few deaths in recent years (11 total deaths since 1970).

Aluminum potroom workers are exposed to strong magnetic fields created by the high amperage direct current (75,000 A) used in the aluminum reduction process. They are also exposed to polycyclic organic matter generated when the binder in the carbon electrodes is burned.

The welder group includes flame-cutters and gas welders who have no electrical exposures. Arc welders work near step-up transformers, but are also exposed to ozone, oxides of nitrogen and metal fumes. The motion-picture projectionists also work near step-up transformers but, like aluminum workers, have exposures to burning carbon electrodes and polycyclic organic matter.

Those electricians engaged in new house wiring have minimal electric field exposures; electricians who work for electric utilities may have high field exposures.

The workers in the other occupations are exposed to electromagnetic fields associated with alternating current flowing in wires and powerlines. The power station operators work in hydroelectric plants along the Columbia River. They are also exposed to ozone, especially when working in the turbine housings.

Results and Discussion

Table 1 presents observed and expected deaths and PMRs for those causes with significant ($p < 0.05$) ex-

*Epidemiology Section, ET-13, Division of Health, Washington State Department of Social and Health Services, Olympia, WA 98504.

MORTALITY FROM LEUKEMIA IN WORKERS EXPOSED TO ELECTRICAL AND MAGNETIC FIELDS

To the Editor: In the course of updating a study of occupational mortality,* I noticed that among men whose occupations required them to work in electrical or magnetic fields there were more deaths due to leukemia than would be expected.

All deaths of Washington State resident men 20 years old or older from 1950 through 1979 were coded to occupation. Proportionate mortality ratios standardized by age and year of death were calculated for 158 cause-of-death groups in each of 218 occupational classes. In all, 438,000 deaths were analyzed.

Table 1 shows the mortality due to all leukemia and acute leukemia for 11 occupations with presumed exposure to electrical or magnetic fields. In 10 of the 11 the proportionate mortality ratio for leukemia was elevated.

Aluminum-reduction workers are exposed to strong magnetic fields induced by high-amperage direct current (75,000 A) used in the pots in the aluminum-reduction process. Arc welders and motion-picture projectionists work near step-up transformers. The other workers are exposed to electrical and magnetic fields associated with alternating current flowing in wires and power lines. The power-station operators work primarily in hydroelectric generating plants along the Columbia River. In these occupations leukemia has a proportionate mortality ratio of 137, and acute leukemia has one of 163.

The available literature on occupational exposure to electrical and magnetic fields has not mentioned carcinogenesis. I am unaware of obvious leukemogenic exposures in these occupations.

These findings suggest that electrical and magnetic fields may cause leukemia.

*Milham S. Occupational mortality in Washington State, 1950-1971. Cincinnati, Ohio: National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluations and Field Studies, 1976.

Table 1. Leukemia Mortality in Men Occupationally Exposed to Electrical and Magnetic Fields. (Washington State White Males, 1950-1979).

Occupation	Mortality					
	All leukemia (204 *)			Acute leukemia (204.3 *)		
	observed	expected †	PMR ‡	observed	expected †	PMR ‡
Electronic technicians	6	4.0	149	3	1.9	162
Radio and telegraph operators	5	4.5	111	3	1.3	239
Electricians	51	37.0	138 §	23	12.9	178 §
Linemen (power and telephone)	15	9.4	159	6	3.3	183
Television and radio repairmen	5	3.2	157	4	1.4	291 §
Power-station operators	8	3.1	259 §	3	1.1	282
Aluminum workers	20	10.6	189 §	11	4.3	258 §
Welders and flame cutters	12	17.9	67	4	7.1	56
Motion-picture projectionists	4	1.7	234	1	0.9	111
Electrical engineers	7	6.1	114	2	2.1	97
Streetcar and subway motormen	3	1.7	175	0	0.4	0
	136	99.2	137 §	60	36.7	163 §

*Coded according to the *International Classification of Diseases* (7th ed.).

†Based on proportionate mortality for Washington state white males. (PMR values are exact; "expected" values have been rounded off.)

‡Proportionate mortality ratio (observed/expected × 100).

§P<0.01.

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Table 1. Mortality in workers occupationally exposed to electromagnetic fields Washington State 1950–1982, white males, age 20+; all causes with statistically significant differences between observed and expected deaths.[a]

Cause of death	7th ICD[b]	Deaths		
		Observed	Expected	PMR[c]
Tuberculosis	001–019	28	48	59†
All malignant neoplasms	140–205	2,649	2,501	106†
Malignant neoplasm:				
Pancreas	157	174	149	117*
Bronchus, trachea and lung	162	789	694	114†
Brain	193.0	101	82	123*
Other lymphomas	200.2,202	51	31	164†
Leukemia	204	146	108	136†
Acute leukemia	204.3	67	41	162†
Neoplasm of unspecified nature	230–239	17	11	162†
Diabetes mellitus	260	147	179	82*
Cerebral hemorrhage	331,334	632	685	92*
Other disease of heart	430–434	336	379	89*
Bronchitis with emphysema	502.0	43	30	145*
Other chronic interstitial pneumonia	525	38	27	143*
Other diseases of lung	527	412	372	111*
Ulcer of stomach	540	60	42	142†
Cirrhosis of liver w/o alcoholism	581.0	139	165	84*
Aircraft accidents	860–866	27	41	65*
Other falls from one level to another	902	58	42	138*
Electrocution	914	105	15	708*

[a] Electrical and electronic technicians, radio and telegraph operators, electricians, power and telephone linemen, radio and television repairmen, motion picture projectionists, aluminum workers, power station operators, welders, and flame-cutters.
[b] International Classifications of Diseases, seventh revision.
[c] PMR = proportionate mortality ratio (observed/expected × 100).
*$p<0.05$.
†$p<0.01$.

Table 2. Mortality in workers occupationally exposed to electromagnetic fields, Washington State, 1950–1982, white males, age 20+, selected cancers.

Occupation	Cancer of pancreas, ICD 157			Cancer of lung, ICD 162			Cancer of brain, ICD 193.0		
	Observed	Expected	PMR[a]	Observed	Expected	PMR[a]	Observed	Expected	PMR[a]
Electromagnetic field exposure									
Electrical and electronic technicians	9	6.3	143	32	35.2	91	7	5.2	134
Radio and telegraph operators	8	7.1	112	20	25.0	80	1	2.6	38
Power and telephone linemen	18	13.8	130	74	61.7	120	6	7.8	77
Radio and television repairmen	4	5.1	79	23	26.4	87	2	3.4	59
Power station operators	3	5.1	59	21	22.6	93	3	2.3	130
Subtotal	42	37.4	112	170	170.9	100	19	21.3	89
Electromagnetic field and other exposure									
Electricians	65	61.3	106	294	272.2	108	46	29.7	155†
Motion picture projectionists	7	2.7	260†	8	10.4	77	2	1.1	188
Alumimum workers	33	18.3	180†	126	99.2	127†	15	10.9	137
Welders and flamecutters	27	29.0	93	191	141.5	135	19	18.8	101
Subtotal	132	111.3	119	619	523.3	118	82	60.5	136
Total	174	148.7	117*	789	694.2	114†	101	81.8	123*

[a] PMR = proportionate mortality ration (observed/expected × 100). Statistical testing was done only on observed values of six or greater.
*$p<0.05$.
†$p<0.01$.

cesses or deficits of deaths in the grouped electrical workers occupations. Since there are 120 separate causes of death for which PMRs are calculated at the $p < 0.05$ level, ($0.05 \times 120 = 6.0$) six causes of death would be expected to show significantly increased or decreased PMRs by chance alone. Actually, 19 causes of deaths had PMRs of $p < 0.05$. Six had lowered PMRs and 13 had elevated PMRs.

Deficits are seen for tuberculosis, diabetes mellitus, cerebral hemorrhage, other diseases of the heart, cir-

Table 3. Mortality in workers occupationally exposed to electromagnetic fields Washington State, 1950–1982, white males, age 20+, cancers of lymphatic and hematopoietic tissues.

Cause of death	7th ICD	Deaths		
		Observed	Expected	PMR*
All lymphatic and hematopoietic cancers	200–205	317	257	123†
Reticulum-cell sarcoma	200.0	12	15	78
Lymphosarcoma	200.1	41	31	130
Hodgkin's disease	201	38	33	114
Other lymphomas	200.2,202	51	31	164†
Multiple myeloma	203	29	37	78
All leukemias	204	146	108	136†
Lymphatic leukemia	204.0	36	29	126
Myeloid leukemia	204.1	29	23	126
Monocytic leukemia	204.2	6	6	104
Acute leukemia	204.3	67	41	162†
Unspecified leukemia	204.4	8	9	90

*PMR = proportionate mortality ratio (observed/expected × 100).
†$p < 0.05$.
‡$p < 0.01$.

Table 4. Mortality in workers occupationally exposed to electromagnetic fields. Washington State, 1950–1982, white males, age 20+, selected cancers of lymphatic and hematopoietic tissues.*

Occupation	All lymphatic and hematopoietic, ICD 200–205			Lymphosarcoma, ICD 200.1			Other lymphomas, ICD 200.2, 202			Leukemia, ICD 204			Acute leukemia, ICD 204.3		
	Obs	Exp	PMR	Obs	Exp	PMR	Obs	Exp	PMR	Obs	Exp	PMR	Obs	Exp	PMR
Electromagnetic field exposure															
Electrical and electronic technicians	19	13.3	143	2	1.7	118	3	1.9	161	8	5.1	158	3	2.4	124
Radio and telegraph operators	15	10.9	137	1	1.4	73	4	1.2	342	5	4.9	102	3	1.4	212
Power and telephone linemen	31	25.2	123	5	3.0	168	5	2.8	177	17	10.8	158	7	3.9	179
Radio and television repairmen	12	9.4	127	1	1.1	90	1	1.2	86	7	4.0	176	6	1.7	344
Power station operators	16	8.2	195†	3	1.0	297	3	1.0	300	8	3.5	226†	3	1.3	238
Subtotal	93	67.0	139†	12	8.2	146	16	8.1	197†	45	28.3	159†	22	10.7	206
Electromagnetic field and other exposure															
Electricians	112	100.0	112	14	12.2	115	14	12.2	115	56	42.7	131*	25	15.6	160
Motion picture projectionists	5	4.1	122	1	0.4	250	0	0.3	0	4	1.8	218	1	.4	250
Aluminum workers	50	32.1	156†	3	3.7	82	11	4.2	260†	22	13.4	164	13	5.6	233
Welders and flame-cutters	57	53.3	107	11	7.0	157	10	6.3	158	19	21.3	89	6	9.0	67
Subtotal	224	189.5	118	29	23.3	124	35	23.0	152†	101	79.2	128†	45	30.6	147
Total	317	256.5	124†	41	31.5	130	51	31.1	164†	146	107.5	136†	67	41.3	162

*Obs = observed deaths; EXP = expected deaths; PMR = proportionate mortality ratio (observed/expected × 100).
†$p < 0.05$.
‡$p < 0.01$.

rhosis of the liver, and aircraft accidents. Excess deaths are seen due to all malignant neoplasms, malignant neoplasms of pancreas, lung, and brain, the other lymphomas, all leukemias, acute leukemia, neoplasms of unspecified nature, bronchitis with emphysema, chronic interstitial pneumonia, other diseases of lung, ulcer of the stomach, falls from one level to another, and accidental electrocution. Sixteen of 17 deaths due to neoplasms of unspecified nature were brain tumors, so this excess may be related to the malignant brain tumor excess. The accidental electrocution excess is limited to linemen (77 deaths observed, 2 expected) and to electricians (20 deaths observed, 4 expected). The excess of deaths due to falls from one level to another is seen only in linemen (24 deaths observed, 5 expected). The excess of deaths due to chronic pulmonary diseases [7th revision, International Classification of Diseases (ICD) Code 502.0 and 525] is seen primarily in those occupations with fume and dust exposures. Bronchitis with emphysema (7th ICD, 502.0) has excess mortality in welders (14 deaths observed, 6 expected) and in electricians (20 deaths observed, 13 expected). Chronic interstitial pneumonia deaths are in excess in welders (9 deaths observed, 5 expected) and aluminum workers (6

deaths observed, 3 expected). Deaths due to stomach ulcers show a slight excess mortality in these workers without any obvious occupational explanation.

Table 2 separates the nine occupations into two groups, one with electromagnetic field exposures only, and one with field exposure plus other occupational exposures. Pancreatic cancer shows a similar PMR in both groups while cancers of brain and lung show lowered PMRs in the electromagnetic field (only) exposure group. The lung, pancreas, kidney, and brain cancer excess is usually greatest in those occupations which have inhalation exposures in addition to electromagnetic field exposures. This suggests that field exposures may not play a role in the etiology of these cancers.

Table 3 shows observed and expected deaths and PMRs for the lymphatic and hematopoietic cancers. Reticulum-cell sarcoma and multiple myeloma show lowered PMRs, while all lymphatic and hematopoietic cancers, the other lymphomas, all leukemias, and the acute leukemias have significantly elevated PMRs ($p < 0.01$). Hodgkin's disease shows a slight but nonsignificant PMR increase with four of nine occupations having a PMR > 100. Only one of the nine occupation groups shows a PMR increase for multiple myeloma (aluminum workers: 8 observed, 5 expected, PMR 167). Similarly, based on small numbers of deaths, only two of nine occupation groups (power station operators and welders) show PMR increases due to reticulum-cell sarcoma.

Table 4 shows mortality by occupation due to lymphosarcoma, the other lymphomas, all leukemias, and acute leukemia. Some misclassification is possible among the reticulosarcoma, lymposarcoma, and other lymphoma categories. If the deaths in these cause groups are added, workers in these nine occupational groups have 104 deaths observed to 78 expected (PMR 133; $p < 0.01$). The highest PMRs are seen in the acute leukemia (162), and other lymphoma (164) categories. The PMRs are slightly higher in those occupations with electromagnetic field exposures only.

There is nothing in the available occupational literature which indicates that nonionizing radiation is a human carcinogen. There are conflicting reports relating residential electrical wiring configurations to cancer mortality (*7–9*). Occupational exposures to electric fields are much higher than those received by virtue of residence.

Weak electromagnetic fields can alter human reaction time (*10*) and circadian rhythm (*11*). Nonionizing radiation has been shown to cause endocrine (*12*), neurologic (*13*), and immunologic (*14*) changes in animals. Weak oscillating electric fields have been shown to affect calcium binding to cerebral tissue (*15*), and weak pulsed-magnetic fields have been shown to be teratogenic for the developing chicken (*16*). In most cases, these effects do not show the usual dose-response relationships. Rather, "windows" of effect of both frequency, power and wave form are seen. There are no systematic studies of the carcinogenicity of electromagnetic fields in animals.

Summary

Leukemia and non-Hodgkin's lymphomas show increased proportionate mortality ratios in men employed in occupations with intuitive exposures to electric and magnetic fields in Washington State.

REFERENCES

1. Milham, S., Jr. Occupational Mortality in Washington State, 1950-1971. DHEW, National Institute for Occupational Safety and Health, Publication No. (NIOSH) 76-175-A,B,C. 1976.
2. Milham, S., Jr. Occupational Mortality in Washington State, 1950-1979. DHHS, National Institute for Occupational Safety and Health, Publication No. (NIOSH) 83-116, October 1983.
3. Milham, S., Jr. Mortality from leukemia in workers exposed to electrical and magnetic fields. N. Engl. J. Med. 307: 249 (1982).
4. Wright, W. E., Peters, J. M., and Mack, T. M. Leukemia in workers exposed to electrical and magnetic fields. Lancet ii: 1160 (1982).
5. McDowall, M. E. Leukemia mortality in electrical workers in England and Wales. Lancet i: 246 (1983).
6. Coleman, M., Bell, J., and Skeet, R. Leukemia incidence in electrical workers. Lancet ii: 982–983 (1983).
7. Wertheimer, N., and Leeper, E. Electrical wiring configurations and childhood cancer. Am. J. Epidemiol. 109: 273–284 (1979).
8. Wertheimer, N., and Leeper, E. Adult Cancer related to electrical wires near the home. Int. J. Epidemiol. 11: 345–354 (1982).
9. Fulton, J. P., Cobb, S., Leone, L., Preble, L., and Forman, E. Electrical wiring configurations and childhood leukemia in Rhode Island. Am. J. Epidemiol. 111: 292–296 (1980).
10. Friedman, H., Becker, R. O., and Bachman, C. H. Effect of magnetic fields on reaction time performance. Nature 213: 949–950 (1967).
11. Wever, R. Influence of weak electro-magnetic fields on the circadian rhythms of humans. Naturwiss. 55: 29–32 (1968).
12. Free, M. J., Kaune, W. T., Phillips, R. D., and Cheng, H. C. Endocrinological effects of strong 60-Hz electric fields on rats. Bioelectromagnetics 2: 105–121 (1981).
13. Hansson, H. A. Lamellar bodies in Purkinje nerve cells experimentally induced by electric field. Brain Res. 216: 187–191 (1981).
14. Lyle, D. B., Schechter, P., Adey, W. R., and Lundak, R. L. Suppression of T-lymphocyte cytotoxicity following exposure to sinusoidally amplitude-modulated fields. Bioelectromagnetics 4: 281–292 (1983).
15. Bawin, S. M., and Adey, W. R. Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. Proc. Natl. Acad. Sci. 73: 1999–2003 (1976).
16. Delgado, J. M., Leal, J., Monteagudo, J. L., and Gracia, M. G. Embryological changes induced by weak, extremely low frequency electromagnetic fields. J. Anat. 134: 533–551 (1982).

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INCREASED MORTALITY IN AMATEUR RADIO OPERATORS DUE TO LYMPHATIC AND HEMATOPOIETIC MALIGNANCIES

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Milham, S., Jr. (Washington State Dept. of Social and Health Services, Olympia, WA 98504). Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies. *Am J Epidemiol* 1988;127:50–4.

To search for potentially carcinogenic effects of electromagnetic field exposures, the author conducted a population-based study of mortality in US amateur radio operators. Ascertainment of Washington State and California amateur radio operators (67,829 persons) was done through the 1984 US Federal Communications Commission Amateur Radio Station and/or Operator License file. A total of 2,485 deaths were located for the period from January 1, 1979 through December 31, 1984, in a population of amateur radio operators which accumulated 232,499 person-years at risk. The all-cause standardized mortality ratio (SMR) was 71, but a statistically significant increased mortality was seen for cancers of the other lymphatic tissues (SMR = 162), a rubric which includes multiple myeloma and non-Hodgkin's lymphomas. The all-leukemia standardized mortality ratio was slightly, but nonsignificantly, elevated (SMR = 124). However, mortality due to acute myeloid leukemia was significantly elevated (SMR = 176).

electromagnetics; leukemia, myelocytic; lymphoma; multiple myeloma; radio

In 1982, an updated occupational proportionate mortality ratio analysis of 429,926 male deaths in Washington State from 1950–1979 suggested that workers in occupations with exposures to electric and magnetic fields had increased mortality due to leukemia (1, 2). An amateur radio operator (Andrew R. Sabol, W2EVE, personal communication, 1982) suggested that it might be of interest to study mortality in members of the American Radio Relay League, a group of amateur radio operators who, in the pursuit of their hobby, are exposed to electromagnetic fields.

Recent deaths in American Radio Relay League members are reported in the "Silent Keys" section of *QST*, the League's monthly magazine. A proportionate mortality ratio analysis of 1,691 deaths of league members from Washington State and California during 1971–1983 revealed a ratio for deaths from leukemia of 191 (24 deaths observed, 12.6 expected; $p < 0.01$) (3). I could not obtain access to American Radio Relay League membership files, so it was not possible to do a standardized mortality ratio analysis of these deaths. Since all amateur radio operators in the US are federally licensed, I instead purchased the 1984 Federal Communications Commission Amateur Radio Station and/or Operator current license file from the National Technical Information Services.

MATERIALS AND METHODS

The Amateur Radio Operator file contains the following information for each licensee: name, call sign, birth date, effective date of current license, expiration date of current license, license class, mailing

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address, and station location (city and state). There were more than 400,000 records in the file. The effective and expiration dates of the current license were exactly five years apart, in accordance with the five-year license period at the time. Starting in 1984, the license period was extended to 10 years. No information was available on the date persons were first licensed or on the number of years licensed.

All amateurs with Washington State or California addresses, licensed between January 1, 1979 and June 16, 1984 (latest date on the file), were selected from the master file. Name (first, middle initial, and last) and date of birth (month, day, and year) were listed and used to search for deaths. A search for deaths by computer with manual backup was done in Washington State. In California, the CAMLIS system (a computer-based probability matching system) was used (4). In both states, all deaths were searched, but the study was limited to males because females made up such a small percentage of Federal Communications Commission registrants. Since the Federal Communications Commission file had no sex code, female names were eliminated manually. In all 67,829 names were searched for deaths in the two states. For a name to be included in the study, deaths and the commission file had to match exactly for date of birth and complete name. Causes of death were translated to *International Classification of Diseases*, Eighth Revision (ICD-8), codes and the standardized mortality ratio cohort mortality program of Monson (5) was run by state for males only. Person-years at risk started at the effective current registration day and ended at day of death or December 31, 1984.

Results

The 67,829 Washington State and California amateur radio licensees accumulated 232,499 person-years at risk and 2,485 deaths (2,083 in California and 402 in Washington) during the study period (January 1, 1979 to December 31, 1984).

Table 1 shows standardized mortality ratios by cause for California and Washington State licensees. Since 84 per cent (2,083 of 2,485) of the deaths occurred in California licensees, California deaths are primarily responsible for the mortality pattern seen here. The all-cause mortality ratio is 71, mainly due to a circulatory diseases ratio of 70. The all-cancer mortality ratio is 89. The rubric cancer of the other lymphatic tissues had a significant ($p < 0.05$) mortality excess. No other cause of death groups had significant excess deaths, while many had large deficits (e.g., cancer of the pancreas, all circulatory diseases, all respiratory diseases, and all accidents). The patterns of mortality seen in the two states are quite similar.

An analysis of leukemia mortality by detailed cause (table 2) shows a slight, but nonsignificant increase in all leukemias and a significant increase in the acute myeloid leukemias (ICD-8 code 205.0). The increase for the rubric acute unspecified leukemia (ICD-8 code 207.0) may also reflect an excess of acute myeloid leukemia.

Discussion

The standardized mortality ratios in table 1 are slightly underestimated, since females are virtually eliminated from the deaths, but not from the population at risk. Further underestimation results from the fact that California and Washington State death rates are slightly lower than the US rates used to calculate expected deaths (table 3). This will result in the standardized mortality ratios as calculated by Monson's program being slightly lower than those calculated using state death rates. The California deaths also exclude 39 out-of-state deaths in California residents. The all-cause standardized mortality ratio of 71 is similar to that seen for Swedish academic cohorts (6). Swedish mining engineers and architects had an all-cause ratio of 65 and 67, respectively.

The 43 deaths in the rubric cancer of

TABLE 1

Mortality in Washington State and California US Federal Communications Commission Amateur Radio Operator Licensees, January 1, 1979 to December 31, 1984

Cause of death	ICD-8 code†	Washington State deaths			California deaths			Washington State and California deaths			95% confidence interval
		Observed	Expected	SMR‡	Observed	Expected	SMR‡	Observed	Expected	SMR‡	
All causes	000-999	402	562.0	72*	2,083	2,916.9	71*	2,485	3,478.9	71*	69-74*
All malignant neoplasms	140-209	112	136.3	82*	629	700.6	90*	741	836.9	89*	82-95*
Esophagus	150	5	3.2	157	17	16.2	106	22	19.4	113	71 172
Stomach	151	7	4.8	146	23	24.8	93	30	29.6	102	68 145
Large intestine	153	8	12.8	63	80	66.2	121	88	79.0	111	89 137
Rectum	154	1	3.0	34	13	15.2	86	14	18.2	77	42-129
Liver	155	2	2.7	73	9	14.1	64	11	16.8	65	33 117
Pancreas	157	3	6.8	44	24	35.1	68	27	41.9	64*	42-94*
Respiratory system	160-163	29	51.8	56*	180	263.8	68*	209	315.6	66	58-76
Prostate	185	21	10.8	195*	57	56.8	100	78	67.6	114	90-142
Urinary bladder	188	2	3.8	52	14	20.3	69	16	24.1	66	38-108
Kidney	189	4	3.3	121	15	16.8	89	19	20.1	94	57 148
Brain	191	4	3.5	115	25	17.3	145	29	20.8	139	93-200
Lymphatic and hematopoietic tissue	200-209	11	11.8	93	78	60.3	129*	89	72.1	123	99-152
Lymphosarcoma/reticulosarcoma	200	1	1.8	57	4	8.8	45	5	10.6	47	15-110
Hodgkin's disease	201	0	0.7	0	5	3.4	147	5	4.1	123	40 288
Leukemia	204-207	5	4.7	106	31	24.3	128	36	29.0	124	87 172
Other lymphatic tissue	202, 203	5	4.3	115	38	22.3	170*	43	26.6	162*	117 218*
All circulatory diseases	390-458	196	276.4	71*	1,012	1,455.3	70*	1,208	1,731.7	70*	66-74*
All respiratory diseases	460-519	28	40.0	70	99	212.5	47*	127	252.5	50*	42 60*
All accidents	E800-E999	19	28.3	67	86	136.2	63*	105	164.5	64*	52 77*

* $p < 0.05$.

† *International Classification of Diseases*, Eighth Revision.

‡ SMR (standardized mortality ratio) = observed/expected × 100.

TABLE 2

Analysis of leukemia deaths in Washington State and California US Federal Communications Commission amateur radio operator licensees, January 1, 1979 to December 31, 1984

Cause of death	ICD-8 code*	Deaths			95% confidence interval
		Observed	Expected‡	SMR§	
All leukemias	204–207	36	29.0	124	87–172
Lymphatic	204	9	8.7	103	47–196
Acute	204.0	3	2.5	120	26–381
Chronic	204.1	6	5.5	109	40–238
Unspecified	204.9	0	0.8	0	
Myeloid	205	18	12.9	140	83–220
Acute	205.0	15	8.5	176*	103–285*
Chronic	205.1	3	3.5	86	17–250
Unspecified	205.9	0	0.9	0	
Monocytic	206	0	0.6	0	
Unspecified	207	9	6.7	134	61–255
Acute	207.0	6	3.4	176	64–384
Unspecified	207.9	3	2.5	120	26–381

* $p < 0.05$.

† *International Classification of Diseases*, Eighth Revision.

‡ Calculated using 1981 US age-specific white male death frequencies by detailed ICD-8 code and a simple proportional model.

§ SMR (standardized mortality ratio) = observed/expected × 100.

TABLE 3

Death rates per 100,000 for selected causes from vital statistics of the United States, 1981 (11)

Cause of death	ICD-8 code*	US	California	Washington State
All causes	000–999	862.4	764.0	759.0
Leukemia	204–208	7.1	6.7	6.9
Other malignant neoplasms of lymphatic and hematopoietic tissues	200–203	9.4	8.6	8.9

* *International Classification of Diseases*, Eighth Revision.

other lymphatic tissue were composed of 22 deaths from ICD-8 code 202 (other neoplasms of lymphoid tissue) and 21 deaths from ICD-8 code 203 (multiple myeloma). Among all US white male deaths, ICD-8 codes 202 and 203 are present in the ratio of 57 per cent to 43 per cent, respectively. This yields crude standardized mortality ratios of 145 for ICD-8 code 202 and 184 for ICD-8 code 203. The excess of deaths for ICD-8 code 202 is not as secure as that for ICD-8 code 203, since there is potential misclassification between the lymphosarcoma-reticulosarcoma group (ICD-8 codes 200.0 and 200.1) and the groups for ICD-8 code 202. When ICD-8 codes 200.0 and 200.1 are considered together, their mortality deficit nearly cancels out the mortality excess for ICD-8 code 202.

The low standardized mortality ratios for malignant and nonmalignant respiratory diseases suggest that the members of the American Radio Relay League have a lower ratio of cigarette smoking than does the general US population.

The fact that the excess of leukemia is limited to the acute myeloid and acute unspecified cell types increases its biologic plausibility. Studies in the US (7) and the United Kingdom (8, 9) suggest a relative increase in acute myeloid leukemia in electrical workers.

Occupational information listed on the death certificates in Washington State showed that 31 per cent of Washington State amateurs (124 of 402) listed occupations with electromagnetic field exposures (radio operator, television repairman, electronics technician, etc.), while these occupations are listed on only three per cent of all male death certificates in the Washington state death file. Five of the 11 Washington State leukemia, lymphoma, and multiple myeloma death certificates listed an occupation with electrical exposure. Occupational information was not available for the California deaths.

In addition to electric and magnetic fields, these males are exposed to electric shock, soldering fumes, and degreasing agents in the pursuit of their hobby. Nearly one-third of the group also work in jobs with electric and magnetic field exposures.

In 1980, the American Radio Relay League surveyed 8,895 US and Canadian amateurs (a random sample of one in 44). Results published in 1981 (10) indicate that the average amateur was a 46-year-old male who was first licensed in 1963 and spent 6.1 hours a week on his hobby. A total of 72 per cent had some education beyond high school, and 43 per cent worked or had worked in a related field. Males accounted for 94 per cent of the amateurs. Some of the variation in mortality seen in Federal Communications Commission licensees may be related to social class.

There is some overlap between the Federal Communications Commission licensee population studied here and the American Radio Relay League deaths ascertained through listing in the League's journal. In the study of mortality in the American Radio Relay League, 1,691 deaths, including 24 leukemias, were ascertained in the years 1971–1983 (3). In the present study, 2,485 deaths, including 36 cases of leukemia, were ascertained in the years 1979–1984 by searching for deaths in a population of 67,829 Federal Communications Commission licensees. All amateur radio operators are required to be licensed by the Federal Communications Commission, but only a fraction of these licensees are members of the American Radio Relay League. In the years of overlap of the two studies (1979–1983), there were six cases of leukemia ascertained through the American Radio Relay League listings and 33 ascertained through a search of the Federal Communications Commission files.

As expected, the overall mortality of amateur radio operators is quite favorable when compared with that of all US males. However, this large population-based study indicates that amateur radio operator licensees in Washington State and California have significant excess mortality due to acute myeloid leukemia, multiple myeloma, and perhaps certain types of malignant lymphoma. Avocational and/or occupational exposures to electric and magnetic fields should be among the possible etiologies considered in explaining this excess mortality.

References

1. Milham S. Mortality from leukemia in workers exposed to electrical and magnetic fields (Letter.) N Engl J Med 1982;307:249.
2. Milham S. Workers in magnetic and/or electrical fields. Occupational mortality in Washington State, 1950–1979. Cincinnati, OH: National Institute for Occupational Safety and Health, 1983:75. (DHHS (NIOSH) publication no. 83-116).
3. Milham S. Silent keys: leukemia mortality in amateur radio operators. (Letter.) Lancet 1985;1:812.
4. Arellano MG, Petersen GR, Petitti DB, et al. California automated mortality linkage system (CAMLIS). Am J Public Health 1984;74:1324–30.
5. Monson RR. Analysis of relative survival and proportional mortality. Comput Biomed Res 1977;7:325–32.
6. Olin GR, Ahlbom A. Cancer mortality among three Swedish male academic cohorts: chemists, architects, and mining engineer/metallurgists. Anal NY Acad Sci 1982;381:197–201.
7. Wright WE, Peters JM, Mack, TM. Leukemia in workers exposed to electrical and magnetic fields. Lancet 1982;2:1160–71.
8. McDowall ME. Leukemia in electrical workers in England and Wales. (Letter.) Lancet 1983;1:246.
9. Coleman M, Bell J, Skeet R. Leukemia incidence in electrical workers. Lancet 1983;1:982–3.
10. Amateur Radio Survey, 1980. A look at ham radio as we enter the eighties. In: Amateuradio. Newington, CT: American Radio Relay League, 1981.
11. Vital statistics of the United States. Hyattsville, MD. US Department of Health, Education, and Welfare, 1981. (DHHS publication no. (PHS) 86-1101).

Exposures to Extremely Low Frequency (ELF) Electromagnetic Fields in Occupations with Elevated Leukemia Rates

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In previous epidemiological studies, elevated leukemia rates have been found in a collection of occupational categories of "electrical workers." In this study, spot measurements were taken of the Extremely Low Frequency (below 100 Hz) electric and magnetic field exposures of "electrical workers" at 114 work sites at an electric utility, an aerospace firm, a municipal government, motion picture theaters, and TV repair shops. For comparison, the fields were measured in 18 residences and 3 offices. The residential measurements had 95th percentiles at 3.4×10^{-7} Tesla for magnetic fields and 33.1 volts/meter for electric fields. For magnetic fields, the 95th percentile of the residential measurements was exceeded by 59 percent of the occupational measurements, covering all the "electrical worker" job categories with the exception of radio operators. The highest magnetic field encountered was 1250×10^{-7} Tesla on a battery-powered fork lift operator, which had not been considered an "electrical worker" occupation previously. Only 25 percent of the occupational electric fields were above the 95th percentile measured in residences, and these were all in the job categories for power line workers, power station operators, and TV repairers. This survey indicates that many "electrical workers" have some exposures to elevated fields. However, the wide variability in field exposures over time and between workers will necessitate better exposure measurements to assess more rigorously the association between leukemia rates and electromagnetic fields. Bowman, J.D.; Garabrant, D.H.; Sobel, E.; Peters, J.M.: Exposures to Extremely Low Frequency (ELF) Electromagnetic Fields in Occupations with Elevated Leukemia Rates. Appl. Ind. Hyg. 3:189–194; 1988.

Introduction

Studies published since 1979 have raised the question of whether high exposure to electromagnetic (EM) fields from alternating current (AC) electrical equipment conveys cancer risk. For a variety of reasons, the studies in occupational settings have not relied on actual measurements of EM fields but generally have used surrogates of EM field exposure. Thus, the purported relationship between EM fields and cancer risk remains vague, and important questions regarding the existence of dose-response relationships remain unanswered. For this reason, field measurements in occupational settings are critically important. This paper presents the measurements of the electric and magnetic fields in an array of occupations that have been previously presumed to have high exposures and which are thought by some to be at increased leukemia risk. These measurements are compared to similar measurements made in residential settings.

The strongest evidence linking EM fields to cancer is contained in four studies[1–4] addressing childhood malignancy, of which three[1,3,4] reported a significant association. Where significant associations are reported, exposures were assessed largely by configurations of electrical distribution wiring, which roughly correlate with the average residential magnetic fields at Extremely Low Frequencies (ELF),[5,6] defined as frequencies below 100 Hz.

For workplace exposures, seven studies[7–13] have examined the risk of leukemia in an assembly of "electrical-workers," a set of occupational codes originally suggested by Milham.[7] These studies are based on populations in the United States, Great Britain, and New Zealand. Although the findings are not identical (and occupational categories, such as "welders and flame cutters," clearly do not have uniform exposures to EM fields), the studies do provide evidence that leukemia rates may be elevated in the "electrical worker" occupations. Although the number of leukemias in specific occupations was generally small, elevated risks were found with some consistency for power station operators, radio and telegraph operators, and electrical engineers. Seven other studies shed varying amounts of light on this issue.[14–20] Four studies[14–17] show a positive association between electrical occupations and cancer; three[18–20] do not.

All occupational studies suffer from two major defects: lack of exposure measurements and no evaluation of confounding leukemogenic exposures such as ionizing radiation and benzene. Occupational exposures to EM fields at ELF have been measured in other studies, but the relevance of the data to the cancer hypothesis is limited. Electric field exposures have been mea-

sured among electric utility workers[21–23] and during farming operations under high voltage transmission lines.[24] In these studies, most workers received little detectable exposure to electric fields and spent relatively short times in measureable electric fields. However, electrochemical dosimeters are not sensitive to fields below several hundred volts/meter (V/m)[25] and, therefore, cannot detect the electric fields in many of the "electric worker" occupations. Spot measurements can use more sensitive electric field instruments and have also been taken near electric utility workers.[26–29]

Occupational and residential exposures to ELF magnetic fields have been reviewed recently.[30] Spot measurements of 50/60 Hz magnetic fields have been done around electrical utility workers,[31–34] electrosteel furnaces, welding machines,[35] and electrical office equipment.[36] From these studies, the maximum magnetic field exposures at 50/60 Hz have been measured near high-voltage transmission lines,[32] electrical distribution substations,[33] and electrical generating stations. Magnetic field exposures have not been measured in any of the other "electrical worker" occupations in the leukemia surveillance studies.

In summary, the published literature suggests that "electrical workers" are at increased risk of leukemia, but the exposure measurements in these occupations is not sufficient to conclude that EM fields in these occupations are actually elevated.

Methods

Instrumentation

A power frequency field meter (Model 113, Electric Field Measurement Co., W. Stockbridge, MA) was used for all EM field measurements. For electric fields, the sensor was the two halves of the meter's metal case, which was mounted either on a fiberglass rod or on a stand made of non-conducting polycarbonate plastic. For magnetic fields, the sensor is a 90-mm diameter coil with 2000 turns.

For both electric and magnetic fields, the sensor was placed adjacent to the worker, and readings were taken in three orthogonal directions. From the three compounds, the vector magnitude was computed for the electric (E) field in V/m and the magnetic (B) field in Tesla (T).

(*Note on units:* In the literature on ELF health effects, two conventions exist for the terminology and units applied to magnetic fields. In the medical and popular literature, "magnetic field" refers to the B field, which is reported in the unit of milliGauss (mG). In the health physics literature, "magnetic field" refers to the H field, and the B field is called "magnetic flux density," reported in the SI units of Teslas. Since the B and H fields are always proportional in non-ferromagnetic matter, the distinction between the two quantities is important to this area of research. Therefore, this study used only the B field, called the "magnetic field" as in the medical literature. For units, 1×10^{-7} T = 1 mG is used so that numerical values in the SI units are the same as found in the medical literature.)

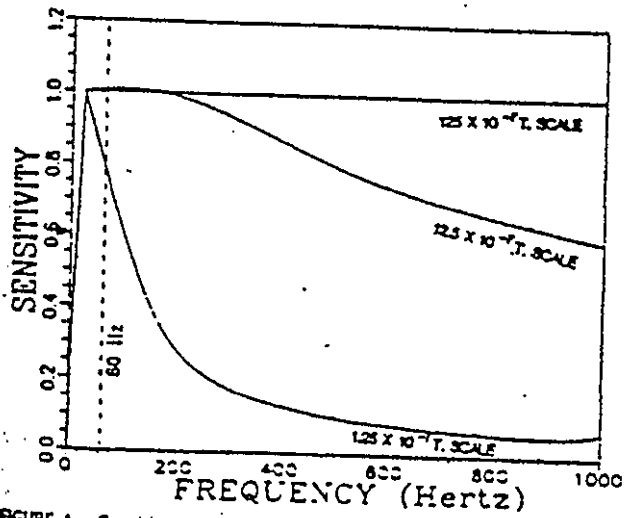

FIGURE 1. Sensitivity of the Power Frequency Field Meter (Model 113) to magnetic fields as a function of frequency and the scale on the meter. Data Source: Instruction pamphlet (1985).

The frequency response of the field meter peaked at approximately 60 Hz since the meter was operated in the "Integrate" mode. The band width of this meter's response curve was a function of the gain (Figure 1), so its response to harmonic frequencies above 60 Hz varied with the scale used in a measurement. Measurement of fields with large harmonics was further complicated because the field meter was an "average" response meter, rather than an rms meter. For the harmonics found in residential fields, the accuracy of this meter has been estimated to be ± 20 percent.[6]

Measurement Sites

The occupations considered to be "electrical workers" included all those initially suggested by Milham,[7] augmented by "electrical and electronic equipment assemblers" which were added in subsequent investigations. However, researchers did not take exposure measurements of aluminum workers and conductors and motormen in urban rail transit because they are not found in the Los Angeles area. Instead, fork lift operators were added as the survey progressed. To assess field exposures in the absence of heavy electrical equipment, the study measured EM fields for secretaries, which was not considered to be an "electrical worker" occupation. Tables I and II list the categories for which exposure measurements were obtained.

To measure EM field exposures, the authors obtained the cooperation of an electric utility, an aerospace firm, a municipal government, three television repair shops, and two motion picture theaters (one indoor, one drive-in). Individual workers were selected for measurement after a walk-through of the immediate work site. The number of measurements taken at each work site was dictated by the varying circumstances and did not represent the distribution of the work force or their work time.

Measurements were taken as close to the worker as possible and in the direction of the most likely field sources (Table III). Since electric fields are deformed by surrounding objects and vary sharply in their vicinity, two measurements were often taken approximately one meter apart and the arithmetic average of the two electric field magnitudes was used to represent the exposure.

To measure residential EM fields, access was obtained to 18 homes of university personnel, selected to cover the 5 electric utilities serving Los Angeles County. In all residences, a standard measurement protocol, adopted from a study of childhood cancer,[4] was followed. The field meter was mounted in the middle of the living room, bedroom, kitchen, and backyard and operated in the same manner as in the work settings. At each site, the electric and magnetic field magnitudes were measured first with all appliances off, and then with a standard list of appliances (refrigerator, electric stove, toaster, iron, television, lamps) turned on one at a time.

TABLE I. Occupational Exposures to ELF Magnetic Fields

Job Class	Environments	N	Magnetic (B) Field ($\times 10^{-7}$ Tesla) Geo. Mean	Range	% Above Residential 95th Percentile
Electricians	Industrial power supply	1	103.1	—	100%
Power line workers	Underground lines	3	57.4	38–91	100*
	Overhead lines	2	42.5	32–57	100*
	Home hook-ups	14	1.1	0.04–12	29*
Welders and flame cutters	TIG/AC	4	41.3	24–90	100*
	TIG/DC	4	6.5	4–15	100*
Power station operators	Transmission station	3	38.6	16–72	100*
	Distribution sub-station	3	28.6	7–54	100*
	Generating station	12	6.0	0.1–118	67*
	Control rooms	8	2.1	1–4	25
Electronics assemblers	Sputtering	2	24.3	14–43	100*
	Soldering	2	1.3	1.3–1.6	0
	Microelectronics	3	0.03	0.01–0.06	0
Projectionists	Xenon arc	7	14.4	1–45	86*
Fork-lift operators	Battery powered	9	11.7	0.9–1250**	67*
Electronics engineers & technicians	Laser lab	9	10.6	2–202	78*
	Calibration lab	4	0.6	0.5–0.7	
	Office	1	0.2	—	0
Radio and TV repairers	Repair shops	11	6.3	1–26	73*
Radio operators	Dispatchers	3	0.3	0.2–0.4	0
Secretaries	VDT	6	3.1	0.8–29	50*
	Other	3	1.1	0.2–4	33
"Electrical workers"		105	5.0	0.01–1250	60*
All occupations		114	4.7	0.01–1250	59*
Residences	Appliances	181	0.6 (GSD = 2.8)	0.05–11	—

*Significant proportion ($p < 0.05$).
**Peak measured during acceleration.

Results and Discussion

Magnetic field and electric field measurements were taken at 114 sites in 22 work environments and 181 sites in 18 residences. The residential measurements were taken in the spring (February through April), and the occupational measurements were taken in the fall (September through November) so that air conditioners were not operating at most locations.

To summarize the measurements, the range of values and the geometric mean (GM) for each work environment, along with the residential measurements for comparison, are presented in Tables I and II. Since the distribution of residential field measurements is skewed towards small values, the field exposures are apparently distributed log-normally, and the geometric mean is a better measure of the central tendency than the arithmetic mean. Examination of the magnetic field measurements (Table I) indicates that in all work environments the geometric means of the "electrical worker" exposures are higher than the mean residential exposures, with the exception of radio dispatchers and a few specific environments in which electronics engineers, technicians, and assemblers work. Examination of the electric field exposures (Table II) shows the geometric means in many work environments to be below the residential mean.

A significance test on these means could be misleading. The number of measurements taken in the various work environments ranged from 1 to 14 and were measured under a wide variety of circumstances (a single reading taken during a brief walk-through, a dozen measurements taken while following a power line crew, etc.). None of the occupational measurements were taken with a standardized protocol as was followed in the residences.

In order to test for elevated occupational exposures more rigorously, it was estimated that the lognormal distribution for residential magnetic field exposures has its 95th percentile at 3.4 $\times 10^{-7}$ T (3.4 mG). In other words, any occupational magnetic field measurement above this value is higher than 95 percent of the exposures occurring in a collection of residences; therefore, such values were defined as "elevated" exposures. Sixty percent of magnetic field measurements in the "electrical worker" categories are above the 95th percentile of the residential exposures (Table I).

To test each work environment for a significant proportion of elevated exposures, an exact binomial test[37] was used with the null hypothesis: "The proportion of elevated fields measured in a work environment is 5 percent, the same as found in resi-

dences." As shown in Table I, proportions of elevated magnetic fields significantly above 5 percent were found in all environments for "electrical workers" with the exception of power station control rooms, the radio dispatcher room, electronics assembly, and the electronics calibration lab. In both secretarial and engineering offices, the proportion of elevated magnetic fields was not significantly different from the residences, except for the measurements taken around a single video display terminal (VDT).

For residential electric fields, the 95th percentile was estimated to be 33.1 V/m and was exceeded by only 24 percent of the measurements in the "electrical worker" categories (Table II). The work environments with significant proportions of elevated measurements were limited to overhead power lines, transmission and distribution stations, and TV repair shops. None of the secretaries' exposures were above residential electric fields. The reason for low electric fields in the presence of heavy electrical equipment appeared to be the effective shielding provided by metal.

The magnetic field exposures also varied widely both between and within the different "electrical worker" categories. Between categories, the geometric mean for the magnetic field exposures went from 103.1×10^{-7} T for electricians to 0.3×10^{-7} T for radio operators, a 343-fold ratio. Within the electronic assembler category, the geometric means varied 810-fold among the different environments.

Both the between- and within-category variability in the magnetic field exposures creates the potential for misclassification errors in the estimates of leukemia risk by occupational category. The wide variation in magnetic fields between job categories, if known more precisely, could be used to reduce the misclassification of EM field exposures and to increase the ability to test the association with occupational leukemia rates in the population-based cancer registries.

Although fork-lift operator was not one of the original "electrical worker" job categories, these workers were exposed to the highest magnetic field measured in this survey. Battery-driven fork and scissor lifts produced magnetic fields ranging from 54 to 109×10^{-7} T while in steady motion with surges up to 1250×10^{-7} T when accelerating. Since many other manufacturing, mining, and construction workers work close to large electric motors, exposure to elevated magnetic fields must be considered for these jobs.

Elevated ELF magnetic fields are also produced by power supplies, transformers, the magnetic disc drives on word processors, and wires carrying heavy currents. Conversely, the small sample of secretaries who did not use VDTs were exposed to EM fields within the residential range. More homogeneous patterns of mag-

TABLE II. Occupational Exposures to ELF Electric Fields

Job Class	Environments	N	Electric (E) Field (V/m) Geo. Mean	Range	% Above Residential 95th Percentile
Electricians	Industrial power supply	1	4.2	—	0%
Power line workers	Underground lines	2	0.8	0.5–1.2	0
	Overhead lines	2	157.6	120–206	100*
	Home hook-ups	13	3.8	0–71	15
Welders and flame cutters	TIG	1	2.0	—	
Power station operators	Transmission station	3	290.0	165–621	100*
	Distribution sub-station	3	71.5	22–222	67*
	Generating station	7	0.4	0–4	0
	Control rooms	4	1.0	0.3–24	0
Electronics assemblers	Sputtering	1	5.5	—	0
	Soldering	2	8.4	8.2–8.7	0
	Microelectronics	2	1.6	0.8–3	0
Projectionists	Xenon arc	4	0.6	0–2	0
Fork lift operators	Battery powered	1	0.2	—	0
Electronics engineers and technicians	Laser lab	4	1.9	0.6–8	0
	Calibration lab	4	1.9	0.5–4	0
	Office	1	1.0	—	0
Radio and TV repairers	Repair shops	11	45.2	4–110	73*
Radio operators	Dispatchers	1	0.8	—	0
Secretaries	VDT	1	3.1	—	0
	Other	3	4.1	2–5	0
"Electrical Workers"		67	4.64	0–621	25
All occupations		71	4.58	0–621	24
Residences	Appliances	178	2.46 (GSD = 5.0)	0–79	—

*Significant proportion ($p < 0.05$).

TABLE III. Sources of ELF Electromagnetic Fields Encountered in the Survey

Job Class	Sources	Voltage
Electrician	Factory power supply	480 V
Power line workers	Underground primary lines	4.2 & 17 kV
	Overhead primary line	4.2 kV
	Overhead secondary lines	220 V
Welders and flame cutters	DC power supply	480 V
	TIG/DC welding gun (30 amp)	21 V
	AC power supply	480 V
Power station operators	Transmission line station	220 & 34.5 kV
	Distribution sub-station	17 & 34.5 kV
	Generating station	13.5, 24 & 34.5 kV
Electronic assemblers	Soldering gun (60 watt)	
	Sputtering chamber	
Projectionists	Rectifiers	240 v
	Xenon arc lamps (2.4 and 4.5 kW)	100 V DC
Fork-lift operators	Scissor lift (550 amp-hr)	36 V DC
	Fork lift (800 amp-hr)	36 V DC
Electronics engineers and technicians	Oscilloscope and meters	120 V
	He-Ne laser	?
Radio and TV repair	Oscilloscopes, meters and TVs	120 V
Secretaries	Video display terminals	120 V
	Electric typewriters	120 V
Radio operators	Dispatcher radios	?
Residences	Refrigerator, toaster, iron, TV, and lamps	120 V
	Electric stove	240 V

netic field exposures can therefore be created by grouping workers according to the electrical equipment used in their jobs. For example, welders using AC equipment (GM = 41.3 × 10^{-7} T) probably should not be grouped with direct current (DC) welders (6.5 × 10^{-7} T) or flame cutters (who were not surveyed).

All these sources are capable of producing magnetic fields in frequencies other than 60 Hz. Since the laboratory studies on the biological effects of ELF magnetic fields show a strong frequency dependence,[38] there is a need for more data on the frequency spectra of occupational magnetic fields.

Another important dimension of EM field exposure is time. Although the measurements in most work environments were taken only at a single instance, a power line crew and a power station electrician were followed for several hours, so their mean exposures were a rough indicator of a time-weighted average. In these two cases, the magnetic field exposures varied widely in the different work sites encountered. For example, the electrician spent time around the control room (B = 1.5 × 10^{-7} T), the generators (118 × 10^{-7} T), a circuit breaker (1.0 × 10^{-7} T), the machine shop (0.3 × 10^{-7} T), and the distribution busses (54 × 10^{-7} T). The geometric mean of all the electrician's exposures was 83.5 × 10^{-7} T, and the geometric standard deviation was 9.92, an extremely large value. With this large variability, the electrician's time-weighted average exposure was difficult to estimate accurately from spot measurements alone and would require a personal dosimeter, which is just now being developed.

Conclusions

Epidemiological studies have raised the hypothesis that "electrical workers" are at increased risk of cancer from ELF electromagnetic fields. In many sites where the "electrical workers" are employed, this survey found magnetic fields significantly above the levels encountered in residences and most offices. Such was not the case for electric fields, for which much less difference was found between "electrical workers" and residential environments.

The elevated workplace exposures to magnetic fields lend support to the hypothesis generated by occupational leukemia studies and support the need for further studies, especially the characterization of exposures to EM fields and confounding carcinogens. This survey indicates that exposure to elevated magnetic fields is not limited to the "electrical worker" job categories, but can occur in proximity to other electrical equipment such as battery-driven fork lifts. Better characterization of both electric and magnetic fields over the ELF is needed in work sites where elevated exposures can be expected. At the moment, the greatest need is full-shift personal monitoring, but data on peak exposure are needed as well. Such data will allow more meaningful comparison of the EM fields encountered in different environments and will provide more meaningful dose estimates for use in epidemiological studies.

Recommendations

It is recommended that occupational exposures to ELF electric and magnetic fields be measured in a wide variety of industries. Reliable instruments for spot measurements are currently available and are easy to use, particularly for magnetic fields. Until more is known about a carcinogenic mechanism for EM fields,

exposure characterizations should include measurements of both peak and time-weighted average fields. Since time-weighted average exposures are vitally important, it is further recommended that the production of instrumentation for full-shift monitoring be expedited.

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References

1. Wertheimer, N.; Leeper, E.: Electrical Wiring Configurations and Childhood Cancer. Am. J. Epidemiol. 109:273 (1979).
2. Tomenius, R.A.; Hellstrom, L.; Enander, B.: Electrical Constructions and 50 Hz Magnetic Field at the Dwellings of Tumor Cases (0–18 years of age) in the County of Stockholm. International Symposium on Occupational Health and Safety in Mining and Tunneling, Prague (1982).
3. Fulton, J.P.; Cobb, S.; Preble, L.; et al: Electrical Wiring Configurations and Childhood Leukemia in Rhode Island. Am. J. Epidemiol. 111:292 (1980).
4. Savitz, D.A.; Wachtel, H.; Barnes, F.S.: Results of Case Control Study of Childhood Cancer and Exposure to Electromagnetic Fields. Department of Energy/Electric Power Research Institute Contractors' Review Meeting, Denver, CO (1986).
5. Barnes, F.S.; Wachtel, H.; Savitz, D.A.; et al: Magnetic Fields and Wiring Configuration. Bioelectromagnetic Society Meeting, Madison, WI (1986).
6. Kaune, W.T.; Stevens, R.G.; Callahan, N.J.; et al: Residential Magnetic and Electric Fields Measured over 24-H Periods. Final report, Power Line Project 21082-18. Battelle Pacific Northwest Laboratories, Richland, WA (1987).
7. Milham, S.: Mortality from Leukemia in Workers Exposed to Electrical and Magnetic Fields. N. Engl. J. Med. 307:249 (1982).
8. Milham, S.: Mortality in Workers Exposed to Electromagnetic Fields. Environ. Health Persp. 62:297 (1985).
9. Wright, W.E.; Peters, J.M.; Mack, T.M.: Leukemia in Workers Exposed to Electrical and Magnetic Fields. Lancet ii:1160 (1982).
10. McDowall, M.E.: Leukemia Mortality in Electrical Workers in England and Wales. Lancet i:246 (1983).
11. Pearce, N.E.; Sheppard, R.A.; Howard, J.K.; et al: Leukemia Incidence in Electrical Workers in New Zealand. Lancet i:811 (1985).
12. Coleman, J.; Bell, J.; Skeet, R.: Leukemia Incidence in Electrical Workers. Lancet i:982 (1983).
13. Calle, E.E.; Savitz, D.A.: Leukemia in Occupational Groups with Presumed Exposure to Electrical and Magnetic Fields. New Engl. J. Med. 313:1476 (1985).
14. Flodin, U.; Fredriksson, M.; Axelson, O.; et al: Background Radiation, Electrical Work, and Some Other Exposures Associated with Acute Myeloid Leukemia in a *Case-Referant* Study. Arch. Environ. Health 41:77 (1986).
15. Milham, S.: Silent Keys: Leukemia Mortality in Amateur Radio Operators. Lancet i:812 (1985).
16. Gilman, P.A.; Ames, R.G.; McCawley, M.A.: Leukemia Risk Among U.S. White Male Coal Miners. J. Occup. Med. 27:669 (1985).
17. Stern, F.B.; Waxweiler, R.A.; Beaumont, J.J.; et al: A Case-control Study of Leukemia at a Naval Nuclear Shipyard. Am. J. Epidemiol. 123:98 (1986).
18. McDowall, M.E.: Mortality of Persons Resident in the Vicinity of Electricity Transmission Facilities. Br. J. Cancer 53:271 (1986).
19. Torqvist, S.; Norell, S.; Ahlbom, A.; Knave, B.: Cancer in the Electric Power Industry. Br. J. Ind. Med. 43:212 (1986).
20. Olin, R.; Vagero, D.; Ahlbom, A.: Mortality Experience of Electrical Engineers. Br. J. Ind. Med. 42:211 (1985).
21. Knave, B.; Gamberale, F.; Bergstrom, S.; et al: Long-term Exposure to Electric Fields. Scand. J. Work Environ. Health 5:115 (1979).
22. Male, J.C.; Norris, W.T.; Watts, M.W.: Exposure of People to Power Frequency Electric and Magnetic Fields. Hanford Life Sciences Symposium: Interaction of Biological Systems with Static and ELF Electric and Magnetic Fields, Richland, WA (1984).
23. Chartier, V.L.; Bracken, T.D.; Capon, A.S.: BPA Study of Occupational Exposure to 60-Hz Electric Fields. IEEE PAS Meeting, Seattle, WA (1984).
24. Silva, M.; Huber, D.: Exposure to Transmission Line Electric Fields during Farming Operations. IEEE Trans. PAS-104:2632 (1985).
25. Bracken, T.D.: Comparison of Electric Field Exposure Monitoring Instrumentation. Report EA-4085, Electric Power Research Institute, Palo Alto, CA (1985).
26. Stopps, G.J.; Janischewskyj, J.; Janischewskyj, W.: Epidemiological Study of Workers Maintaining HV Equipment and Transmission Lines in Ontario. Research Report. Canadian Electrical Association, Montreal, Quebec (1979).
27. Battisti, S.; Grandolfo, M.; Onori, S.; et al: Occupational Exposure to Power-frequency Electric and Magnetic Fields: Results of a Survey. In: Radiation Risk Protection, Proc. 6th Int. Congr., Berlin (1984).
28. Checcucci, A.: An Epidemiological Investigation of HV Substation Workers: Study Design and Preliminary Results. In: Biological Effects and Dosimetry of Static and ELF Electromagnetic Fields. Plenum Press, London (1985).
29. Baroncelli, P.; Battisti, S.; Checcucci, A.; et al: A Health Examination of Railway High-voltage Substation Workers Exposed to ELF Electromagnetic Fields. Am. J. Ind. Med. 10:45 (1986).
30. Stuchly, M.A.: Human Exposure to Static and Time-varying Magnetic Fields. Health Phys. 51:215 (1986).
31. Hassenzahl, N.; Mahaffy, M.W.; Weinhafen, O.: Evaluation of Environmental Control Technologies for Magnetic Fields. Report No. DOE/EV-0029. U.S. Dept. of Energy, Washington, DC (1978).
32. Lambdin, D.L.: A Comparison of Measurement Techniques to Determine Electric Fields and Magnetic Flux under EHV Overhead Power Transmission Lines. Report ORP/EAD 78-1. Office of Radiation Protection, U.S. Environmental Protection Agency, Las Vegas, NV (1978).
33. Anderson, F.J.; Phillips, B.G.: Electric Field Strengths and Magnetic Flux Densities around Electric Power Generating and Distribution Facilities in Alberta. Report. Alberta Workers' Health, Safety and Compensation, Edmonton, Alberta (1984).
34. Krause, N.: Exposure of People to Static and Time Variable Magnetic Fields in Technology, Medicine, Research and Public Life: Dosimetric Aspects. Symp. on Biological Effects of Static and Extremely Low Frequency Magnetic Fields, Neuherberg, Federal Republic of Germany (1985).
35. Lovsund, P.; Oberg, P.A.; Nilsson, S.E.P.: ELF Magnetic Fields in Electrosteel and Welding Industries. Radio Sci. 17(5S):35S (1982).
36. Stuchly, M.A.; Lecuyer, D.W.; Mann, R.D.: Extremely Low Frequency Emissions from Video Display Terminals and Other Devices. Health Phys. 45:713 (1983).
37. Rosner, B.: Fundamentals of Biostatistics, pp 214–219. Duxbury Press, Boston, MA (1982).
38. Chibrera, A.; Nicolini, C.; Schwan, H.P. (Eds.): Interactions Between Electromagnetic Fields and Cells. Plenum Press, London (1985).

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Considerations in Exposure Modelling

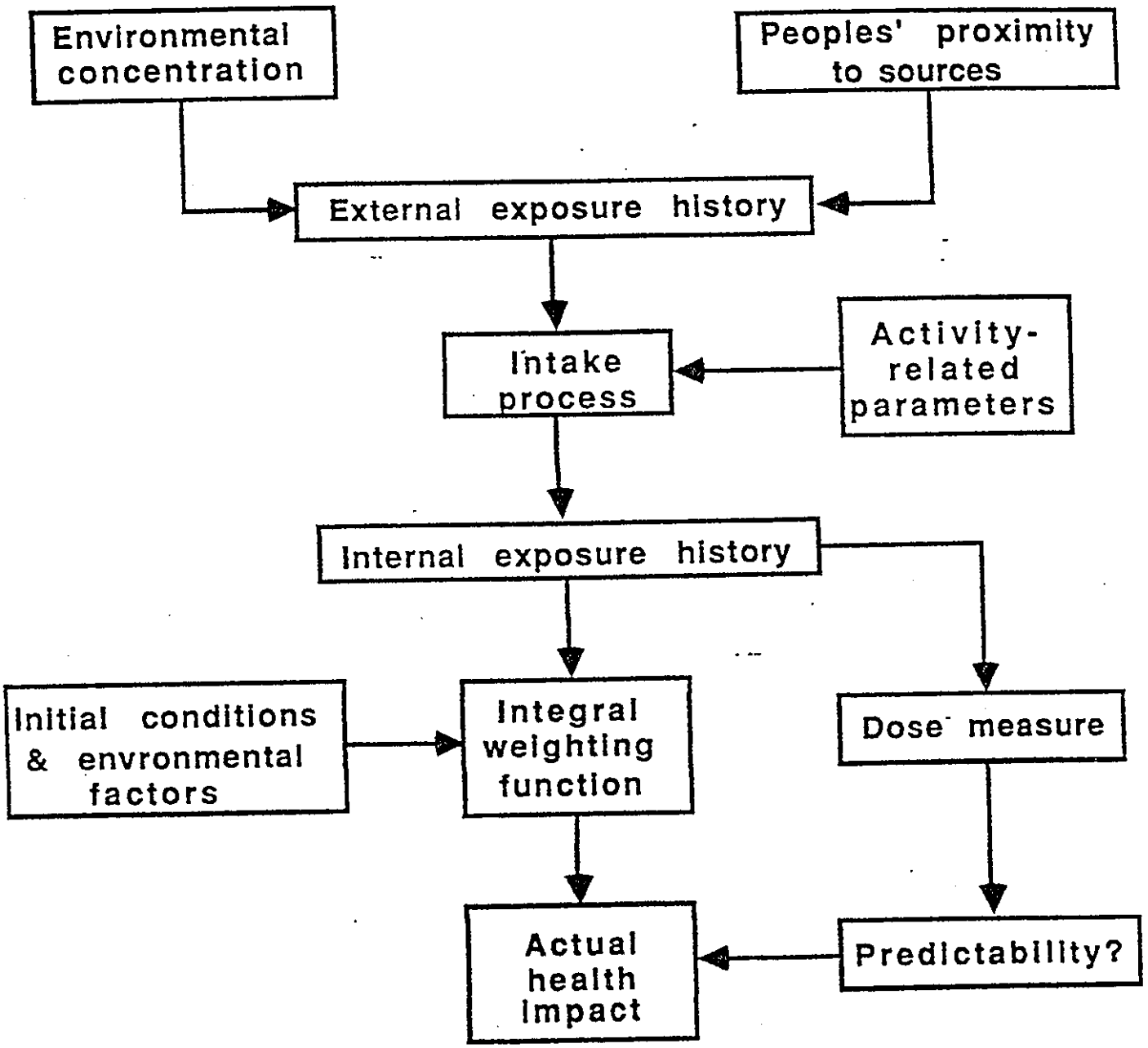
- Three sources of power-frequency fields
  - Transmission lines
  - Distribution lines
  - Indoor wiring and appliances

- Three exposure mechanisms
  - Electric induction
  - Magnetic induction
  - Contact currents

- Three stages of exposure model
  - Source characteristics
  - Activities of people relative to sources
  - Dosimetry

Choice of "Dose" Measure is Arbitrary

- Measures of instantaneous intensity
  - unperturbed field
  - electric field on body surface
  - current density within body
  - magnetic field within body
  - thresholds
- Spatial
  - whole-body average
  - peak
  - organ specific
- Temporal
  - time average
  - peak
  - rate of change


Environmental concentration
Peoples' proximity to sources
External exposure history
Intake process
Activity-related parameters
Internal exposure history
Initial conditions & envronmental factors
Integral weighting function
Dose measure
Actual health impact
Predictability?

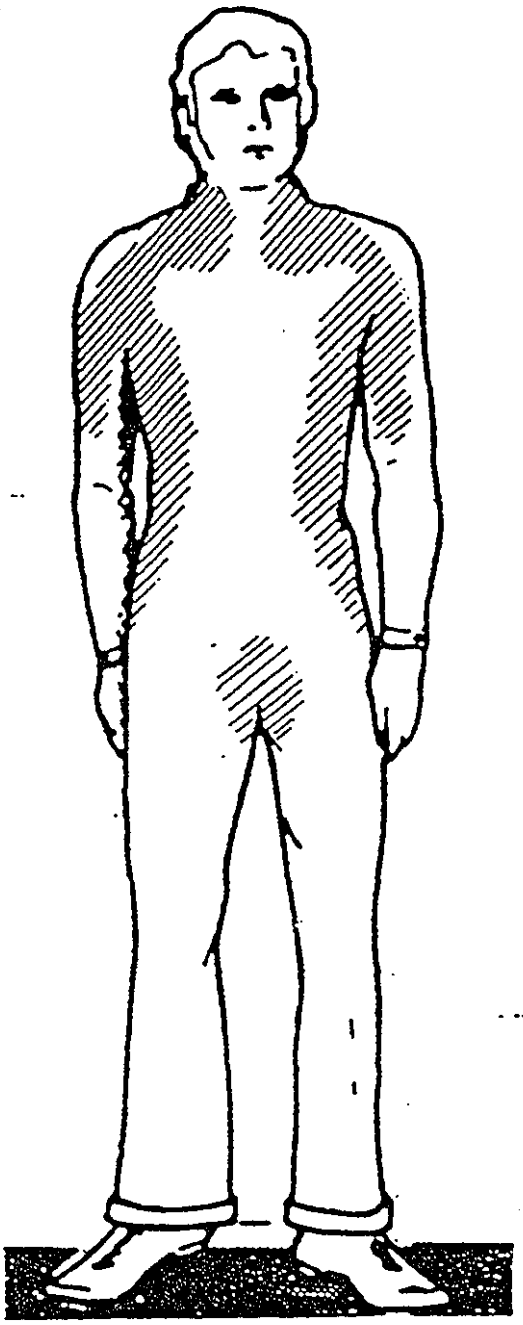


Figure 4-2: Regions of most intense current density induced by a uniform 60 Hz magnetic field perpendicular to the frontal plane. (Deduced from [Guy 76]).

CANDI / DIANE

The proposed corridor will result in the following activities:

Right of Way Clearing

Access Road Construction

Structure Foundation Construction

Structure Assembly & Erection

Conductor & Shieldwire Stringing & Tensioning

Site Restoration

The above activities will result in compaction and soil structure disruption of the various types of soils found along the proposed route. What impact will these activities have on runoff?
What impact will these activities have on drainage?
What impact will these activities have on erosion?
What impact will these activities have on existing vegetation in the proposed corridor and its perimeter?
How does Puget Power plan to mitigate any consequences relating to the above concerns?
What types of soils are found in the proposed corridor and how will each type of soil react to the problems of runoff, drainage and erosion?
How will the changes resulting from filling or grading affect runoff, drainage and erosion?

Puget Power states the steepest anticipated slope along any portion of the proposed route will not exceed 10 percent; however, a portion of this route is considered to be approximately a 35 percent grade. The nature of the soils in this area and the right of way clearing needed for this proposed

project would significantly contribute to erosion. What impact would this erosion have on aquatic ecology of waterways, streams and wetlands?

What impact would this erosion have on vegetation both in the proposed corridor and the perimeter?

Several areas along the proposed corridor would require the removal of considerable amounts of trees in our forested land, many of which have thrived in the protection of surrounding trees, thus resulting in less established root systems. Due to the nature of strong winds both from the south and the north-east, what significant impact would the right of way clearing have on the remaining trees along this proposed corridor?

The forested lands have provided natural wind breaks. What impact would this new open space have on newly exposed dwellings, both human and animal?

How many acres of forested land would be eliminated by this proposed corridor?

How many acres of prime farmland would be affected?

How many acres of wetlands would be affected?

How many acres of recreational land would be affected?

Vegetation grown under the canopy of trees is quite different than the vegetation grown in open space. How will this change in the natural environment impact the variety of plant species currently found along the proposed corridor?

What will be the ramifications on the food chain of the wildlife

habitat caused by this change in vegetation?

What consequences would the potential changes in drainage have on existing wet soil plants?

What indigenous plant species exist within the proposed corridor?

What is the impact on existing vegetation within the right of way and fringe of the proposed corridor from the following:

Clearing?

Construction?

Maintenance?

Changes in soil climate?

Fallout of electro-magnetic waste?

What impact would construction activities, destruction of vegetation and increased runoff and erosion have on nearby dwellings? On riparian areas?

What kind of herbicids/chemicals are intended for use to maintain the proposed corridor?

What chemicals would be used to treat the poles and crossarms?

Describe in detail the chemical properties of each and what effects each of these treatments would have on water, soil, air, plant vegetation, wildlife, fish, aquatic organisms, animals and humans.

What would be the methods of applications of these herbicides?

What determination would be made as to what herbicide would be used in regards to the various soil types found along the

proposed corridor?

Studies have shown that fallout of electro-magnetic waste increases vegetative growth. What would the ramifications be of repeated use of such chemicals?

As the result of herbicide use, what measures would be used to avoid runoff? Adsorption? Volatilization? Absorption? Leaching?

Should any of these situations occur, how many acres of land would be affected?

Analyze the effects rainwater coming into contact with the proposed high voltage powerlines would have on vegetation? Wildlife? Animals? Water systems? Humans?

Give an analysis of temperature change resulting from the proposed high voltage powerlines on air? Water? Land?

NEIGHBORS OPPOSING POWER ENCROACHMENT

1. INTRODUCTION

Mr. Chairman, thank you for this opportunity to appear before the Committee. I am William Ross Adey. Since 1977, I have served as Associate Chief of Staff for Research and Development at the Pettis Memorial VA Medical Center at Loma Linda, California. I am a Distinguished Professor Medicine (Neurology) at the affiliated Loma Linda University School of Medicine, where I also act as Assistant Dean for Research. From 1957-77, I was a faculty member at UCLA School of Medicine and Director of the Space Biology Laboratory of the UCLA Brain Research Institute. For the past 44 years, my research career has covered a broad spectrum in neurology and the brain sciences, in environmental medicine, in biomedical and communication engineering, and in cell biology of the molecular and atomic processes by which cells of the brain and body tissues communicate with one another.

These latter processes have been the exclusive focus of our team's research for more than 15 years. We have played a pioneering role in understanding how body cells "whisper" to one another; and in so doing, we have discovered some of the keys to understanding how electromagnetic fields, so weak that until quite recently many scientists have regarded them as incapable of biological effects, are detected by living tissues, and what are the likely implications of these findings for human health.

I deeply appreciate the privilege of presenting the following

testimony on a matter that may be significant in broadly shaping the future of our society. At the same time, these same concerns are likely to touch all our lives in very personal ways. My testimony is presented in a private capacity.

2. CURRENT PERSPECTIVES ON THE ELECTROMAGNETIC ENVIRONMENT: NATURAL AND MAN-MADE FIELDS

In a biological perspective, all life on earth has evolved in a sea of natural low-frequency electromagnetic fields, generated in part from the sun and also from the huge energy of thunderstorm belts in the Amazon basin and in central Africa. In an historical perspective, this natural electromagnetic environment has been vastly perturbed since the beginning of the 20th century by an ever-increasing level of artificial electromagnetic fields.

These artificial fields now bathe us throughout our lives, in our homes, in the workplace, and in the environment. They differ from the natural electromagnetic environment in two important ways. First, they are typically hundreds and in some cases millions of times stronger than the natural fields. Second, whereas most of the natural fields occur at frequencies below 100 cycles per second (that is, they surge back and forth less than 100 times per second as oscillating fields), man-made devices and systems now expose us all to an electromagnetic environment of almost unbelievable complexity from conception to death.

Although public interest has focused increasingly on possible health hazards associated with the use of electric power distributed throughout the world at either 50 or 60 Hz, it must be remembered

that most urban and suburban environments also involve exposures to radiofrequency and microwave fields. The magnitude of these exposures obviously depends on proximity to the sources, whether in industrial heating devices, for example, or to radio, TV and microwave transmitters widely scattered in most urban and suburban environments, or in the use of handheld portable transceivers placed close to the head of the user.

We may pause for a moment to consider the complexities of some of these exposures as they occur in our daily routine. In the morning, we may use an electric shaver or an electric hair dryer. We may stand close to a microwave oven in cooking breakfast. En route to work, we may use a cellular car phone. At work, we may spend hours at a computer terminal, or at the office copy machine. At night we may sleep under an electric blanket or on a heated water bed.

Much public concern centers on exposure to high voltage AC power transmission systems and distribution lines running through suburban areas. In assessing total personal daily exposures, we must also take account of the devices and systems just cited. The utility industry is ever ready to point out that fields generated by these devices are as large or larger than those in the vicinity of power transmission and distribution systems.

There are most important differences which industry representatives fully understand, but fail to state. First, fields around toasters, hair dryers, refrigerators and similar appliances decrease rapidly at even short distances from the device. Second, users are only briefly exposed to these fields each day. In sharp

contrast, power line fields are pervasive and essentially unvarying in every room of nearby dwellings. They decrease quite slowly at increasing distances from the line. Exposures to these fields may be virtually continuous on a daily basis and over a lifetime. Children attending schools adjacent to power lines and transformer substations may be captives to magnetic field exposures far above those typical of most home environments for 8 hours daily from kindergarten to high school graduation.

Much further research is necessary, not only in the area of potential health hazards from exposure to a wide spectrum of environmental electromagnetic fields, but also to support new and extremely important application of these nonionizing electromagnetic fields in the realm of medical research, and in development of new diagnostic and therapeutic procedures. These fields are the key to development of new medical imaging techniques, far transcending any existing systems in their capacity to display details of body structure and function. They offer keys to urgently needed therapies in healing body tissues and in treatment of cancer.

Relatively little effort has been directed to improving the general public's understanding of the physical nature of these fields, even in simple descriptive terms. There is therefore widespread confusion at a very fundamental level, particularly with respect to differences between ionizing and nonionizing electromagnetic radiation. In previous testimony on this subject before the House Subcommittee on Water and Power Resources in October, 1987, I submitted a brief and highly simplified overview of

electromagnetic concepts, in the expectation that this would facilitate a more detailed discussion of current knowledge that relates to establishment of health safety standards and future research needs. I shall not repeat that material here, but respectfully suggest that Committee members may find it useful as they pursue the vexing question of public instruction.

3. CURRENT STATE OF RESEARCH IN HEALTH EFFECTS OF ELECTROMAGNETIC FIELDS

Despite totally inadequate funding from either Federal or other sources in the USA over the past decade, two major streams of new knowledge have emerged as highly significant contributions by US scientists to the mainstream of a world endeavor. On the one hand, these studies have addressed the epidemiology of human diseases that now appear ever more closely related to environmental electromagnetic field exposure. On the other, laboratory studies in cells, tissues and animal models have disclosed in a wealth of detail many of the fundamental mechanisms by which extremely weak electromagnetic fields interact with cells and tissues.

It is important to set a correct perspective on the high quality of the essence of US science in the field, despite enormous fiscal difficulties that have beset its accomplishments. Concluding that much of the research is "of very high quality," the Congressional Office of Technology Assessment stated in its report on health effects of power line frequency electromagnetic fields (June 1989):

> "Electric and magnetic fields produced by electric power systems may pose public health hazards. Although as recently as a few years ago, scientists stated that available evidence showed no health risks from power frequency fields, emerging evidence no

longer allows a categorical denial that risks exist.

A growing number of studies have now clearly demonstrated that, under specific circumstances, even weak electric and magnetic fields can affect living cells and systems. The cell membrane has emerged as the primary site of interaction between electric and magnetic fields and the cell. Studies have demonstrated that extremely small signal changes can trigger major biochemical responses critical to the functioning of the cell.*

It is important to emphasize that these studies at the cell and molecular level have built, and continue to build, a series of critically important bridges between laboratory science and human epidemiology; so that it is no longer possible to say that mechanisms mediating interactions of electromagnetic fields with biomolecular systems remain unknown with respect to potential health problems.

As long as we lack broad and detailed knowledge of mechanisms that mediate electromagnetic field interactions with body tissues, epidemiological studies remain little more than straws in the wind of the extent and possible seriousness of human hazards. In many respects, studies of mechanisms provide essential signposts and directives that will determine the very nature of further epidemiology studies. For example, laboratory studies have revealed enhanced effects of chemical cancer promoters in joint actions with electromagnetic fields; thus, the epidemiological hunt for the basis of increased cancer risk now invites detailed consideration of possible joint effects of environmental chemical pollutants and electromagnetic fields.

What are the major benchmarks from laboratory research on mechanisms of field-tissue interactions and from epidemiological studies?

3.a. Salient Findings in Studies of Cell and Tissue Sensitivities to Electromagnetic Fields

i) Actions on Cells of the Immune System

The body's immune sytem is the fortress built by nature against infection and the creeping claws of cancer. Reduced immune competence is therefore followed by dire consequences for the individual, whether it results from aging, from the ravages of infection such as AIDS, or from environmental chemical pollution. Lymphocytes of the immune system can be "targeted" against tumor cells, destroying them by breaking their covering membranes on contact.

In studies with cell cultures, either electric fields simulating 60 Hz high voltage power line fields or weak microwave fields that vary in intensity at a 60 Hz rate can reduce the killing capacity (cytotoxicity) of lymphocytes targeted against human malignant lymphoma cells (a malignant tumor of lymph glands) (Lyle et al., 1983, 1987). These fields also disrupt activity of enzymes that act as internal messengers inside lymphocytes by up to 60 percent (Byus et al., 1984).

In terms of human exposures and epidemiological studies, these and related findings offer an important bridge to epidemiological reports of reduced immune surveillance, with increased incidence of certain lymphomas and other malignancies, discussed below (Davis and Milham, 1990; Matanoski, 1989; Milham, 1985).

ii) Identification of Cell Membranes as Site of Action of Environmental Electromagnetic Fields in Laboratory Cancer Models

Available evidence indicates that these fields do not function as classical initiators in the etiology of tumor formation by causing damage to DNA and gene mutation in cell nuclei. However, they may function as promoters, by reason of their actions on cell membranes that form a closing envelope around all cells.

Research supported primarily by DOE and EPA has established that the main site of action of electromagnetic fields is at cell membranes (Adey, 1989, a,b,c.). Many chemical tumor promoters also act at cell membranes. They include insecticides (DDT), polychlorbiphenyls (PCBs) formerly used as electrical insulators and coolants, tobacco proteins and certain other plant substances associated with human cancer.

Basic concepts in the biology of cancer have been substantially revised in recent years through studies of joint actions of chemical cancer promoters and electromagnetic fields at cell membranes leads to uncontrolled growth (Trosko and Chang, 1986). Chemical cancer promoters disrupt this "whispering together" between normal cells. Actions of these promoters are enhanced by weak electromagnetic fields, but there may be no effects of fields alone (Fletcher et al., 1986).

These findings imply that environmental fields may act jointly with chemical cancer promoters, including environmental pollutants, to disrupt normal communication between cells, leading

to uncontrolled growth. Again, these findings offer an important bridge to epidemiological studies that have repeatedly emphasized enhanced cancer risk for those exposed to chemical carcinogens and electromagnetic fields, including occurrence of brain tumors in microwave workers (Thomas et al., 1987), brain tumors in children with fathers in electrical occupations (Johnson and Spitz, 1989), lymphomas in workers in aluminum reduction plants (Davis and Milham, 1990), and a high cancer risk in telephone workers exposed to electromagnetic fields and chemical toxins (Matanoski, 1989).

iii) Electromagnetic Field Influences on Fetal Development, Body Growth and Sexual Maturation

Laboratory studies have shown adverse developmental effects of environmental electromagnetic fields on fetal development in birds and mammals. Increased fetal deaths and fetal abnormalities follow exposure of mice to fields of computer terminals (Frolen et al, 1986; Tribukait et al., 1987). Increased birth defects were seen in swine exposed to 60 Hz high voltage power line fields (Sikov et al., 1987).

Electromagnetic field exposure of rats in late pregnancy leads to serious postnatal and psychosexual effects in the offspring, and to a doubling of weights of sexual organs (McGivern et al., 1990). These subtle but challenging findings relate to hormonal control of biological rhythms and sexual development by the pineal gland in the brain; and in the adult, to pineal control in inhibiting cancer development, specifically in skin malignant melanomas, and breast and uterine cancers (Blask and Hill, 1988).

These findings clearly invite much further research.

3.b. Salient Findings in Epidemiological Studies

In the past 5 years, epidemiological surveys have been conducted in many countries. Although all these studies have various imperfections, they have developed a strong consensus that certain environmental field exposures in homes and in the workplace may be associated with health hazards. These include effects on fetal development, on the immune system, on brain and neuroendocrine control mechanisms, and on control of growth, including cancer promotion and tumor formation.

i) An independent follow-up study of children in the Denver area supports earlier findings (Wertheimer and Leeper, 1979) of increased risks for leukemia, lymphoma and brain tumors, and suggests increased risks in homes where 60 Hz fields exceed 2 milligauss (Savitz et al., 1988). By way of comparison, typical levels in the home are in the range 0.1-0.5 milligauss except in close proximity to appliances. Fields measured at the edge of rights-of-way for high voltage transmission lines or near distribution lines and transformer substations may be in the range 10-100 milligauss. This study by the State of New York concludes that 10 percent of childhood cancer in the USA may relate to environmental EM field exposure, accounting for approximately 1000 cases annually.

ii) Occupational studies implicate possible combined actions of electromagnetic fields and chemical factors. A National Cancer Institute study has reported a 10-fold increased risk of malignant

brain tumors in microwave workers with more than 20 years' job experience, if they were also exposed to electronic solvents or soldering fumes (Thomas et al., 1987). Chemical factors alone carry a risk factor around 2.

iii) Electrical workers in Los Angeles county have a 5-fold increased risk of certain brain tumors (Preston-Wilson et al., 1989).

iv) In a population of 51,000 New York telephone workers, a subset of 4800 line splicers exposed to a mean 4 milligauss 60 Hz field and to solvents and soldering fumes had a doubling of risks for all cancers; and risks as high as 7 for leukemia, brain tumors and male breast cancer (Matanoski et al., 1989).

v) In a population of 350 workers at one aluminum reduction plant, 5 deaths from lymphoma occurred in a 7 year period. This "pot room" environment involves extremely high magnetic fields and a variety of chemical fumes. In a subset of 23 pot room workers, 14 of 23 showed a reversal of the normal ratio of "helper" to "suppressor" lymphocyte cells that regulate levels of antibody production by the immune system. These high levels of suppressor cells are strong indicators of possible interference with normal immune functions, increasing risks of infection and cancer (Davis and Milham, 1990).

vi) An increased incidence of malignant brain tumors has been reported in children of fathers exposed to radiofrequency fields and electronic solvents (Johnson and Spitz, 1989).

vii) A doubling of miscarriage rates has been reported in women working at computer terminals for more than 20 hours/week in the

first three months of pregnancy (Goldhaber et al., 1988). Increased miscarriage rates have also been reported in homes with electrical heating wiring in floors and ceilings and in women using electric blankets and heated water beds (Wertheimer and Leeper, 1982, 1985).

4. SHOULD FEDERAL RESEARCH ON ELECTROMAGNETIC FIELDS BE REVAMPED IN ACCORDANCE WITH PROPOSALS MADE IN H.R. 4801?

Current knowledge of cellular and molecular mechanisms is primarily the fruit of Federal programs initiated in the 1970s. Though smaller in scope but reflecting far-sighted concerns, programs initiated by a few electric utilities in the same period on an individual basis have also contributed importantly, long before the appearance of a much larger centralized industry-based program.

This Federal program in civilian agencies initially involved the FDA Bureau of Radiological Health (now the Bureau of Medical Devices and Radiological Health), the Environmental Protection Agency, and the Department of Energy. Now, only the DOE supports a small national program at a mere $3 million annually as the sole civilian effort.

4.a. The Current DOE Research Program

This continuity of funding by DOE has been a critically important benchmark. Directed by the Office of Energy Systems, it has allowed survival of a highly productive, high quality research program. It is multifaceted in its approach to key questions of mechanisms of electromagnetic field action. Its management has been flexible in reshaping the main objectives of the program as the base of scientific knowledge has evolved. As a criterion of its

effectiveness, a clear majority of this new knowledge on mechanisms of interaction cited above has been derived over the past decade from this program.

Yet biased, uninformed and irresponsible critics abound, many with their own hidden agendas. In recent Congressional testimony, Dr. David Carpenter, who directed a 5-year study for the State of New York on possible health hazards of 60 Hz fields stated that, in his capacity as a consultant to this DOE program, he had only attended two cocktail parties and that there was only poor research by poor researchers. The research record clearly gives the lie to such an assessment, and such remarks demean us all.

Hirelings of industry are ever ready to clack a paid opinion. Dr. Kirby Holte, described by the Los Angeles Times (July 12, 1990) as a University of Southern California faculty member and a consultant to a large Southern California electric utility corporation, is quoted: "In 22 years and more than $50 million in research, no one has ever conclusively proved that electromagnetic fields are dangerous to health." This attitude, not unknown today even in some cognizant Federal agencies or individuals within those agencies, can only be described as wearing blinders in the face of available scientific evidence, with the same apparent lack of good sense as the executives of the tobacco industry who never admit to even the slightest danger in smoking.

4.b. DOE Missions in Future Electromagnetic Field Research under H.R. 4801.

First, it is appropriate that DOE should exercise the role of lead

agency in a significantly expanded national research program of health related research, in part by reason of the unique scientific experience and management capabilities that have guided the existing program in the Office of Energy Systems.

There are other, perhaps more important reasons. For more than 20 years, the DOE Office of Health Effects Research (OHER) has supported a broad research program on biological and medical effects of ionizing radiation in National Laboratories and in academic institutions. In the late 1970s, this office initiated studies of health-related effects of nonionizing environmental electromagnetic fields. Support for this research ceased in 1980.

It may now be time for OHER to consider new missions in health-related effects of environmental nonionizing electromagnetic fields, in studies of field interactions with major biological regulatory systems; as for example, in effects on the immune system, on embryonic and fetal development, on neuroendocrine regulation, and on regulation of normal and abnormal tissue growth. There is a broad vista of needed knowledge at this system level in the pathophysiology of human disease. This knowledge generated through an OHER research program would complement studies of biophysical and physico-chemical interactions now studied at the atomic level in the existing program of the DOE Office of Energy Systems.

These DOE programs would fill needs for sharply expanded research in the basic sciences related to mechanisms of electromagnetic field bioeffects. At the same time, DOE programs should avoid commitments in areas better suited to missions of other agencies. DOE should not

become involved in extensive epidemiology studies, nor in extensive field measurements in homes or workplaces that might determine "windows" of safe field intensities for human exposure as part of programs aimed at mitigating procedures.

4.c. Missions of the Environmental Protection Agency (EPA) and the National Institute of Environmental Health Sciences (NIEHS) under H.R. 4801

It is appropriate that the historical records of EPA and NIEHS be taken into account in projecting their future roles in electromagnetic field research; for neither is without taint. And if their future participation is to be effective, their managements should make plain that past practices and deficiencies will not recur.

From 1978 through 1986, EPA funded an excellent intramural program at its laboratories at Research Triangle Park, NC. Staffed by outstanding scientists, its research programs and contributions to knowledge received world acclaim. Yet by administrative fiat at a high level within the agency, this team was disbanded in 1986 and dispatched to work in chemical toxicology, all the years of their unique research experience willfully cast aside. That this was no ill-considered administrative caprice was made abundantly plain at hearings of the House Subcommittee on Water and Power Resources in October 1987, when in response to a direct plea from the Committee chairman, EPA representatives flatly and unequivocally declined to make a commitment to further research in nonionizing electromagnetic radiation.

May I therefore respectfully suggest that, in proceeding with H.R. 4801, this Committee may wish to examine in some detail EPA's intentions to fufill whatever clearly stated research goals may be established in the legislation.

Beginning in the early 1970s, NIEHS also established a mission in nonionizing electromagnetic radiation, with small intramural and extramural programs. It also accepted administrative responsibility for a USA-USSR Exchange Program established under the Nixon-Brezhnev Agreement in 1974.

However, it was abundantly clear that these activities always remained low priorities in the Institute's missions, consistently overshadowed by commitments to perceived greater concerns with environmental chemical toxicology, such as lead poisoning in children. The NIEHS intramural program in microwave research, conducted by highly competent scientists, was disbanded in the early 1980s. The Soviet exchange program, effectively administered in behalf of the USA by these same scientists, was offered to other Federal agencies and is now under the direction of FDA.

Again, there is the nagging question of a dedicated commitment by NIEHS to what will inevitably require long years of unremitting effort by its scientists and the unswerving support of its administration.

5. WHAT TYPES OF STUDIES SHOULD THE GOVERNMENT UNDERTAKE IN THE HEALTH FIELD?

Though couched in specific terms, the following topics are suggested as representative of the classes of programs and projects

needing effective support in the health field. With clear intent, they emphasize the importance of basic science studies in mechanisms of field action:

a. Studies of field effects on the immune system, assessed by markers in the blood of man and animals, and evaluating the separate roles of electric and magnetic field components. Similar studies would test radiofrequency/microwave fields having low-frequency sinusoidal or pulsed modulation. For man, this would involve testing subjects in industrial environments, such as those associated with electromagnetic pulse (EMP) generators, welding plants, etc.

b. Developmental studies of neurobehavioral and psychosexual development in man and animal models after fetal exposure to ELF sinusoidal and pulsed magnetic fields. These studies would extend available evidence indicating defective psychosexual development following brief intrauterine exposures in animal models.

c. Examination of pineal hormone (melatonin) regulatory mechanisms in response to 60 Hz and other low-frequency field exposures, focusing on body growth and sexual development, and on possible mechanisms linking melatonin functions with normal and abnormal estrogen receptor mechanisms in breast tissue, and thus possibly to breast cancer.

d. Studies of the cell biology of growth regulation, including possible electromagnetic field effects on DNA synthesis, RNA transcription, and enzymatic regulation of cell growth.

e. Attempt a determination of <u>cumulative dose</u> as an aspect of

repeated, intermittent field exposures. Since there are many on and off effects in tissue responses, there is an urgent need to define these processes in ways that would permit extrapolation to permissible exposures in man.

f. A focus in epidemiological studies on clustering phenomena that have repeatedly characterized occurrence of cancer in situations where environmental electromagnetic fields are a suspected factor. Epidemiologists have expressed doubts about the wisdom of such a focused interest (Neutra, 1990), but the world-wide occurrence of clustering as a frequent aspect of this problem leaves little doubt that it should be directly confronted. At this time, I am not aware of Federally supported research into this clustering.

In a related context, one may question the merit of an epidemiological study proposed by the National Toxicological program for longitudinal studies in animals or man. They appear ill-advised, since there would be little chance to take appropriate account of the vast range of low-level factors acting concurrently that are the essence of the human situation in urban societies.

6. WHAT SHOULD BE THE ROLE OF THE PRIVATE SECTOR IN ENVIRONMENTAL ELECTROMAGNETIC FIELD RESEARCH?

There can be no question that private funding should play a significant role in a mission-oriented national research program. However, there must be grave ethical concerns over conflict of interest inherent in an industry conducting research in its own

behalf, without the buffer of independent fiscal control and total independence in design, performance and evaluation of research programs. These concerns are even more pressing where the issues involve the public health and welfare.

For these reasons, it is a matter of concern that a single large industry-funded program, such as that of the Electric Power Research Institute, with an annual budget in the range of $6 million has come to overshadow by a factor of two the entire US Federal support. There is no scrutiny of EPRI research programs beyond its own advisory committee. Yet it presumes to speak with authority through its own publications for this field of science as a whole, nationally and internationally, and as a spokesperson for the field to foreign governments.

I shall leave it others to address in detail EPRI's relations with the industry that funds it, but I invite the Committee's attention to the recent development of an industry-funded research program to operate totally independent of EPRI. A consortium of utilities operating under the rubric of the American Power Association has planned a 5-year research program on mechanisms of biological interaction, to be conducted primarily through universities and other established basic research institutions. The Association's commitment would be in an amount of $20 million, with support after 3 years coming jointly from the Federal government and industry.

There is a counter-coin to questions of credibility and integrity of research conducted by industry in its own behalf. In order to sustain an independent, unbiased and competent source of research and

information on issues affecting the public welfare, not only is a strong Federally supported research program essential, but it is equally important that scientists engaged in this research, either in government laboratories or in independent institutions, refrain from involvement in litigant causes. It is a matter for public outrage that scientists employed by the National Cancer Institute, for example, received large personal fees for court appearances in behalf of electric power companies by declaring in an issue far beyond their individual or collective competence that there are no mechanisms by which electromagnetic fields could play a role in cancer. And this they did in the very month that NCI put forth a national request for proposals to study the epidemiology of childhood leukemia in relation to electromagnetic field exposures. What should the public's expectation be for the credibility of such a study?

7. THE ISSUE OF PUBLIC INSTRUCTION

It is unfortunately true that only a small minority of the American public has adequate education to arrive at even a modestly critical judgment regarding the impact of the electromagnetic environment on their personal welfare. Lacking that capacity, it is all the more important that adequate information be disseminated to prevent uninformed overreaction.

It is simply not an option to consider turning back the clock and avoid the ever-growing daily use of electrical and electronic devices and systems. Yet much can be done to minimize exposures by indoctrination in the growing number of protocols for "prudent avoidance".

These steps are obvious and important. But a responsibility also devolves on those charged with the conduct of these research programs. No experiments have yet proven a relationship between electromagnetic fields and cancer. But that day may come, and regulatory agencies would then be faced with designing and implementing codes governing safe human exposure. This need should be continually in mind as the research proceeds in the coming years. As with the general public, there should be no last minute panic reaction, with implementation of futile regulations for which no appropriate background has been developed. I respectfully suggest that this should, indeed, be an ever-present benchmark throughout the proposed research program.

8. SCOPE AND CONTENT OF OVERSEAS RESEARCH PROGRAMS

There are currently research programs on health effects of these environmental fields in Sweden, Germany, the United Kingdom, Japan, Poland, Czechoslovakia and the Soviet Union.

Countries of the Soviet bloc first drew serious attention to possible health effects in the 1960s. In the west, many studies were industry-funded and offered in rebuttal to prove that there were no effects. It is in western countries that a remarkable metamorphosis has begun in the last two years, with a new philosophy that the studies evaluate the extent of possible hazards. The Swedish government is an exception and has pursued a comprehensive series of clinical and basic science studies in power line and radiofrequency fields for the last 10 years. Government funded research is now undergoing substantial expansion in Germany and the United Kingdom.

Despite limited funding, there do not appear to be major avenues of foreign research that have been neglected or ignored in the USA. However, the pace of our acquisition of needed knowledge has been far from optimal.

REFERENCES

1. Adey, W.R. (1989a) Cell membranes, electromagnetic fields and intercellular communication. In: Dynamics of Sensory and Cognitive Processing in the Brain, Second Symposium, Basar, E., Bullock, T.H., eds. Springer Verlag, pp. 26-42.

2. Adey, W.R. (1989b) Nonlinear electrodynamics in cell membrane transductive coupling. In: Membrane Transport and Information Storage, Advances in Membrane Fluidity, Vol. 4, Aloia, R.C., Curtain, C.C., Gordon, L.M., eds. Wiley-Liss, New York. pp. 1-27.

3. Adey, W.R. (1989c) Electromagnetic fields, cell membrane amplification and cancer promotion. In: Extremely Low Frequency Fields: the Question of Cancer, Wilson, B.W., Stevens, R.G., Anderson, L.E., eds. Battelle Press, Columbus, Ohio. pp. 211-250.

4. Blask, D.E., Hill, S.M. (1988) Melatonin and cancer: basic and clinical aspects. In: Melatonin: Clinical Perspectives, Miles, A., ed. University Press, Oxford.

5. Byus, C.V., Lundak, R.L., Fletcher, R.M., Adey, W.R. (1984) Alterations in protein kinase activity following exposure of cultured lymphocytes to modulated microwave fields. Bioelectromagnetics 5:34.

6. Davis, R.L., Milham, S. (1990) Altered immune status in aluminum reduction plant workers. In press.

7. Fletcher, W.H., Shiu, W.W., Haviland, D.A., Ware, C.F., Adey, W.R. (1986) A modulated microwave field and tumor promoters similarly enhance the action of alpha-lymphotoxin (aLT). Proc. 8th Annual Meeting Bioelectromagnetics Soc., p. 12.

8. Frolen, H., Svedenstal, B.M., Bierke, P. (1987) Repetition of a study of the effect of pulsed magnetic fields on the development of fetuses in mice. Swedish National Institute of Radiation Protection, Project 346-86, Final Report.

9. Goldhaber, M.K., Polen, M.R., Hiatt, R.A. (1988) The risk of miscarriage and birth defects among women who use visual display terminals during pregnancy. Am. J. Industrial Med. 13:695.

10. Johnson, C.C., Spitz, C.C. (1989) Childhood nervous system tumors: an assessment of risk associated with paternal occupations involving use, repair or manufacture of electrical and electronic equipment. Internat. J. Epidemiol. 18:756.

11. Lyle, D.B., Ayotte, R.D., Sheppard, A.R., Adey, W.R. (1988) Suppression of T lymphocyte cytotoxicity following exposure to 60 Hz sinusoidal electric fields. Bioelectromagnetics 9:303.

12. Lyle, D.B., Schechter, p., Adey, W.R., Lundak, R.L. (1983) Suppression of T lymphocyte cytotoxicity following exposure to sinusoidally amplitude-modulated fields. Bioelectromagnetics 4:281.

13. Matanoski, G., Elliott, E.A, Breysse, P.N. (1989) Cancer incidence in New York Telephone workers. U.S. Dept. of Energy, Office of Energy Storage and Distribution, Proc. Annual Conf. on Biological Effects of 50/60 Hz Electric and Magnetic fields. p. P-10.

14. McGivern, R.F., Sokol, R.Z., Adey, W.R. (1990) Prenatal exposure to a low-frequency electromagnetic field demasculinizes adult scent marking behavior and increases accessory sex organ weights in rats. Teratology 41:1.

15. Milham, S. (1985) Mortality in workers exposed to electromagnetic fields. Environ. Health Perspectives 62:297.

16. Neutra, R.R. (1990) Counterpoint freom a cluster buster. Am. J. Epidemiol., 132:1.

17. Preston-Martin, S., Mack, W., Henderson, B.E. (1989) Risk factors for gliomas and meningiomas in males in Los Angeles County. Cancer Res. 49:6137.

18. Savitz, D.A., Wachtel, H., Barnes, F.A., John, E.M., Tvdrik, J.G. (1988) Case-control study of childhood cancer and exposure to magnetic fields. Am. J. Epidemiol. 128:21.

19. Sikov, M.R., Rommereim, D.N., Beamer, J.L., Buchsbom, R.L., Kaune, W.T., Phillips, R.D. (1987) Developmental studies of Hanford miniature swine exposed to 60 Hz electric fields. Bioelectromagnetics 8:229.

20. Thomas, T.L., Stolley, P.D., Stemhagen, A., Fontham, E.T.H., Bleecker, M.L., Stewart, P.A., Hoover, R.N., (1987) Brain tumor mortality risk among men with electrical and electronics jobs: a case-controlled study. J. Nat. Cancer Inst. 79:223.

21. Tribukait, B., Cekan, E., Paulsson, L-E. (1987) Effects of pulsed magnetic fields on embryonic development in mice. In: Work with Display Terminals, Knave, B., Wideback, P-G., eds. North Holland, Elsevier.

22. Wertheimer, N., Leeper, E. (1979) Electrical wiring configurations and childhood cancer. Am. J. Epidemiol. 109:273.

23. Wertheimer, N., Leeper, E. (1986) Possible effects of electric blankets and heated water beds on fetal development. Bioelectromagnetics 7:13.

24. Wertheimer, N., Leeper, E. (1989) Fetal loss associated with two seasonal sources of electromagnetic field exposure. Am. J. Epidemiol. 129:220.