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Panel's Final Report

BIOLOGICAL EFFECTS OF POWER LINE FIELDS

NEW YORK STATE POWER LINES PROJECT SCIENTIFIC ADVISORY PANEL FINAL REPORT

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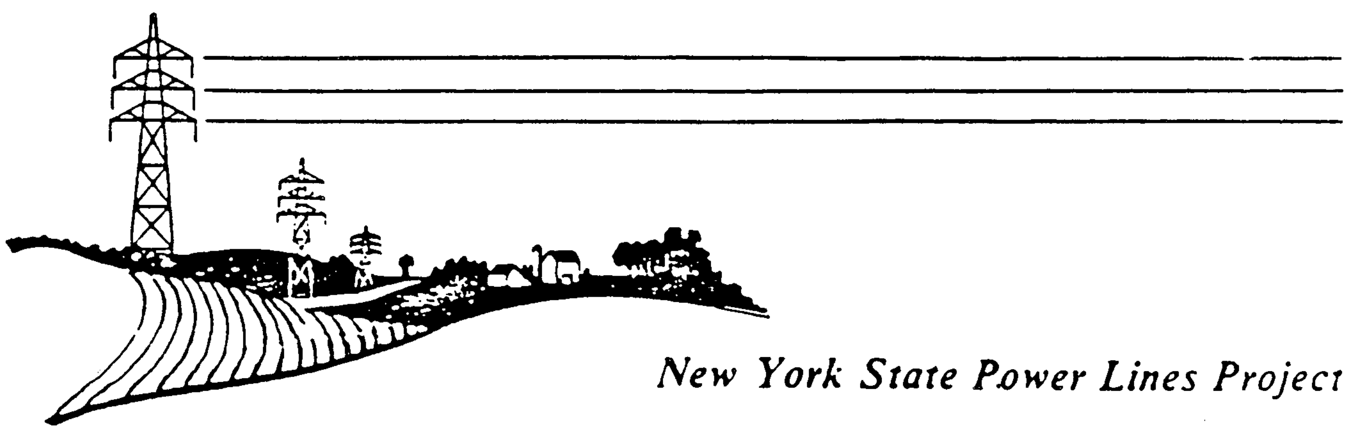

New York State Power Lines Project

The research was undertaken in seven general subject areas as follows:

1. Genetic, cytogenetic, teratogenic and reproductive studies: Three studies were performed in this area: one in which two strains of mice were exposed either to fields of two different intensities or control (unexposed) conditions for three generations (Carsten, Appendix 10) and two projects in which human lymphocytes (Cohen, Appendix 4; Livingston, Appendix 6) and Chinese hamster fibroblasts (Livingston, Appendix 6) in tissue culture were exposed.

   The Carsten studies revealed no significant effects in the incidence in mice of dominant lethal mutations, fertility as measured by impregnation, gestation time, litter loss, litter size, weight gain or average generation time. None of the studies on sister-chromatid exchange, chromosome breakage, mitotic rate, cell-cycle duration, rate of cell proliferation, DNA content or reproductive integrity as measured by a standard colony assay (clonogenicity) showed significant differences between exposed and controls.

2. Cell biology studies: Investigations were performed on osteoblastic cell lines (Rodan, Appendix 13), because electric and magnetic fields have been reported to alter bone growth. However, no effects of fields were found on rate of growth or ligand-receptor interactions as measured by parathyroid hormone activation of adenylate cyclase. Small but significant stimulation of ^{3}H-thymidine incorporation into DNA by electric fields was observed.

   Because of the exposure of the eyes to the environment and known effects of other forms of electromagnetic irradiation on ocular tissues, a study was done on corneal and lens cell and organ cultures (Basu, Appendix 5). Little effect was found on DNA and protein synthesis, ATPase activity, cell viability or growth characteristics, lens hydration or corneal wound healing.

In a study of cells of the immune system, canine and human leukocytes in culture exposed to fields did not show significant changes in functional responses to mitogens, levels of DNA, RNA or protein synthesis or levels of cell surface ligand receptors and immunoglobulins (Winters, Appendix 9).

3. <u>Proliferation of cancer cells in culture:</u> Although not a part of the original contract, Winters (Appendix 9) performed studies using soft agar cloning assays to assess the proliferative response of normal cells and human colon carcinoma cells to fields, and reported that for the cancer cells, but not the normal cells, magnetic or combined magnetic and electric fields caused increased cell proliferation, increased numbers of surface transferrin receptors, increased resistance to natural-killer-cell activities and increased expression of tumor cell-surface antigens. The observation that normal cells did not grow in soft agar is consistent with the conclusion that exposure to the fields did not cause cells to become cancerous. The observations with the cancer cells, however, suggested to the investigators the possibility that magnetic fields stimulate the rate of cancer cell growth. Even if this observation were confirmed, however, extrapolation to the behavior of cancer cells in humans it is not justified because behavior of cells in soft agar is not predictive of their behavior in the whole organism. Furthermore, there is no basis to extrapolate between growth of cells which are already malignant and initiation or promotion of cancer in the whole organism.

Because this experimental design was not part of the original contract (which was to perform immunologic studies), outside consultants expert in this research area were asked to site visit and review the experimental design and data (Drs. J. Trent and R. Buick, Appendix 18). In their report these experts indicated that the conclusions drawn by the contractor were not justified by the experimental data.

However, because the reported results generated consideration attention and concerns, the panel solicited a replication of the study by Cohen and Hamburger (Appendix 18). Using the same cell lines as Winters (but a slightly different field geometry), Cohen and Hamburger concluded that neither magnetic or magnetic plus electric fields affected clonogenicity in soft agar of either cell line. Attempts to demonstrate altered oncogene expressions were not successful (Trent, Appendix 18).

4. Neurobiology: Three projects investigated various nervous system effects. To pursue reports from other laboratories that fields cause specific and severe pathological changes in the cerebellum of developing animals, Gona (Appendix 11) performed studies in which rat pups were exposed pre- and postnatally to electric or magnetic fields or both. He found no significant morphological or ultrastructural changes of the cerebellum or cerebrum, no differences in DNA, RNA, protein or cerebroside content and no differences in time of eye opening, motor activity or body weight between exposed and control animals. The cerebellum of the developing animal is a sensitive structure whose development and maturation in many animals and humans are similar. A lack of morphological and biochemical changes argues against major direct effects of the fields on the processes of cell differentiation,

migration or synaptogenesis. Specific questions of neuronal connectivity are not answered by these studies, but the apparently normal behavior of the offspring suggests that major connections are intact.

Gundersen (Appendix 5) found no effects of 60-Hz electrical fields of up to 30 kV/m (air equivalent) and circularly polarized magnetic fields of 100 μT (1 G) on calcium efflux from dissociated spinal cord neurons, but did find small (up to 26%) but statistically significant increases in frequency of miniature end plate potentials (events reflecting spontaneous transmitter release) induced by linearly but not circularly polarized magnetic fields. Gundersen and colleagues speculate that the changes in frequency are related to alteration of intracellular calcium concentration.

Wolpaw and Seegal (Appendix 17) studied a variety of electrophysiological and neurochemical indicators in awake monkeys exposed to fields for prolonged periods of time. No significant effects were found in measures of general well-being, demeanor, weight, blood chemistries or performance of a simple motor task. There were no effects on early or mid-latency components of the auditory, visual and somatosensory evoked potentials, although late components of the somatosensory evoked potentials were decreased, as has been reported by others. Exposure to combined electric and magnetic fields were associated with a significant decrease in the concentration of two neurotransmitter metabolites, homovanilic acid (HVA) and 5-hydroxyindoleacetic acid (5-HIAA), in cerebral spinal fluid. There was an eventual return of HVA to normal while there was a long-term suppression of the 5-HIAA levels. The mechanism and significance of this effect is unknown, but the investigators believe that the changes in somatosensory evoked potential in the absence of alterations of auditory or visual evoked potentials could be due to changes in central opiates. Both the 5-HIAA and the somatosensory evoked potential results point to spinal cord localization of the effect.

5. Behavior: Four studies were principally behavioral (Ossenkopp, Salzinger, Sulzman and Thomas). All studies demonstrated significant alterations of behavior.

In his original project Ossenkopp (Appendix 12) looked for effects of magnetic fields on susceptibility to seizures in rodents. Magnetic fields at some [100-150 μT (1.0 - 1.5 G)], but not all flux densities significantly reduced mortality from drug-induced seizures, and in kindled animals there was a significant decrease in the duration of the after discharge in exposed animals. At the request of the New York Panel this contract was extended to a study of effects of magnetic fields on morphine-induced analgesia, studied in rats. While no significant effects were observed on daytime analgesia levels, there was a significant reduction in the analgesic effect of morphine at night in exposed animals which was a linear function of field strength. Additional studies showed that magnetic fields function as a weak environmental cue which could gain stimulus control over the expression of tolerance to morphine administration.

These observations implicate effects on circadian rhythms, and this assumption was documented by the studies of Sulzman and Murrish (Appendix 7) who studied the circadian rhythms of squirrel monkeys and found that electric fields altered free-running circadian periods in an intensity dependent fashion. At higher intensities the alterations were prolonged. Magnetic fields were held constant in these studies. Salzinger's study (Appendix 14) focused on behavioral alterations of rats exposed *in utero* and for the first eight days of life. He found the groups conditioned on the multiple random interval schedule to show a significant reduction on response rate relative to controls after exposure to electric plus magnetic fields. The difference in performance was maintained and even increased with further conditioning and extinction. This test is one designed to measure one kind of memory, and thus the results may be important.

Thomas (Appendix 8) found no significant effects of 60-Hz electric or magnetic fields on several behavioral tasks and on the behavioral effects of amphetamine and chlordiazepoxide. He did find, however, a significant effect of combining a low level 60-Hz magnetic field with a low level static magnetic field. Animals so exposed consistently exhibited changes in rate and pattern of responding to the same tests which were applied above, suggesting that static magnetic fields of the order of those of the earth may alter the effects of superimposed 60-Hz fields.

6. Multidisciplinary studies of human exposure: Graham and co-workers (Appendix 2) developed a system for controlled exposure of human volunteers in electric fields of 0-16 kV/m and/or magnetic fields of 0 to 40 μT (0.4 G). The investigators first determined human perception of fields and found that individuals varied in their ability to detect fields, but 90% had thresholds above 9 kV/m. Perception was dependent upon body position, but not time of day. The second part was a double-blind study of healthy male volunteers in whom a variety of physiologic and behavioral tests were done before and after exposure to

risk. This held for all childhood cancers, especially for leukemias, and to a lesser degree, for brain tumors. There appeared to be a dose-response relation, in spite of the inexact measures of exposure. The relative risk was above 2 for the highest exposed group. No sources of bias were identified to explain the results although the somewhat limited response rate remains a concern.

In the study of adult non-lymphocytic leukemia (Stevens) similar procedures in general were used but no association between cancer and magnetic field exposure, as measured by wiring configuration, direct field measurement or an engineering-based code, was found in the 164 cases and 204 controls.

In conclusion, results of the New York funded projects document biologic effects of electric and magnetic fields in several systems. The variety of effects of magnetic fields have not been previously appreciated. Several areas of potential concern for public health have been identified, but more research must be done before final conclusions can be drawn. Of particular concern is the demonstration of a possible association of residential magnetic fields with incidence of certain childhood cancers. Further study of this possible association and mechanisms to explain it are important. The variety of behavioral and nervous system effects may not constitute a major hazard because most appear to be reversible, but they may impact temporarily on human function. Further research should also be done in this area.

fields at various intensities for 6-hour sham and actual exposure periods. No significant effects were observed on vital signs except for a small but statistically significant lengthening of the cardiac interbeat interval. Sleep, appetite, sexual activity, cognitive and physical functions were not changed, nor were several monitors of mood. There was a reduction in amplitude of late components of the evoked potential to a signal detection task and an attenuation of the normal reduction in amplitude of late components of the evoked response in the auditory oddball task. While most performance tests were unchanged, several were altered in small but significant ways.

7. Epidemiology of cancer incidence: Because Wertheimer and Leeper (1979; 1982) reported an association between residential exposure to magnetic fields and incidence of cancer in children and adults in Denver, Colorado, two epidemiological investigations were done to a) study incidence of cancers in children in the Denver, Colorado area (Savitz, Appendix 15) and b) study the incidence of adult nonlymphocytic leukemia in Seattle, Washington (Stevens, Appendix 16) as a function of residential exposure to electric and magnetic fields.

In the Savitz case-control study, all cases of childhood cancer (ages 3-14) between 1978 and 1983 were selected. Controls were identified through random digit dialing and matched by age and sex. Exposure was estimated by determination both of wiring configuration outside the home, as developed by Wertheimer and Leeper (1979), and by direct measurement of the fields. Wiring configuration was found to correlate with the field measurements, and the major factor contributing to magnetic fields was found to be distribution lines. There was a positive association between wiring configuration and increased cancer

III. HISTORICAL PREFACE

A. INTRODUCTION

In 1973, the New York State Public Service Commission received two applications for Certificates of Environmental Compatibility and Public Need for construction of 765-kV power transmission lines. One application (Case 26529) was submitted by the New York Power Authority for a line from the Canadian border near Massena, NY to Utica, NY. The other application (Case 26559) was submitted by two private corporations, the Rochester Gas and Electric Corporation and the Niagara Mohawk Power Corporation, for construction of a line from Rochester, NY to Oswego, NY.

In the face of substantial public concern about possible health hazards, effects on weather, and audible noise involved in the proposed lines, the Administrative Law Judges in the two cases ordered joint hearings on the issues of common interest. The findings of these hearings were embodied in an Opinion (No. 78-13) issued by the New York Public Service Commission on June 19, 1978, which approved construction of the proposed power lines, but with provisos based on the unrefuted inferences of risks. These provisos included the establishment of a research program to determine possible human health risks arising from the electric and magnetic fields of overhead power transmission lines, and a rule establishing a 350-foot right-of-way corridor surrounding each 765-kV power line within which residences are not allowed. The latter rule was based on the idea that the electric field at the edge of the corridor of a 765-kV power line should be no greater than the value of 1.6 kV/m found at the edges of the corridors of existing 345-kV power lines. No standard for magnetic fields was established.

The agreement subsequently signed by the New York Power Authority and the New York State Public Service Commission (February 7, 1980) provided for establishment of a $5,000,000 research program, to be funded by contribution from the Power Authority and from New York State investor-owned utilities (listed in Table 1), to be directed by the Board of New York Powerline Project, administered by the New York State Department of Health under the guidance of an impartial scientific panel, and to be conducted by contract with independent investigators.

B. <u>BOARD OF THE NEW YORK STATE POWERLINES PROJECT</u>

By agreement of the New York State Power Authority and the Public Service Commission, the Board responsible for establishing the Powerlines Project was to consist of the Commissioner of the New York State Department of Health, the Chairman of the New York State Power Authority, and the Chairman of the New York State Public Service Commission. Dr. David O. Carpenter, then Director of the Wadsworth Center for Laboratories and Research of the New York State Department of Health, was given responsibility for the administration of the project for the Board.

C. <u>SCIENTIFIC ADVISORY PANEL</u>

The Scientific Advisory Panel members were selected for the Powerlines Project as a body of scientists and engineers with outstanding reputations in the fields of Anatomy, Physics, Biochemistry, Pharmacology, Genetics, Psychology, Neurology, Epidemiology, Electrical Engineering, and Bioengineering. While engineering members were selected to have a strong background in electromagnetic and nonionizing radiation, other members were selected for their prominence in their field whether or not they had previous interest in electromagnetic field effects. The duties of the Panel were to solicit, select and oversee the research contracts awarded under the

Powerlines Project. Panel members were screened for conflicts of interest, and all members were approved by the Board, representing the three state agencies. Members were chosen on the basis of their professional expertise in the above areas and their lack of financial or professional conflicts of interest.

The Scientific Advisory Panel originally selected included:

Ernest Albert, Ph.D.
Department of Anatomy
George Washington
University Medical Center
2300 I Street, NW
Washington, DC 20037

Antony Fraser-Smith, Ph.D.
Space, Telecommunications
& Radioscience Laboratory
Department of Electrical Engineering
Stanford University
Stanford, CA 94305

Alan J. Grodzinsky, Ph.D.
Department of Electrical Engineering
and Computer Science
Massachusetts Institute of Technology
Cambridge, MA 02139

Michael T. Marron, Ph.D.
Biomedical Research Institute
University of Wisconsin-Parkside
Kenosha, Wisconsin 53141
Present Address:
Office of Naval Research
Molecular Biology Program
800 North Quincy Street
Arlington, VA 22217

Alice O. Martin, Ph.D.
Department of Obstetrics & Gynecology
Northwestern University Medical School
333 East Superior Street
Chicago, IL 60611

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Neuroscience Laboratory
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Sudbury, Ontario
Canada P3E2C6

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Department of Pharmacology
New York University Medical Center
550 First Avenue
New York, NY 10016
Present Address:
Department of Pathology
Columbia-Presbyterian Med. Center
630 West 168th Street
New York, NY 10032

James H. Stebbings, Sc.D.
Division of Epidemiology
School of Public Health
University of Minnesota
Minneapolis, MN 55455
Present Address:
Division of Biological &
Medical Research
Argonne National Laboratory
Argonne, IL 60439

Edward R. Wolpow, M.D.
Department of Neurology
Harvard Medical School
Boston, MA 02115

In addition, Dr. Arthur C. Upton, Department of Environmental Medicine, New York University Medical Center was appointed to the Panel, but resigned in 1981. Since the establishment of the Scientific Advisory Panel, Dr. Stebbings has resigned and has been replaced by:

Anders Ahlbom, Ph.D.
Department of Epidemiology
National Institute of Environmental Medicine
Box 60208
S-104 01 Stockholm, Sweden

The first responsibility of the panel was to examine the state of knowledge on health effects of electric and magnetic fields having frequencies and field strengths typical of the vicinity of power lines, and to identify the research areas most relevant to possible health hazards of electromagnetic fields.

D. NEGOTIATION OF RESEARCH CONTRACTS

After reviewing the literature, the Panel issued a request for pre-proposals for research studies in seven areas:

1. Genetic, Cytogenetic, Teratogenic, and Reproductive Studies;
2. Cell and Organ Culture Studies;
3. *In Vivo* Animal Physiology and Pathophysiology;
4. Animal and Human Neurobiology;
5. Animal and Human Behavior;
6. Multidisciplinary Human Studies with Controlled Exposure Conditions;
7. Epidemiology of Human Populations.

A total of 164 pre-proposals were reviewed by the Advisory Panel on October 31, 1981. About one-third of the authors were invited to submit detailed proposals, which were reviewed by the Panel on February 19-21, 1982. By the end of 1982, twelve research contracts had been awarded, with four subsequently negotiated, giving a total of 16 research contracts. Table 2 presents the details of these contracts, with principal investigators and their affiliations, funding awarded, and extensions when granted. In addition, on January 1, 1986, a second contract was awarded to Dr. M.M. Cohen to replicate the experiments of one of the other contractors.

E. DOSIMETRY

One of the prime concerns of the Powerlines Project has been to have well documented exposure in the various studies. For this reason, considerable funds were allocated to develop state-of-the-art exposure facilities and much stress has been placed on accurate dosimetry of the electric and magnetic field distribution in the exposure apparatus employed by the different investigators.

The panel also decided that field exposures for animal and human studies should include both electric and magnetic fields. This decision was prompted by two considerations. The first was that although both electric and magnetic fields are present under power transmission lines, magnetic field effects had been ignored by most investigators up to the time of the initiation of this program. The second consideration was based on the notion that electric and magnetic fields, when applied simultaneously, may have quite different effects on living systems, than observed with only electric or only magnetic fields. At the time these considerations were made there was ample evidence that magnetic fields alone could produce effects, although they had not been systematically investigated.

Consultants were hired to advise the panel on construction and dosimetry in the exposure facilities. These consultants were Dr. Donald W.

Deno, General Electric, Pittsfield, MA, Dr. Stephen D. Umans, Massachusetts Institute of Technology, Cambridge, MA and Dr. Anthony R. Valentino, Argonne National Laboratory, Argonne, IL. The field distributions were monitored during site visits to the installations before, during and after the course of experiments by an engineering staff involving collaboration of the National Bureau of Standards and W/L Associates Ltd. of Gaithersburg, Maryland, to verify constancy of the field distributions. Table 3 lists the dates and site visit teams for each of the contractors.

F. REVIEW OF CONTRACTORS' PROGRESS

An ongoing responsibility of the Scientific Advisory Panel was to review the progress of the contractors. This was done in several ways. Three panel members were assigned primary responsibility for each project, one to be responsible for the engineering aspects (either Drs. Marron, Fraser-Smith or Grodzinsky) and two of the other panel members to be responsible for the biologic aspects of the study, one of whom was designated as lead biologist (Table 4). Assignments were made on the basis of the areas of expertise of individual panel members. Panel members were expected to follow the assigned projects closely, to participate in site visits as often as needed, and to request consultant assistance as needed. Assigned panel members have prepared critiques of each project upon completion and reviewed the draft final reports and recommended clarifications as needed. The main focus of this review was to ensure that the scientific results were presented in a clear, consistent format, that all pertinent data are properly incorporated in the report, that dosimetry of the electric and magnetic fields had been properly performed, and that the long-range implications of the study were clearly presented. The chapters of this final report were prepared by individual Panel members in their areas of expertise, and reviewed and revised by the entire Panel.

The Scientific Advisory Panel has met on at least an annual basis over the duration of this project to review progress in all studies and to re-direct efforts as needed. When the Panel meeting was held in the State of New York it was coupled with a public meeting, announced in advance, where questions about the program were answered by the Panel; when the Panel meeting was not held in New York State, Dr. Shelanski, the Chairman of the Panel, and Dr. Carpenter met with the public in Albany. At least one public meeting was held each year.

The public meetings were held on March 23, 1981, June 12, 1981, July 31, 1981 (in Massena, NY), February 19, 1982 (in New York, NY), April 27, 1982, March 28, 1983, March 26, 1984, May 3, 1985, May 30, 1986 and April 24, 1987. Meetings were held in Albany, NY unless otherwise stated. Starting in 1983, these meetings were announced by publication of a summary status report outlining the progress of the Powerlines Project, which was circulated to the entire mailing list of the project, including the media and interested public groups.

Table 1

Contributions of Support to the Powerlines Project

New York State Power Authority	$ 650,000.00
Consolidated Edison	1,350,000.00
New York State Gas & Electric	498,407.06
Rochester Gas & Electric	236,518.73
Central Gas & Electric	149,222.61
Long Island Lighting Company	599,136.73
Orange & Rockland Utilities	137,198.48
Niagara Mohawk	1,379,516.39
TOTAL POWERLINES SETTLEMENT	$ 5,000,000.00
Empire State Electric Energy Research Corporation contribution for replication study by Cohen	90,000.00
US Department of Energy support for dosimetry	198,600.00
Interest earnings and miscellaneous revenue	99,863.00
TOTAL FUNDS AVAILABLE	$5,388,463.00

Table 2

Research Contract Awards by the New York State Powerlines Project

1. Prasanta K. Basu, M.B.
Department of Ophthalmology
University of Toronto
Toronto, Ontario, Canada

"Biological Effects of Extremely Low Frequency Electric and Magnetic Fields on Ocular Tissues: an *In Vitro* Study"

Term: 4/1/83 - 6/30/85

Extension: 12/1/85

Funding Awarded: $176,956

2. Arland L. Carsten, Ph.D.
Medical Department
Brookhaven National Laboratories
Upton, New York

"Mutagenicity and Toxicity of Electric and Magnetic Fields"

Term: 10/1/82 - 9/30/85

Extension: 12/31/85

Funding Awarded: $604,968

3. Maimon M. Cohen, Ph.D.
Department of Obstetrics and Gynecology
University of Maryland School of Medicine
Baltimore, Maryland

a. "*In Vitro* Genetic Effects of Electromagnetic Fields"

b. "The Effects of Low-Level Electromagnetic Fields on Cloning of Two Human Cancer Cell Lines (Colo 205 and Colo 320)". Separate contract awarded for replication of the results of the study of Dr. W.D. Winters.

Term: a. 11/2/82 - 6/30/85
b. 1/2/86 - 1/1/87

Extension: b. 2/28/87

Funding Awarded: a. $213,177
b. $82,200

Table 2 (continued)

4. Amos G. Gona, Ph.D.
   Department of Anatomy
   University of Medicine and Dentistry of New Jersey
   Newark, New Jersey

   "Effects of 60-Hz Electric and Magnetic Fields on the Developing Rat Brain"

   Term: 9/1/82 - 8/31/85

   Extension: 4/30/86

   Funding Awarded: $169,388

5. Charles Graham, Ph.D.
   Life Sciences Department
   Midwest Research Institute
   Kansas City, Missouri

   "Influence of 60-Hz Fields on Human Behavior, Physiology, and Biochemistry"

   Term: 9/1/82 - 6/30/84

   Funding Awarded: $465,068

6. Ross W. Gundersen, Ph.D.
   Life Sciences
   University of Wisconsin-Parkside
   Kenosha, Wisconsin

   "Effects of 60-Hz Electromagnetic Fields on Calcium Efflux and Neurotransmitter Release"

   Term: 7/1/82 - 6/30/85

   Funding Awarded: $159,757

7. Gordon K. Livingston, Ph.D.
   Department of Pediatrics
   University of Utah Medical Center
   Salt Lake City, Utah
   Present Address: Department of Environmental Health
   University of Cincinnati Medical Center
   Cincinnati, Ohio

   "Reproductive Integrity of Mammalian Cells Exposed to 60-Hz Electromagnetic Fields"

Table 2 (continued)

Term: 7/1/82 - 9/30/84

Funding Awarded: $192,044

8. Klaus-Peter Ossenkopp, Ph.D.
Department of Psychology
University of Western Ontario
London, Ontario, Canada

"ELF Low Intensity Magnetic Fields and Epilepsy"

Term: 7/1/82 - 12/31/85

Extension: 3/31/86

Funding Awarded: $58,343

9. Gideon A. Rodan, M.D., Ph.D.
Department of Oral Biology
University of Connecticut School of Medicine
Farmington, Connecticut
Present Address: Merck, Sharp & Dohme
West Point, Pennsylvania

"Effect of 60-Hz Electric and Magnetic Field on Neural and Skeletal Cells in Culture"

Term: 1/1/83 - 3/31/85

Funding Awarded: $135,032

10. Kurt Salzinger, Ph.D.
Department of Psychology
Polytechnic Institute of New York
Brooklyn, New York

"Behavioral Effects of ELF"

Term: 7/1/82 - 6/30/85

Extension: 3/31/86

Funding Awarded: $292,271

Table 2 (continued)

11. David A. Savitz, Ph.D.
    University of Colorado Health Sciences Center
    Denver, Colorado
    Present Address: Department of Epidemiology
    University of North Carolina
    Chapel Hill, North Carolina

    "Childhood Cancer and Electromagnetic Field Exposure"

    Term: 12/1/83 - 11/30/85

    Extension: 9/30/86

    Funding Awarded: $355,905

12. Richard G. Stevens, Ph.D.
    Battelle Memorial Institute
    Pacific Northwest Laboratories
    Richland, Washington

    "Epidemiological Studies of Cancer and Residential Exposure to Electromagnetic Fields"

    Term: 12/1/83 - 6/30/86

    Extension: 9/30/86

    Funding Awarded: $401,612

13. Frank M. Sulzman, Ph.D.
    Department of Biological Sciences
    State University of New York at Binghamton
    Binghamton, New York
    Present Address: Space Medicine Branch
    National Aeronautics and Space Administration
    Washington, D.C.

    "Effects of Electromagnetic Fields on Primate Circadian Rhythms"

    Term: 7/1/82 - 6/30/85

    Extension: 1/31/86

    Funding Awarded: $192,436

14. John R. Thomas, Ph.D.
    Naval Medical Research Institute
    Bethesda, Maryland

Table 2 (continued)

"Investigation of Potential Behavioral Effects of Exposure to 60-Hz Electromagnetic Fields"

Term: 11/15/82 - 11/14/84

Extension: 11/14/85

Funding Awarded: $101,190

15. Wendell D. Winters, Ph.D.
Department of Microbiology
University of Texas Health Sciences Center
San Antonio, Texas

"Biological Functions of Immunologically Reactive Human and Canine Cells Influenced by _In Vitro_ Exposures to Electric and Magnetic Fields"

Term: 7/1/82 - 6/30/84

Extension: 11/30/84

Funding Awarded: $142,668

16. Jonathan R. Wolpaw, M.D.
Wadsworth Center for Laboratories and Research
New York State Department of Health
Albany, New York

"Chronic Effects of 60-Hz Electric and Magnetic Fields on Primate Central Nervous System Function"

Term: 7/1/82 - 6/30/85

Extension: 8/30/86

Funding Awarded: $283,901

Table 3

History of Site Visits of Powerlines Project Contractors

BASU		
	May 1, 1986	Fulcomer[1], Misakian[1] and Wisecup[2]
	May 8, 1985	Albert and Wisecup
	March 18, 1985	Wisecup, Rosen[2] and Dietrich[3]
	October 11, 1984	Fulcomer and Misakian
	September 13, 1984	Albert, Wisecup, Rosen and Dietrich
	January 25, 1984	Grodzinsky, Umans[4] and Dietrich
	January 18, and February 7, 1984	Albert, Wisecup, and Rosen
CARSTEN		
	January 29, 1986	Fulcomer, Wisecup and Misakian
	August 9, 1985	Wisecup, Rosen, and Dietrich
	March 31, 1985	Martin, Albert and Fraser-Smith
	March 21, 1985	Wisecup, Rosen and Dietrich
	December 10, 1984	Martin and Fraser-Smith
	October 26, 1984	Wisecup, Rosen and Dietrich
	September 17, 1984	Martin, Albert and Fraser-Smith
	July 27, 1984	Wisecup, Rosen and Dietrich
	April 12, 1984	Wisecup, Rosen, Dietrich, Misakian and Fulcomer
	March 5-6, 1984	Martin, Albert, Fraser-Smith, Wisecup, Rosen and Dietrich
	March 28-29, 1983	Martin, Albert, Fraser-Smith, Deno[5], Dietrich, Brudner[6], Misakian, Rosen and Wisecup
COHEN		
	May 6, 1986	Rosen, Misakian and Fulcomer
	July 17,1985	Wisecup, Rosen, Misakian, Fulcomer and Dietrich
	June 7, 1985	Marron and Martin
	June 12, 1984	Misakian and Fulcomer
	August 27, 1984	Misakian and McKnight[1]
	July 25, 1984	Wisecup, Rosen and Dietrich
	March 6, 1984	Marron and Martin
	November 15, 1983	Wisecup, Rosen and Dietrich
	October 12, 1983	Wisecup, Rosen and Dietrich
	July 22, 1983	Valentino[6]
	April 18, 1983	Grodzinsky, Martin, Shelanski, Umans, Brudner, Wisecup, Rosen and Dietrich
COHEN II		
	December 18, 1986	Rosen, Fulcomer, Wisecup and Misakian
	September 11, 1986	Martin and Marron and Trent[7]
	May 6, 1986	Misakian, Fulcomer and Rosen

Table 3 (continued)

	Date	Team
GONA		
	April 11, 1986	Wisecup, Fulcomer and Misakian
	March 21, 1985	Wisecup, Rosen, and Dietrich
	December 11, 1984	Fraser-Smith, Albert, Wisecup, Rosen and Dietrich
	May 9, 1984	Misakian, Albert, Wisecup, Rosen and Dietrich
	January 9, 1984	Albert, Marron, Wisecup, Brudner, Rosen and Dietrich
	September 26, 1983	Albert, Marron, Deno, Wisecup, Brudner, Rosen and Dietrich
GRAHAM		
	February 20, 1986	Wisecup, Rosen and Dietrich
	May 26, 1985	Dietrich
	January 25, 1985	Wisecup, Rosen, Dietrich and Landau[2]
	May 2, 1984	Wisecup, Rosen, Dietrich and Klein°
	January 10, 1984	Marron and Shelanski
	November 10, 1983	Marron, Shelanski, Wisecup, Rosen, Klein, Hebner[1], Misakian and Dietrich
	March 17-18, 1983	Misakian and Fulcomer
	January 23-24, 1983	Martin, Albert, Carpenter, Marron, Persinger, Shelanski, Wolpow, Valentino, Wisecup, Brudner, Rosen and Dietrich
	September 30, 1982	Dietrich, Marron, Valentino and Wisecup
GUNDERSEN		
	May 18, 1983	Fulcomer, Misakian, Wisecup, Rosen and Dietrich
	January 26, 1983	Albert, Shelanski, Marron, Valentino, Wisecup, Rosen and Dietrich
	October 8, 1982	Marron and Valentino
LIVINGSTON		
	October 11, 1985	Marron, Martin and Trent
	August 28, 1985	Misakian, Fulcomer, Wisecup, Rosen and Dietrich
	April 16-17, 1985	Trent
	April 24, 1984	Martin, Valentino and Klein
	February 13, 1984	Martin, Valentino, Klein, Wisecup, Rosen and Dietrich
	July 27, 1983	Wisecup, Misakian, Dietrich and Rosen
	June 22-23, 1983	Martin and Valentino
	April 1, 1983	Valentino
	January 25, 1983	Albert, Marron, Martin, Shelanski, Valentino, Brudner, Wisecup, Rosen and Dietrich

Table 3 (continued)

	Date	Team
OSSENKOPP		
	April 25, 1984	Persinger, Albert, Carpenter, McDermott,[9] Wisecup, Rosen and Dietrich
	July 14, 1983	Persinger, Fraser-Smith, Deno, Wisecup and Dietrich
RODAN		
	July 26, 1984	Wisecup, Misakian, Rosen and Dietrich
	April 17, 1984	Martin, Grodzinsky and Umans
	September 16, 1983	Martin, Grodzinsky, Umans, Brudner, Wisecup, Rosen and Dietrich
	September 6, 1983	Grodzinsy, Dietrich, Umans, Rosen, Wisecup and Brudner
SALZINGER		
	July 22, 1985	Misakian, Fulcomer, Wisecup, Rosen and Dietrich
	March 20, 1985	Wisecup, Rosen and Dietrich
	June 27, 1984	Misakian and McKnight
	April 11, 1984	Fraser-Smith, Wisecup, Rosen and Dietrich
	March 6, 1984	Fraser-Smith, Wisecup, Rosen and Dietrich
	July 13, 1983	Persinger, Fraser-Smith, Deno, Wisecup, Dietrich and Shelanski
SAVITZ		
	August 18, 1986	Ahlbom
	July 22, 1986	Wisecup, Rosen, Landau and Dietrich
	March 20, 1986	Stebbings
	May 17, 1985	Stebbings, Marron, Wisecup, Rosen, Landau and Dietrich
	May 17-18, 1985	Stebbings and Marron
	January 24, 1985	Stebbings, Wisecup, Rosen, Landau and Dietrich
	July 23, 1984	Stebbings
	May 22, 1984	Marron, Wisecup, Rosen and Dietrich
	February 6-7, 1984	Stebbings, Marron and Brudner
STEVENS		
	August 20, 1986	Martin and Ahlbom
	June 11, 1986	Wisecup, Rosen and Dietrich
	February 25, 1986	Wisecup, Rosen and Dietrich
	June 14, 1985	Stebbings, Marron, Wisecup, Rosen, Landau and Dietrich
	July 30 and August 17, 1984	Wisecup, Dietrich, Rosen, White[9], Williams[8], Marron and Stebbings
	May 24, 1985	Marron, Wisecup, Rosen, Landau and Dietrich
	May 23, 1985	Wisecup, Rosen and Dietrich
	June 14, 1985	Stebbings, Marron, Wisecup, Rosen, Dietrich and Landau
	October 5, 1984	Marron, Stebbings, Wisecup, Dietrich, and Wilson[2]

Table 3 (continued)

	Date	Team
SULZMAN		
	April 9, 1986	Wisecup, Rosen, Misakian, Fulcomer and Dietrich
	March 19, 1985	Wisecup, Rosen and Dietrich
	October 23, 1984	Wisecup, Rosen and Dietrich
	March 20-21, 1984	Fulcomer and Misakian
	March 8, 1984	Marron, Valentino, Wisecup, Rosen and Dietrich
	March 29, 1983	Persinger, Marron and Valentino
	August 7, 1982	Marron and Valentino
THOMAS		
	July 16, 1986	Wisecup, Rosen and Dietrich
	October 15, 1984	Marron
	August 17, 1984	Stebbings, Marron, Wisecup, Rosen, Dietrich, Wilson and White
	April 19, 1984	Carpenter, Albert and Marron
	January 17, 1984	Misakian, Fulcomer, Wisecup, Dietrich and Rosen
	July 12, 1983	Albert, Persinger, Fraser-Smith, Zelingher[9], Deno, Wisecup and Dietrich
WINTERS		
	August 29, 1984	Buick[10], Trent[7], Shelanski and McDermott
	February 1, 1984	Martin, Marron, Shelanski, Wisecup, Klein and Dietrich
	December 15, 1983	Wisecup, Rosen, Dietrich, Misakian and McKnight
	May 4-5, 1983	Wisecup, Rosen, Dietrich, Misakian and Fulcomer
	March 7, 1983	Grodzinsky and Umans
WOLPAW		
	April 8, 1986	Wisecup, Rosen, Misakian, Fulcomer and Dietrich
	March 14, 1985	Wisecup, Rosen and Dietrich
	October 22, 1984	Wisecup, Rosen and Dietrich
	March 19-20, 1984	Fulcomer and Misakian
	March 7, 1984	Marron, Valentino, Wisecup, Rosen and Dietrich
	March 28, 1983	Persinger, Marron and Valentino
	December 14, 1982	Wisecup, Rosen and Dietrich
	August 6, 1982	Valentino and Marron

Affiliations of members of site visit teams other than Scientific Advisory Panel members are: [1]National Bureau of Standards, [2]W/L Associates, [3]Electric Research and Management, [4]Massachusetts Institute of Technology, [5]General Electric Company, [6]Argonne National Laboratory, [7]The University of Arizona College of Medicine, [8]Department of Energy, [9]New York Power Authority, and [10]The Ontario Cancer Institute.

Table 4

Assigned Responsibilities of Members of the Scientific Advisory Panel for Review of Contractors' Projects

Contractor	Assigned Panelists
Basu	Albert, Grodzinsky and Wolpow
Carsten	Martin, Fraser-Smith and Albert
Cohen	Martin, Marron and Shelanski
Gona	Albert and Fraser-Smith
Graham	Shelanski, Marron and Persinger
Gundersen	Shelanski, Grodzinsky and Albert
Livingston	Martin, Marron and Shelanski
Ossenkopp	Persinger, Fraser-Smith and Stebbings
Rodan	Shelanski, Grodzinsky and Martin
Salzinger	Persinger, Fraser-Smith and Shelanski
Savitz	Stebbings, Ahlbom and Marron
Stevens	Stebbings, Ahlbom and Marron
Sulzman	Persinger, Marron and Wolpow
Thomas	Persinger, Fraser-Smith and Albert
Winters	Shelanski, Grodzinsky and Martin
Wolpaw	Wolpow, Marron and Persinger

IV. ELECTROMAGNETIC FIELDS AND EXPOSURE OF HUMAN POPULATIONS

A. INTRODUCTION

Although there has been an increasing trend in recent years toward the long-distance transmission of electric power by high-voltage DC (HVDC) lines (Ellert and Hingorani, 1976), most of the electric power transmitted over long distances in the United States is still carried on AC lines. The AC electric power is normally generated and transmitted within a balanced three-phase voltage system, with the implication that the lines transmitting the power will have a basic configuration (called a single circuit) consisting of three conductors, in which the voltages have the same amplitude and frequency of variation (60-Hz in the United States and Canada and 50-Hz in Europe) but are out of step, i.e., differ in phase, by 120°. The conductors used in the lower-voltage circuits usually consist of a single wire, but for the higher-voltage circuits it is normal for a group of connected wires (known as a bundle) to be used for each conductor, in order to decrease the incidence of the electrical discharge known as corona. Thus a typical single-circuit 765-kv power line has three bundles, each of which is made up of four wires.

The transmission voltage used on these lines depends on the distance over which the power is transmitted and on the amount of power to be transmitted. Over long distances there is a very definite advantage in terms of reduced power loss in the lines to having as high a voltage as possible. Thus, as electric power has become more and more widely used, and as the required technology has been developed, there has been a steady increase in line voltage. In the early days of AC electric power transmission, the voltages used on the wires were typically 30-40 kilovolts (kV), but by 1920 the majority of the lines were being operated at 132-kV and nowadays the voltages for long-distance transmission are typically either 500-kV or, most recently, 765-kV (Scherer and Vassell, 1985). Even higher transmission voltages are under study and the historical trend toward higher voltages suggests that they will surely receive widespread use in the future.

B. UNITS OF MEASUREMENT

Despite efforts at standardization, a variety of units continue to be used in electric and magnetic field measurements. We will use the Systeme International (SI) system, which is the basic system of units in use throughout the world. In this system the unit for electric field **E** is the volt per meter (V/m) and the unit for the magnetic flux density **B** is the tesla (T). In free space, or in air to a good approximation, the magnetic flux density is related to the magnetic field intensity **H** (units ampere per meter, or A/m) through the relation

$$\mathbf{B} = \mu_0 \mathbf{H}, \tag{1}$$

where the constant $\mu_0 = 4\pi \times 10^{-7}$ henry per meter.

As we have indicated by the use of a bold script, the electric and magnetic fields are vector quantities. Thus, at each point in space, the field quantities **E** and **B** have both a magnitude and direction, and in general both the magnitude and direction vary with time and with position. We will denote the magnitude of the vectors by using normal script, i.e., E denotes the magnitude of the electric field, and B the magnitude of the magnetic flux density.

Within the SI system of units, there are several different size representations of the basic volt per meter and tesla units of measurement that are relevant to this report. We have already quoted voltages in kilovolts, where 1 kilovolt is 1000 volts, and the electric fields produced by power lines are frequently measured in kilovolts per meter (kV/m). The tesla unit for magnetic flux density is a large unit, and smaller denominations are frequently more convenient to use. The most common of these denominations are the millitesla (mT), microtesla (μT), and nanotesla (nT), representing one thousandth (10^{-3}), one millionth (10^{-6}), and one billionth (10^{-9}) of a tesla, respectively. Two other common units in use are the gauss (G), where 1 G = 100 μT (or 1 G = 10^{-4} T), and the gamma (γ), where 1 γ = 1 nT.

C. AMBIENT ELECTRIC AND MAGNETIC FIELDS

The earth has a quasi-static electric field at the surface that is typically directed downwards and has a magnitude of the order of 100 V/m during good weather which may change to an upwards directed field of the order of 5 kV/m during a local thunder storm (Volland, 1984). The earth's magnetic field is much less dependent on local conditions, but it tends to vary over the earth's surface. Its magnitude changes from maximum values in the range 60-70 μT (0.6-0.7 G) at high latitudes (there are two points of maximum in the northern hemisphere, and one in the southern hemisphere) to a minimum of about 23 μT (0.23 G) off the coast of Brazil. The magnitude is typically small, in the range of 25-40 μT (0.25-0.40 G), at low latitudes. Power line electric and magnetic field magnitudes may be compared with these typical quasi-static values for the earth, but it is important to remember that the latter values are effectively DC and their comparison with magnitudes of power line and other more rapidly oscillating fields may have little biologic significance.

Measurements have been made of the natural electric and magnetic field fluctuations in the lower part of the extremely-low frequency range (ELF;

frequencies in the range 3-Hz to 3-kHz), which includes the 60-Hz power line frequency, and there is a major study of global electromagnetic noise in the frequency range 10-Hz to 32-Hz currently in progress (Fraser-Smith and Helliwell, 1985). The data presented in the latter reference suggest that a typical amplitude range in the United States for naturally occurring magnetic field fluctuations at 60-Hz is 0.04-0.4 pT (measured in a 1-Hz bandwidth centered at 60-Hz), where the picotesla (pT) is 0.001 nT. These amplitudes are very small compared with the amplitudes of the 60-Hz magnetic fields normally encountered in the vicinity of power lines (cf Section G, below).

Data on the natural 60-Hz electric field amplitudes in the United States are provided by Maxwell and Stone (1963) and Maxwell (1966). Typical values lie in the range 0.1-0.6 mV/m. Once again, in the following section we will see that these amplitudes are very small compared with those normally encountered in the vicinity of power lines.

D. ELECTRIC AND MAGNETIC FIELDS IN THE HOME AND WORKPLACE

Fields in both the home and workplace have been characterized. Measurements by Gauger (1985), Miller (1974), and Norris et al. (1986) are summarized in Figs. 1 and 2. Also shown in the Figures are related values for the ambient fields discussed in the previous section, and field levels near the vicinity of power transmission and distribution lines. Magnetic fields in the home and workplace can be in the same range as those found near power lines although the distribution of fields within the home varies a great deal. On the other hand, electric fields beneath transmission lines are at least an order of magnitude greater than those experienced by the general population in all but a few specialized circumstances. Electric field strengths beneath distribution lines are similar to those found in the

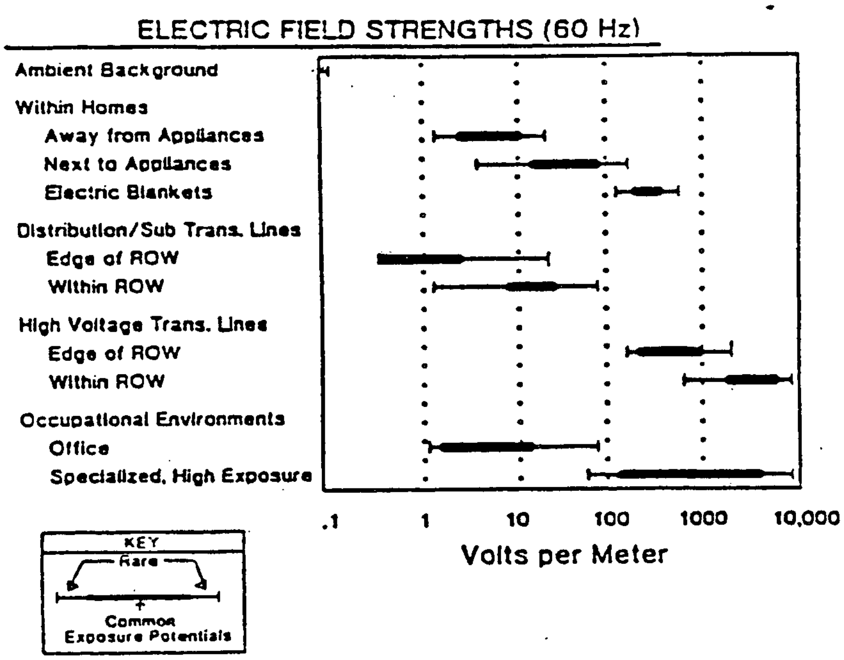

Figure 1. Electric fields measured in various locations. (Adapted with permission from WEST Associates, 1986)

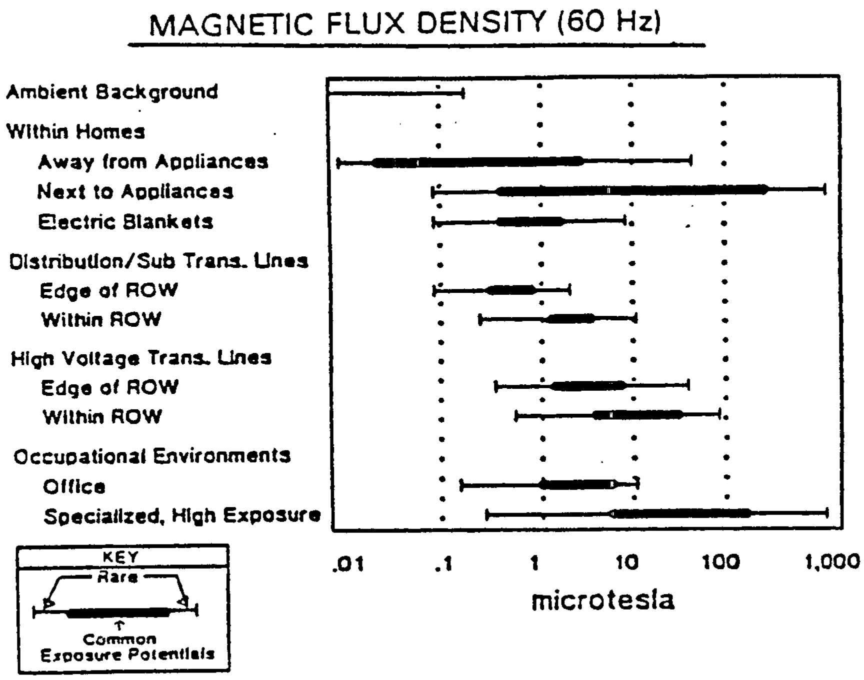

Figure 2. Magnetic flux densities measured in various locations (Adapted with permission from WEST Associates, 1986).

home near appliances. These figures are adapted from the WEST Associates Report (1986).

Measurements of fields in homes were made and reported in the two epidemiological studies supported by the New York State Power Lines Project (Appendices 15 and 16). Generally speaking, measurements made in these very detailed studies of electric and magnetic fields in the home agree with those reported in the studies cited above, at least within the fairly wide range of variability characteristic of such measurements.

The measurements performed by Kaune and associates as part of the Stevens' project (Appendix 16) were extensive and involved sampling both electric and magnetic fields in 43 different homes every two minutes during a 24-hr period. Each residence was completely characterized in terms of the electrical power distribution wiring that serviced the home and the neighborhood. One conclusion of this study is that residential magnetic fields are correlated with the external distribution wiring servicing the home as characterized by the wiring code developed by Wertheimer and Leeper (1979; 1982). Kaune and associates also present an improved prediction model for magnetic fields in the home that uses the total number of service drops, the distance to neighboring transmission lines, and the number of phase conductors in neighboring primary lines.

One additional conclusion of the study by Kaune and associates is that obvious sources of magnetic fields — lights, appliances, etc. — are not major contributors to residential fields in regions far from the appliances. The findings of both this study and the study by Savitz et al. (Appendix 15) support the original hypothesis of Wertheimer and Leeper (1979) that stray ground currents are a very important source of residential magnetic fields.

Standards for either population or occupational exposure to 60-Hz electric fields have been adopted in several countries and six states within the US, including New York State. These are summarized in the World Health Organization Environmental Health Criteria Document (1984) are reproduced in Table 5. Note that only in Oregon is the standard codified as a law. The New York State standard was adopted as a temporary standard by the Public Service Commission pending the outcome of this Project, and reflects the situation beneath the existing 345-kV transmission lines. The only existing standard for exposure to power line frequency magnetic fields known to us is the Soviet standard summarized in the Table 6. The scientific basis for the Soviet standard is not known to us.

E. ELECTRIC AND MAGNETIC FIELDS NEAR TRANSMISSION LINES

The electric and magnetic fields produced in the vicinity of extra-high-voltage (EHV) power transmission lines have been carefully measured and well documented. One of the most general references is the "Transmission Line Reference Book," which is published by the Electric Power Research Institute (EPRI) and contains measurements made largely by the General Electric Company (EPRI, 1982). Useful results for 500-kV lines have been published by Bracken (1976) (525-kV line; electric field results only) and by Lambdin (1978) (510-kV line; electric and magnetic fields). However, the results of most interest to us are those pertaining to 765-kV lines and here, in addition to the EPRI (1982) handbook just cited, Allan and Salman (1974), Deno (1976), Driscoll (1975), Lee et al., (1979), Tell et al., (1977), and Zaffanella and Deno (1978) provide much pertinent information. In general, there is greater emphasis on the electric fields produced by the lines, but adequate data are available for the magnetic fields (Deno, 1976; Driscoll, 1975; EPRI, 1982; Zaffanella and Deno, 1978). Details of the recommended field measurement techniques have been published by a committee of the Institute of Electrical and Electronics Engineers (IEEE, 1978).

TABLE 5

MAXIMUM ELECTRIC FIELD LEVELS (kV/M) FOR HIGH VOLTAGE TRANSMISSION LINES

State	In RoW*	Edge RoW	Comments
Minnesota	8	-	
Montana	7	1	In RoW at road crossings
New Jersey	-	3	
New York	7	1.6	In RoW at road crossings
North Dakota	9	-	
Oregon	9	-	State Law

* RoW = Right of Way

TABLE 6

SOVIET STANDARD FOR EXPOSURE TO 50-HZ MAGNETIC FIELDS

Time (hr)	Field (A/m)	Flux Density (mT)	Flux Density (G)
1	6000	7.5	75
2	4900	6.1	61
3	4000	5.0	50
4	3200	4.0	40
5	2500	3.1	31
6	2000	2.5	25
7	1600	2.0	20
8	1400	1.8	18

There are important general differences between the electric and magnetic fields produced by power transmission lines which should be emphasized. The first of these differences concerns the sensitivity to the current flowing in the lines. Once a power transmission line is raised to its operating voltage, the amplitudes of the electric fields produced by the line are essentially independent of the currents flowing in the conductors comprising the line. On the other hand, the magnetic fields produced by the line depend primarily on the currents flowing in the conductors, and not on the line voltage. Thus a specification of line voltage alone is inadequate to define the magnetic field levels that a particular line is likely to produce.

Another important difference concerns the directions of the fields. The electric fields on the ground beneath an overhead power transmission line are necessarily very nearly vertical at all times, whereas the magnetic fields on the ground are largely confined to planes perpendicular to the lines (although there can be a small component parallel to the lines), where, due to the phase differences of the currents flowing in the individual line conductors, the horizontal and vertical components combine to give a total magnetic field vector that rotates at the power line frequency.

F. ELECTRIC FIELD MEASUREMENTS

In an investigation involving both measurements and computations of the electric field beneath 765-kV overhead power transmission lines, Tell et al. (1977) obtained the following results for a particular line, which can be considered typical: The maximum measured electric field strength beneath the 765-kV line was approximately 10 kV/m at 3 feet above the ground, with the two symmetrical points of maximum field being located just outside the outer phase conductors. At the same locations, at a height of 6 feet above the ground, the field increased to 12.5 kV/m. The field strength decreased to 1 kV/m at approximately 170 feet from the center of the right of way (RoW; the center of the RoW also represents the central point of a cross-section of the line) and to 100 V/m at approximately 360 feet from the RoW center. Figure 3 shows a view of the line with an electric-field measurement in progress.

Note that the above measurements were made beneath the lowest point of the 765-kV line, which was 47 feet above the ground, when measured to the center conductor, and 48-49 feet above the ground when measured to the two outer conductors. The maximum electric field observed on the ground, or more specifically at the standard distance of 3 ft above the ground, increases as the height of the lines decreases, as would be expected (Driscoll, 1975; Deno, 1976). However, the minimum height that can occur, with present 765-kV line design, appears to be about 40 ft (Tell et al., 1977), and for this height the maximum electric field is about 12 kV/m.

The electric fields beneath power lines can be calculated by using well-established techniques and the computed values agree well with measured values. To illustrate, a comparison of calculated and measured electric field strengths is made in Figure 4, taken from Tell et al. (1977). It will be seen that there is good agreement between the values shown in the figure and even better agreement would probably have been possible if allowance had been made for deviations of the actual line heights from the assumed nominal value of 46 feet.

Some computed total electric field profiles for a typical 765-kV line with various line clearances in the range 30-70 ft are shown in Figure 5. It can be seen that decreasing the clearances of the line increases the electric field substantially in the vicinity of the line.

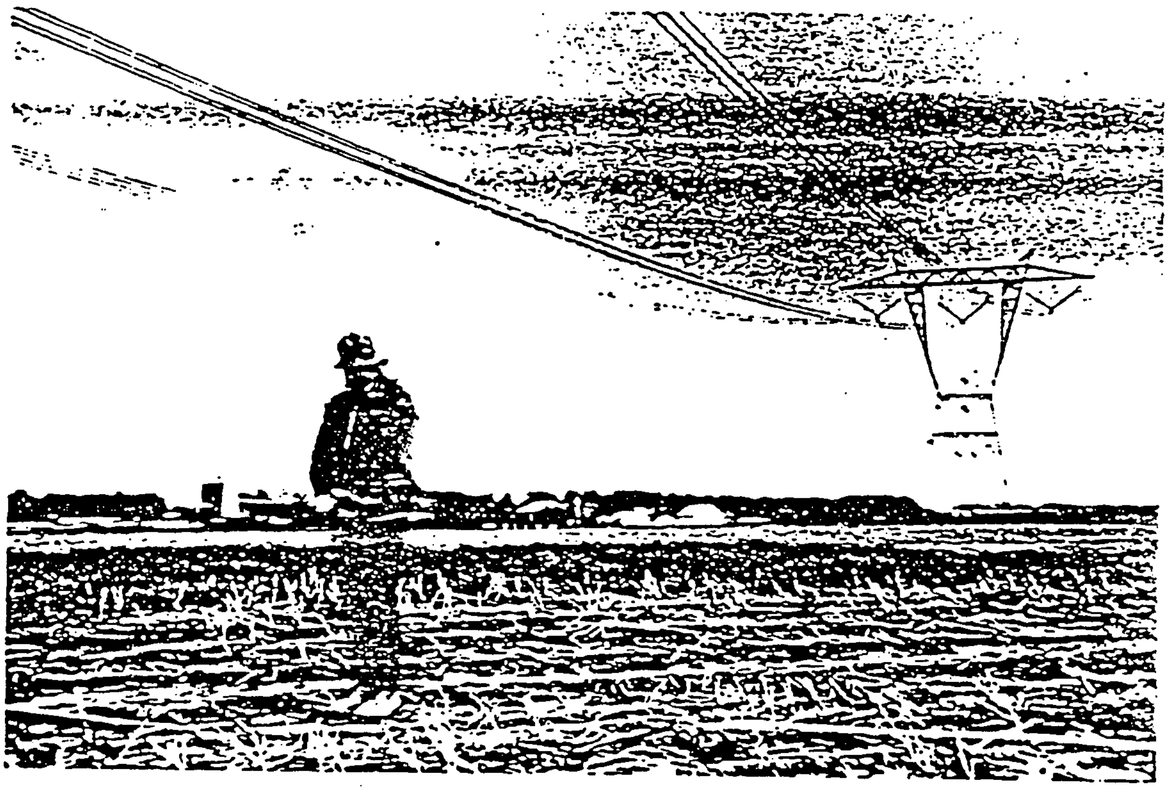

Figure 3. Photograph of an electric field measurement under a 765-kV overhead power transmission line (Tell et al., 1977).

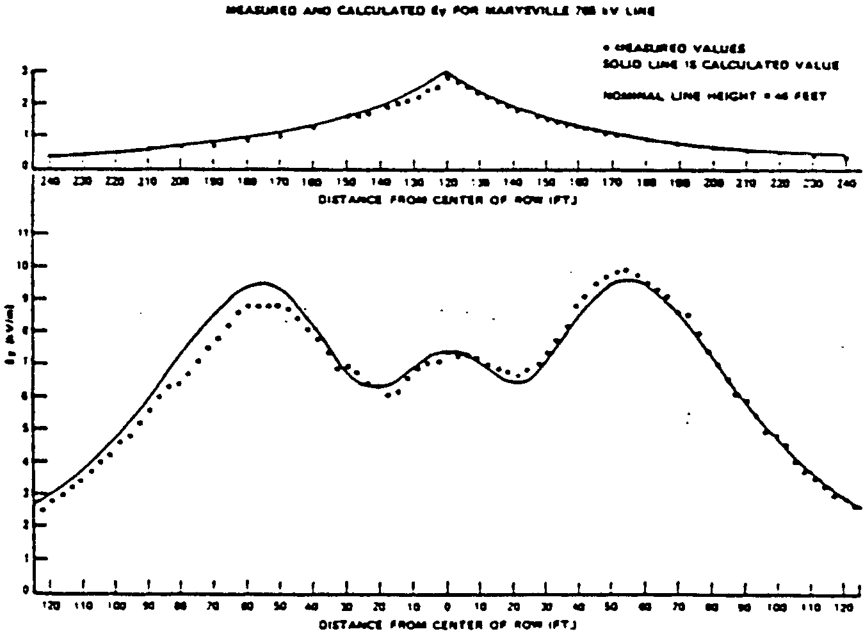

Figure 4. Measured and calculated values of the vertical component of the 60-Hz electric field beneath a 765-kV power transmission (Tell et al., 1977). The top panel shows the field variation in the distance range 120-240 feet to either side of the center of the right-of-way.

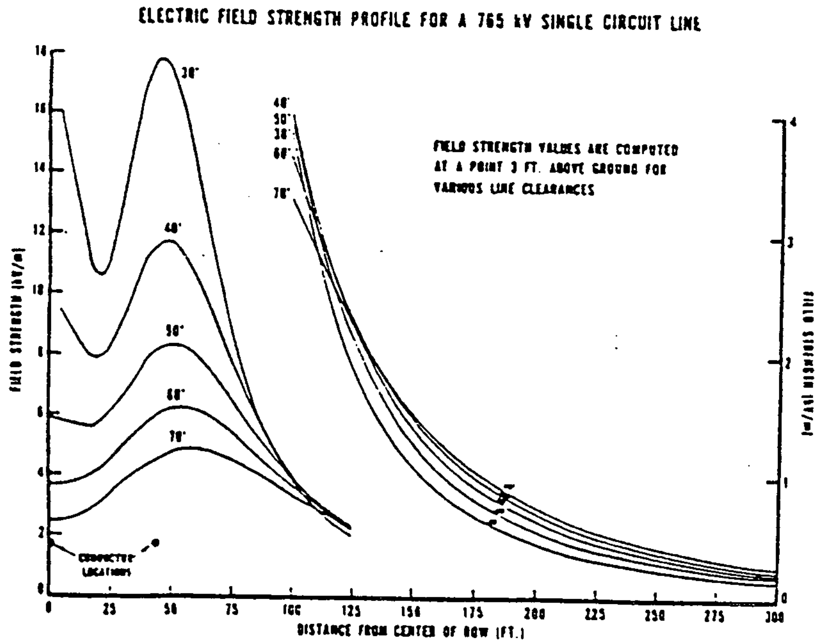

Figure 5. Variation of the total electric field as a function of height above the ground for a 765-kV overhead power transmission line. The left-hand vertical scale applied to the curves on the left, which cover distances out to 125 ft from the center of the line, and the right-hand scale applies to the curves on the right, which cover distances greater than 125 ft (Tell et al., 1977). The profiles are symmetrical about the center of the line, i.e., about the central conductor of the three-conductor line.

Figure 6 shows the variation of the computed maximum total electric field (which occurs just outside the outer conductors of the line) as a function of height above the ground for the simple single-circuit 765-kV line considered by Tell et al. (1977). The electric field obviously increases rapidly once the point of observation approaches the line itself. Close to the ground, however, the field varies very little with increasing height.

Finally, Figure 7 compares the magnitudes of the calculated vertical and horizontal electric field components produced 6 ft above the ground in the vicinity of a 765-kV line (Tell et al., 1977). The horizontal component, E_x, is so small in comparison with the vertical component, E_y, that the magnitude of the total field is indistinguishable from that of E_y. Deno (1976) shows the electric field vector loci at many different positions around a 765-kV line, and provides other additional data confirming the predominantly vertical nature of the electric field near the ground.

From these experimental and computed results, we can conclude the following: (1) the electric fields produced beneath 765-kV power lines are well understood and can be calculated accurately, (2) the magnitudes of the fields vary substantially depending on the height of the line above the ground, and with the position of the field point beneath the line, and (3) the fields are predominantly vertical and vary little with height near the ground. Further, it appears that the maximum electric field amplitude that is likely to be observed beneath a standard 765-kV line in normal operation is of the order of 10 kV/m. Comparing this latter value with the magnitude of the naturally-occurring electric noise that would probably be observed at the same location in the absence of the overhead line, we can also conclude that the power-line electric fields are substantially greater than the

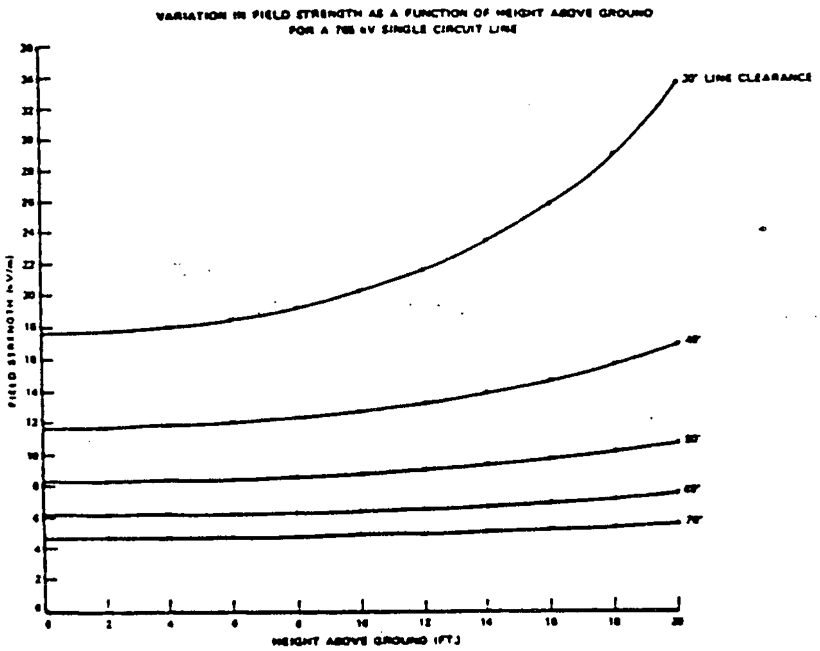

Figure 6. Computed variation of the total electric field as a function of height above the ground for a 765-kV single-circuit overhead power transmission line (Tell et al., 1977).

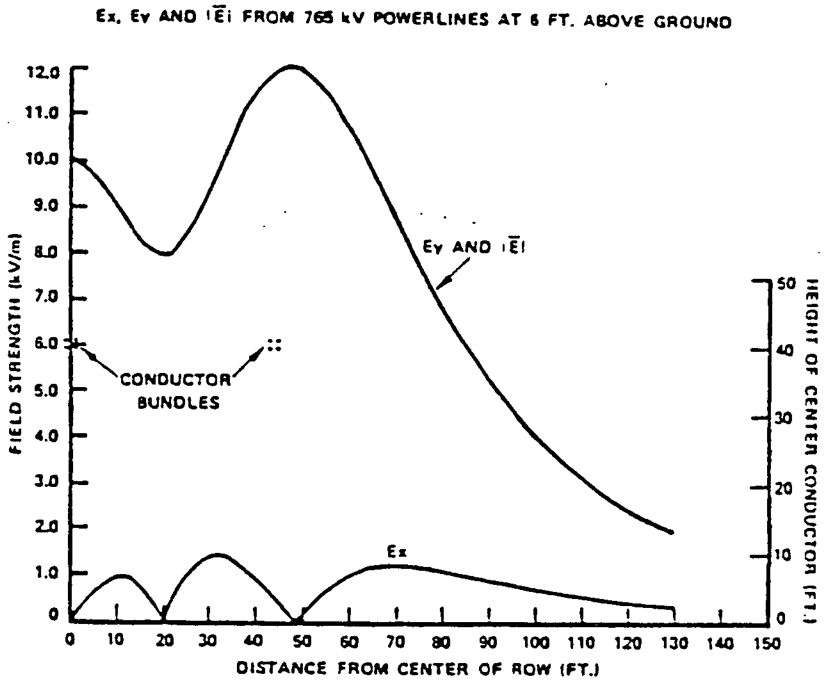

Figure 7. Variation of the magnitudes of the horizontal, vertical and total electric field at 6 ft above the ground beneath a 765-kV power line (Tell et al., 1977). The right-hand vertical scale gives the height of the conductor bundles. The left-hand scale applies to the curves.

natural fields: a 10 kV/m field is 7-8 orders of magnitude larger than the typical natural 60-Hz field of 0.1-0.6 mV/m described in Section 3.

G. MAGNETIC FIELD MEASUREMENTS

The magnetic fields produced by EHV power lines are more complex in terms of their spatial and temporal variations than the electric fields, and they have been less studied. However, there are adequate measurements and computational results available for us to describe their properties in general terms.

Figure 8 shows 4 different total magnetic flux density profiles for a 765-kV line carrying 4000 A. Once again, as might be expected, the largest fields near the ground occur for the line with the lowest height above the ground. In the example shown, the magnetic flux density reaches a maximum at a point just inside the outer conductor and its value is about 66 μT (0.66 G) for the line with a height of 42 ft. Interpreting the data in the figure more broadly, we see that the magnetic flux density is likely to exceed 20 μT (0.2 G) for all points within a distance of 100 ft from the center of the right-of-way.

The magnetic fields produced by a 765-kV overhead line appear to vary more with height of the measurement point above the ground than do the electric fields. To illustrate, taking a line 42 ft above the ground and carrying 4000 A, Driscoll (1975) shows the maximum flux density increasing from about 63.3 μT (0.633 G) at 1 meter above the ground to 78.5 μT (0.785 G) at 3 m above the ground, for a 24% increase. This is larger than the corresponding electric field increase for a 40-ft line height shown in Figure 6.

Deno (1976) and Zaffanella and Deno (1978) show many loci of the magnetic-flux-density vector ellipse in the vicinity of a 765-kV line. Near

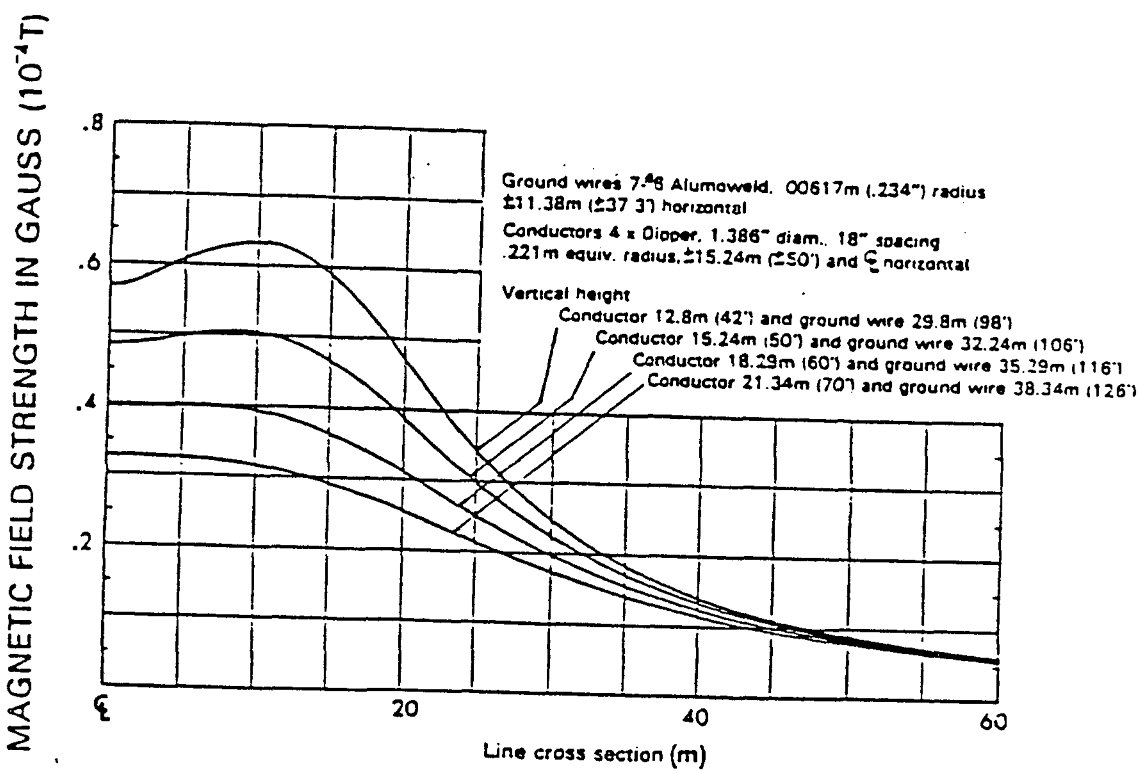

Figure 8. Magnetic field magnitudes at 1 meter above the ground for a 765-kV overhead power transmission line carrying 4000 A and with conductor heights at four different heights in the range 42-70 ft (Driscoll, 1975).

the ground at large distances from the line (distances greater than 60 meters) the vertical component of the flux density is substantially greater than the horizontal component, but just outside the outer conductors of the line the horizontal component can greatly exceed the vertical; directly beneath the center conductor the two components are comparable in size. In general, therefore, the magnetic flux density vector near the ground rotates in an ellipse with highly variable characteristics.

Deno (1976) and Zaffanella and Deno (1978) also compare a number of computed and measured magnetic flux density values for a variety of overhead power lines, with relatively good agreement observed.

As we have pointed out, the magnetic fields produced by power lines depend on the current that is flowing in the wires. We have only seen magnetic field data for currents less than or equal to 4000 A, and we will assume that that is a typical maximum current flowing in a 765-kV line. With that assumption, we may conclude the following: (1) the magnetic fields beneath 765-kV overhead power lines are well understood and can be calculated accurately, (2) the magnitude of the fields varies substantially depending on the height of the line above the ground and with position of the field point beneath the line, and (3) the fields have significant horizontal and vertical components near the ground, with the vertical predominating at large distances from the line. Further, it appears that the maximum magnetic flux density amplitude that is likely to be observed beneath a 765-kV line in normal operation is of the order of 70 μT (0.7 G). Comparing this latter value with the magnitude of the naturally-occurring magnetic noise that would probably be observed at the same location in the absence of the overhead line, we can also conclude that the power line magnetic fields are substantially greater than the natural fields: a 70 μT field is roughly 5-6 orders of magnitude larger than the typical natural 60-Hz field of 0.04-0.4 pT described in Section C.

H. SPECIFICATION OF FIELDS FOR STUDIES FUNDED BY THE POWER LINES PROJECT

The request for proposals issued in 1981 contained an appendix that provided specifications for exposure systems. This appendix is reproduced as part of Appendix 1 to this report, together with a document prepared later and distributed to all contractors explaining and altering the original specifications for the phase relationship between electric and magnetic fields. Exposure systems constructed with support from this Project all employed the phase-angle relationship described in Appendix 1.

During the past two years four studies have appeared that suggest biological systems may respond to power line fields differently depending on the intensity and, possibly, the direction of the ambient DC magnetic field (Blackman, et al., 1985; Thomas et al., 1986; Leal et al., 1986; and Smith et al., 1987). One of these (Thomas et al. 1986) was supported by funds from this Project. In future studies it would be important to carefully document the direction and levels of ambient DC magnectic fields. It should be noted that the earth's DC magnetic field does not vary substantially over time. If lack of information of the ambient DC magnetic field of past studies should ever prove to be a problem, it probably could be reconstructed to a good approximation from a measurement of the earth's field at the relevant laboratory's location.

V. EFFECTS OF ELECTRIC AND MAGNETIC FIELDS ON BIOLOGIC SYSTEMS

A. REPRODUCTION AND DEVELOPMENT

A review of the literature existing in 1981 on genetic, chromosomal, teratogenic and reproductive effects of 60-Hz electric and magnetic fields revealed no unassailable proof of induction of these types of biological damage. However, there were several reasons why studies in this area were designated of major importance for research sponsored by the New York State Power Lines Panel:

- If any biological damage of these types is associated with power line exposures, there could be a significant impact on public health.
- Some studies reported deleterious effects on fertility of rodents and on European electric-power-station workers. Although the results and conclusions of these studies could not be accepted by the panel because of serious methodologic flaws in their design and implementation, nonetheless, the question whether there is a basis for the concerns generated in the public mind by these publications needed to be explored.
- Theoretical considerations of effects of electric and magnetic fields make it unlikely, but not impossible, that damage to gametes and conceptuses could be produced by exposure to these agents.
- These biological variables are always included in investigations of potential deleterious agents by regulatory and scientific bodies because of their major impact on human populations.

To appreciate the rationale behind the studies of discussed in this section, it may be helpful to review some basic biological principles.

The phenotype, or total composition of an organism, may be assessed by various endpoints: anatomy (body structure), physiology (body function), behavior, health and reproduction. The blueprint for the phenotype is contained in the genetic material (genotype, DNA), contained in the parental chromosomes in the egg and sperm which unite to form the zygote, the beginning of the next generation. The zygote (later called the embryo and fetus) is exposed to the maternal environment per se, and through the mother, is also exposed to agents of the outside world. These environmental agents interact with the genotype to produce the phenotype. There is a normal range of prenatal development for humans. Deviations from this range may be caused by abnormal genes (such as those for hemophilia or dwarfism), abnormal amounts of chromosomal material (for example, the chromosomal defect producing Down syndrome), impaired maternal health (such as diabetes, which increases the risk for spina bifida), or teratogens which reach the fetus through the maternal environment and act directly on the fetus (for example, thalidomide which causes limb reduction). Agents increasing the rate of gene mutations are said to be mutagenic, those causing chromosome damage are clastogenic, those acting directly on the fetus to cause abnormal development are called teratogenic. Miscarriages, stillbirths, and the production of physically malformed and mentally retarded individuals can result from any of these causes.

The question of concern to this Project is whether or not electric and/or magnetic fields act to disturb reproduction and development, thus increasing the background rate of abnormalities. This question is amenable to experimental investigation. For example, if early miscarriage rate is the endpoint of interest, it can be studied directly through epidemiologic investigation of human populations and/or by laboratory studies of animals. Ethical and legal considerations preclude exposing human fetuses to potentially harmful agents, therefore the only epidemiological approach available is to study the response of humans to "natural" exposures. However, evidence of induction of chromosome damage to cells in tissue culture by electromagnetic fields in laboratory studies can provide indirect evidence of reproductive loss because most (60%) first trimester miscarriages are caused by chromosomal abnormalities (Boue et al., 1975). Chromosomal abnormalities can also impair reproduction in the adult through effects on hormones or gametogenesis. If chromosomal damage cannot be demonstrated in the laboratory, it is not likely to occur in exposed humans. Animal studies are also valuable for testing the possibility of deleterious effects of environmental agents. The limitations of these approaches are cost and the possibility of different responses of humans and animals.

Although studies of humans have appeal because they directly examine the organisms of interest, it is usually very difficult to determine whether an environmental agent increases the rate of genetic mutation or of chromosomal aberrations (changes in number or structure of the chromosome) by conducting epidemiologic investigations in the human population. Even if exposure to some environmental factor induces such damage, it may not be expressed for several generations or the mutation or chromosomal aberration may be selected against so early in egg or sperm formation that it is not detectable in the human population studies. In addition other causes of gametic or fetal damage must be ruled out, such as age of the mother. Another difficulty in studying possible reproductive effects of electric and/or magnetic fields in humans directly is that one must rule out many other known or potential hazardous substances, such as defoliants, which may be associated with power lines. Furthermore, such studies usually require large numbers to be investigated in the necessary detail, and there is considerable difficulty in classifying exposures. The numbers of births that occur to women living close to overhead transmission lines may not be large enough to give an adequate sample size (due to low population density in those areas), making it unlikely that a small but significant increase in birth defects will be detectable.

For all these reasons, the Panel elected to pursue evidence for genetic chromosomal, teratogenic and reproduction effects in laboratory studies of whole animals and tissue cultured cells rather than epidemiologic surveys. If evidence of damage were found, epidemiologic studies might be warranted in the future, and could be more focused based on the types of damage found in laboratory studies. If no damage were found, expenditures on human studies might not be a high priority.

The principles used to select and design relevant studies were based on principles used to establish the safety of other environmental agents, in particular those to which pregnant women may be exposed. Experimental designs for such studies have been developed over the years by various investigators, governmental regulatory agencies, and scientific organizations. Although no comprehensive protocol has reached the status of an absolute standard, the Panel incorporated several of the well established protocols, guidelines and recommendations [current FDA protocols for drug safety testing, (Bloom, 1981; Wilson and Clarke-Fraser, 1979)] and well established principles of genetics as defined by experimental breeding. These criteria have indeed leed to the detection of deleterious agents in the past.

1. Chromosomal (Cytogenetic) Damage; Sister Chromatid Exchange

Investigations of chromosomes from cells exposed *in vitro* are useful because agents known to damage chromosomes in the intact organism, e.g., ionizing radiation such as x-rays, will also show evidence of damage *in vitro.* However, if damage is shown in laboratory studies of exposed cells in tissue culture, it does not necessarily mean that exposed humans will also show evidence of chromosomal damage. It would mean that further studies on whole organisms are needed. Conversely, if no chromosome damage is detected *in vitro*, these results are reassuring, assuming exposures encompassing those to which humans are subjected are actually delivered to cells in the laboratory. Studies of cell cycle can also be predictive of fetal effects because development is a carefully orchestrated sequence of cellular interactions, disruption of which can lead to birth defects.

The chromosomal endpoints chosen for investigation by the Panel were sister chromatid exchange (SCE) frequencies, chromosomal aberrations and micronuclei formation. SCE is a well established assay for mutagens and carcinogens, although it is not a perfect correlate. Micronuclei formation is correlated to exposure to established clastogens, e.g., ionizing radiation. Three different groups investigated SCE frequencies and found no effects:

- Brookhaven (Carsten and Benz, Appendix 10) analyzed chromosomes derived from blood samples of chronically exposed mice; no increases of SCE were found, but sample sizes were small; more slides may be scored in the future.
- University of Maryland (Cohen, Appendix 4) performed extensive studies on SCEs from human lymphocytes exposed in vitro; no effects were found. (See also Cohen et al., 1986a and b)
- University of Utah (Livingston, Appendix 6) found no effect on either SCE or micronuclei (an assay of chromosomal aberration) frequencies in either human blood lymphocytes or Chinese hamster ovary (CHO) cells.

These studies were all performed using well tested and monitored exposure apparatus, were done blinded to avoid scorer bias, and were replicated. Therefore, SCE can be said not to be induced by electromagnetic fields at the levels tested. This is reassuring and suggests that further SCE testing is not required. Micronuclei were also not increased in the CHO study, and chromosomal aberrations were not detected in human or CHO cells. These results suggest that it is unlikely that electromagnetic fields damage human chromosomes. Single gene mutations were not investigated in cells, although they were in animals (see section V.A.3). Also mutation assays to detect DNA alterations, such as the Ames test, were not included among the New York projects, but such effects have not been found in other studies (Juiitianen and Limatainen, 1986; Riverie, 1976). Most such studies are performed in bacterial cells or cell lines, and the focus of the projects supported here was on human cells (although a CHO cell line was used in one set of experiments by Dr. Livingston). Effects on isolated DNA were not pursued because ELF fields are not expected to produce enough energy to break DNA bonds and even if DNA damage occurred, there are interpretive difficulties in extrapolating to human health hazards.

2. Cell Cycle (Generation) Time

No exposure effects were found by the Brookhaven Laboratory on lymphocyte cell cycle time. However, sample sizes were small and only one cell type was examined. Nonetheless, this does not support the hypothesis that cell growth is affected by chronic exposure. The Utah group also studied cell cycle in CHO cells and concluded that exposure had no effect.

3. Teratogenesis, Growth and Development and Fertility

The need for an animal study to investigate effects of exposure on fetal development and fertility was met by the Brookhaven investigation. The goal was to investigate two different species, rat and mouse, in order to control for species variability because perfect correlation does not exist between animal and human responses. Because of funding and logistic difficulties (reconstructing special cages for rats), only a mouse study was completed. However, two strains of mice were used. This is desirable because it is well known that some agents are only harmful to animals of certain genetic backgrounds, that is to say that strain specificity as well as species specificity exists. In addition, effects vary depending on the developmental stage. Several endpoints were investigated after exposure of both male and female gametes, including frequency of dominant lethal gene mutations (DLM test), multigenerational effects (litter sizes; postnatal growth as measured by weight) and induction of recessive lethal mutations on the X chromosome as inferred by sex-ratio deviations. Fertility was also measured by impregnation rates. The mouse study was multigeneration to simulate long-term exposures in humans, and to increase the likelihood of autosomal recessive gene expression. Exposures were for 20/24 hours per day, for the animals' lifetime. Mice were housed in three rooms with as identical environments as possible except for the presence of fields (high, low and no exposure, see Appendix 10 for details). Skeletal and other anatomic defects would only be revealed by dissection and were not within the scope of the time and funding limitations. However, large samples of mice have been preserved for future analysis.

If effects had been detected in the mouse study, further investigations could have been designed and implemented to focus on the mechanism of damage. However, because no effects were found, further testing of mice is not indicated for these same endpoints. Extrapolation of risks from results of animal studies to humans is tenuous given the complexities of human exposures (possible interactions with other agents to which humans are exposed), different physical sizes of the organisms, and lack of perfect correlation in biologic responses to the same agent. However, the fact that no damage has been detected in the two strains of mice in the Brookhaven study is reassuring even if this does not constitute definitive proof that humans are similarily not vulnerable to these fields.

4. General Review of Previous Work

a. Electromagnetic Fields and Growth and Development: Although animals are traditionally used to investigate fetal effects of environmental agents (see above), it is problematic whether animal models adequately simulate human exposures to electromagnetic fields because of differences in size, shape and orientation of the bodies, which in turn affect surface electric fields and internal current densities. Furthermore, if animals are exposed to intense fields practical difficulties arise because of shock, corona and other factors which may cause artifactual biologic effects (see review by WHO, 1984).

Of the numerous studies of the effects of 60-Hz fields on growth and development of rats, mice, swine and rabbits, most show no conclusive evidence for deleterious effects (see review by the WHO, 1984). There are, however, several studies reporting effects on mice, rabbits and swine which have received considerable attention, although in all cases they are tainted by the possibility of causes other than fields, as discussed below.

Knickerbocker (1967) reported decreased body weight in male offspring of exposed mice. Reports of fields effects on growth and development in mice were published by Marino et al. (1976; 1980). Three successive generations of mice were exposed 24 hours per day from mating through the 119th day of life of the third generation. In comparison to controls, mice exposed to vertical fields (15 kV/m) exhibited increased infant mortality in all three generations, while those exposed to horizontal fields (15 kV/m) showed increased infant mortality only in the first generation. Body weights were also measured but no consistent effects were found. The authors suggest that "the increased mortality must be ascribed to a nonspecific action of the electric field - the field produced a biological stress...". However, the major criticism of these studies is that spark discharges from water bottles have not been ruled out and may constitute a source of stress to the animals and have affected fetal development through maternal deprivation.

The findings of Marino et al. (1976; 1980) have not been confirmed. Fam (1980) exposed mice to 240 kV/m 60-Hz fields for three months and found no developmental effects of any kind in the offspring. Konermann and Mönig (1986) found no developmental effects in rats exposed to fields. Sikov, et al. (1979; 1984) exposed Sprague-Dawley rats to 60-Hz fields at 100 kV/m, 20 hours per day throughout mating, pregnancy, and up to day 25 after birth using cages designed to eliminate effects of corona discharge and ozone production. Sikov et al. found no lasting differences in any aspect of reproduction and development, including body weights, fetal abnormalities, brain pathology, postnatal mortality, or a variety of behavioral and neurological tests. However, significant transient differences were found in motile behaviors and the righting reflex in 14-day rats. At 21 days of age the differences were no longer significant, raising the possibility of neurological repair of potential field-induced damage.

Other reports of field effects are on growth and development in rabbits (Hansson, 1981). He reported stunting of growth of wild rabbits reared outdoors in a 50-Hz field, but did not find effects when the same rabbits were exposed in a laboratory setting. Other aspects of, and problems with, this study are discussed below in Section D-1.

Phillips and colleagues (1981; 1983; Sikov et al., 1982; 1985) studied the effects of uniform, vertical 60-Hz electric fields on reproduction and development of Hanford miniature swine followed for three generations. They report an increased incidence of fetal malformations in the second but not the third generation, but no consistent differences in litter size, fetal weight or weight of fetal organs. The authors suggest that the effect, if real, was probably secondary to some maternal alteration, possibly an epidemic which occurred during that period, and indicate that the change in incidence of malformations between generations make it impossible to unequivocally conclude that there was a cause-and-effect relationship (Sikov, 1985).

There is evidence that electric fields are involved in directing embryonic cell migrations which are crucial for fetal development. Epithelial layers in developing embryos generate small DC fields in the embryo, and patterns can be altered by exposing cells in vitro (Erickson and Nuccitelli, 1984).

Cameron et al., (1985) observed retardation of fertilization of Medaka fish eggs exposed to magnetic fields (100 μT), or electric (300 mA/m^2) plus magnetic fields for 48 hours. The authors scored "stage", which they define. Regardless of "effect", all eggs hatched and no abnormalities were observed. However, their analysis does not compare the distribution of eggs at each stage for each treatment. Instead, they treat "stage", as a continuous variable leading to standard errors expressed as "0.2 of a stage", which is meaningless. Inappropriately plugging those numbers into analysis of variance may give significant differences between "mean stages" unless all eggs are at exactly the same stage.

Application of electrostatic pulsed fields (28.5 kV/m in air, pulse width 10 μ sec 300-Hz) to mice chronically (4 hrs/day) from the first to 17th day of pregnancy were reported to produce increased preimplantation resorptions, late resorptions, and dead fetuses in small samples (~20) (Lekarstvi, 1980). Hematomas were observed in the placentas and membranes of the exposed groups. No malformation or weight differences were observed. No exposure details were provided, so other factors attending exposure, e.g., microshocks, cannot be ruled out to explain the defects. Nakagawa (1979) claimed that homogeneous static magnetic fields retarded gestation, number of live births, birth weight and growth in mice.

b. Electromagnetic Fields and Chick Embryogenesis: Delgado and colleagues (Delgado, et al., 1982; Ubeda, et al., 1983) studied the effects of magnetic fields on embryogenesis in chicken eggs. Pulses were applied at three frequencies, 10-, 100- and 1,000-Hz, with current adjusted to provide magnetic flux densities of 0.12, 1.2 and 12 μT at each frequency. After 48 hours of incubation they reported that 13.4% of control but 78.5% of exposed embryos were abnormal. These effects were said to occur at a "window" of 100-Hz and 1.2 μT, and fewer abnormalities were seen at 10-Hz or with lower (0.12 μT) or higher (12 μT) fields. At all frequencies the cephalic nervous system was most commonly affected. Staining with Alcian blue (pH 3) revealed the complete absence of glycosaminoglycans in the extracellular matrix in eggs exposed to 100-Hz, 1.2 μT fields. These molecules are thought to be involved in normal cellular migration and development and could, by their absence, be a sole cause of the stunted development found by Delgado and coworkers. Ubeda et al. reported that pulse shape also influence the results.

Delgado's findings have not been confirmed by other laboratories. Neither Maffeo et al. (1984) or Martucci, et al. (1984) has found abnormalities in exposure of chick eggs while using experimental parameters similar to Delgado's. While differences in wave-forms, egg handling, or strain may be responsible for these discrepancies, there may be a larger problem in reproduction of Delgado's techniques. Even if Delgado's results are replicated, extrapolation cannot be made from these studies to human fetuses, because developmental control is so different in these species. Experimental effects on chick embryos have not been found to be predictive of any human fetal effects of the same agent (Wilson, 1978).

c. Reproductive and Chromosomal Studies in Humans: With regard to studies on humans, the article by Knave et al. (1979) extensively describes the Swedish State Power Board study of reproduction. In addition to being based on a small sample, one of the serious biases inherent in their analysis is the lack of comparability of control and highly exposed groups, although matching for age, geographic location, and duration of employment was attempted. The fertility differences could easily be explained by the differences in educational level (social economic status) which is correlated with reproduction patterns, and differences in psychological performance demonstrated by the authors. More importantly, as the authors themselves point out, the differences in numbers of children and per cent of males was present 10-15 yrs. before the "experimental" group worked in the 400-kV substations, and therefore must be due to other factors. Other variables which must be included in fertility analyses are age at marriage, length of time married and contraceptive use. It is interesting that workers in high-voltage fields are said to be away from home more than "control" workers. This could also affect fertility, as could the stress of their jobs. The authors themselves admit that fertility effects are "thought to be related to factors other than exposure". Consequently, this study has not demonstrated fertility effects of occupational exposure.

In their more expanded study (Nordstrom et al., 1983) sample size was increased, and the authors now claim increased congenital malformations. Comparison of the types of "malformations" scored reveals many categories that should not be included because they are not considered "major malformations" but rather variants or minor anomalies. Furthermore, based on what is known about these anomalies it is difficult to postulate how exposed sperm could contribute to their etiology. Specifically: a) hip joint deformities may merely result from breech deliveries (5-6%), b) hydroceles are very common in the first years of life, some may lead to inguinal hernias (1% of males) and c) retentia testis is also fairly common. Types b and c should not be considered major malformations, and if genetic, would have to be due to dominant gene mutations in sperm. This would be unusual as known mutagens such as ionizing radiation do not act through sperm.

If heart murmurs were included as "heart malformations" those should also be excluded, but we will assume for purposes of discussion the authors only refer to "major" cardiac anomalies. Turner's syndrome is the only chromosomal defect found in the study; the "multiple malformations" are not necessarily due to chromosomal syndromes or mutations. Thus chromosomal aberrations are not a likely mechanism to explain their observations. If analysis is restricted to major malformations, the comparisons among the 3 groups are: group 1 = 8/154 (5.2%), groups 2 + 3 = 2/364 (0.5%), group 4 (control) = 6/171 (3.5%). The differences are not startling. Casting further doubt that the etiology of any of the malformations is due to paternal exposure to fields is the lack of specificity in the classification of the "malformations".

No chromosomal aberrations or increased SCE frequencies were found in switchyard workers in Germany occupationally exposed for more than 20 years to 50-Hz AC (380-kV) fields compared to controls (Bauchinger et al., 1981). This contrasts with results on Swedish switchyard workers which attribute chromosomal aberrations to spark discharge (this hypothesis was supported by their <u>in vitro</u> work).

The claims for increases in chromosomal aberrations in peripheral blood cultures obtained from workers in high voltage electromagnetic fields were not conclusive in the early reports (Knave et al., 1979). The frequencies of chromosome breakage were compared between 8 employees exposed to 400-kV and a "reference group" of 19. Several methodological problems made this study inconclusive. i) The sample size was very small. ii) In view of the many well established factors which increase the frequency of chromosomal aberrations (viral infection, age, drugs, x-rays, laboratory techniques) it is crucial to match controls carefully, and rule out these factors, or to examine a large enough sample to randomize these effects. The Nordstrom study did not correct for these biases; in fact, it was mentioned that smokers showed a higher frequency of aberrations. iii) It is not sufficient to state that "chromosome breakage" was increased without specifying the type of aberrations, laboratory techniques (aberration background frequencies vary over time in different laboratories) and methods for randomization and blinding.

The 1983 study by Nordstrom et al. removed some of these problems in that smokers were not included in either exposed or control groups, cultures were scored blindly and control and exposed cultures were processed concurrently. However, a big difference still exists among comparison groups in exposure to organic solvents, which are likely to be clastogenic. Although chromosomal rings and dicentrics characteristic of ionizing radiation exposure are listed among the exposed, they are not discussed and suggest exposure to other clastogens. The authors attribute breaks to spark discharge. Spark discharges are most likely to affect peripheral blood cells (fingertips) from which the chromosomes in the study were prepared, and the authors' speculation about testicular exposure effects are difficult to justify.

The claims of Wertheimer and Leeper (1986) that use of water beds and electric blankets affects fetal growth do not appear justified. A biased sample of births was selected by phoning parents who had published birth announcements. These two criteria (phone, publication) would eliminate lower socio-economic and non-English speaking families from the sample. The authors also note a bias toward older parents. The authors assume without proof that use of water beds and electric blankets is randomly distributed among the group selected, so comparisons still could be made between users and non-users. Further biases may result from the use of only 30% (1256/4271) of eligible cases.

The claim of "seasonal patterns in fetal growth and abortion rate for families using electrically heated beds" is not justified because:

- Numbers of abortions are used without knowing how many pregnancies occurred – therefore fetal loss rates <u>cannot</u> <u>be</u> and <u>were</u> <u>not</u> determined in this study. Furthermore induced abortions were not determined and excluded.
- The measures devised by the authors for "slow", "average" and "fast" fetal growth is clinically meaningless because it cannot be converted to birth weight differences, for which standard, clinical criteria exist.
- Information on water beds and electric blankets was very crude and not necessarily correlated with pregnancies in the sample (68% of the 42% of families publishing birth announcements were asked over the phone if they were "users" in the last 8 years, and what heat settings they preferred); there is subjective switching of categories between "users" and "non users" if the bed was only used part of the year before conception.
- The "seasonal categories" selected by the authors are September – June vs. July – August. This is totally arbitrary and creates uneven comparison categories. Results may differ if different groups are chosen.

The authors state that when using traditional, clinically relevant defintions of "low birth weight" there is no difference between "users" and "non-users". Attempts to discern temporal trends from such small samples (e.g., 6 defective) is tenuous given the well-known artifacts in temporal clustering of defective births examined in large series of births. High intensity fields might cause developmental defects by hyperthermia, but maternal homeostatic mechanisms would be expected to insulate against all but extreme variation.

In summary, proof of human fetal effects of electric or magnetic fields does not exist and such effects are unlikely, based on what information is available from studies of non-human organisms, and from knowledge of the mechanisms of action of established teratogens. There are no standard epidemiologic investigations of the effects of electromagnetic fields on fertility and birth defects. The few studies purporting to examine these questions show no convincing deleterious association with exposure. Indeed it would be difficult to conduct appropriate epidemiological studies which would answer this question because of the very large samples that would need to be studied. Clearly defined endpoints would have to be determined in standard fashion to remove bias. Such studies if done properly, are unlikely to be informative given the difficulties of obtaining "controls" free of exposure in a modern population, or of estimating "dose". Meanwhile, caution in exposure to magnetic fields is clearly warrented until more work on magnetic fields is done. Statements such as that made by Smith et al. (1984) that exposure of human fetuses to magnetic fields in clinical magnetic resonance imaging is completely safe at all stages of pregnancy are unjustified by either human or animal studies. If further studies are done they should focus on magnetic fields, since the few reported positive results implicate magnetic field, rather than electric field exposures.

B. <u>CANCER</u>

1. <u>IN VITRO STUDIES: GROWTH (CLONOGENICITY) OF CANCER CELLS IN SOFT AGAR</u>

a. <u>Initial Results:</u> Although not an objective of the original New York State research protocols, the results of Drs. Winters and Phillips (Appendix 9; Phillips et al., 1986a and b)) regarding clonogenicity of tumor cells in soft agar must be discussed because

- this work was made possible by funding under the New York program which was used to construct the exposure apparatus and to support Dr. Winters and his laboratory;
- public concern was generated by these investigators' claims that magnetic fields stimulate growth of tumor cells in soft agar.

It is important to note that these investigators did not find evidence of transformation of normal (non-malignant) cell lines after electromagnetic field exposure as measured by soft-agar cloning. Indeed, had they presented evidence that transformation of normal cells was induced by electromagnetic exposure, this might have been of some significance. Increased cloning in soft agar is far more meaningful if observed for normal cells than for tumor cells, since tumor cells already have the capability of division prior to exposure. The cloning assay was developed by Hamburger and Salmon (1977 a and b) for comparing the differential response of malignant cells to drugs.

The cloning in soft agar test would not have been the assay of choice in investigating the effects of electromagnetic fields on cancer induction and/or promotion for a variety of reasons (Croce, 1986) including:

- there is only loose if any association of clonogenicity with clinical parameters such as a) metastatic behavior, b) progression of disease and c) response to therapy or survival of cells derived from tumors;

- there is no correlation of clonogenicity of cells derived from tumors with tumor induction in mice, although there is some correlation with tumor induction for normal fibroblastic tissues;
- there is extreme variability inherent in the assay, meaning that to be meaningful, intraexperiment differences observed must exceed the normal interexperiment variation and experiments must be carefully done and replicated to guard against artifacts caused by i) lack of linearity between colony numbers and cell numbers plated, ii) cell cloning rather than colony formation and iii) general health of the culture.

These investigators exposed many cell lines, both normal and malignant to either electric, magnetic or electric and magnetic. These cells and unexposed controls were then plated in soft agar, and the number of clones that grew were scored. Winters and Phillips found their "dramatic effects" on one of their first 27 experiments that reported a "24-fold" increase in clonogenicity after exposure to magnetic fields. This was said to be a permanent effect based on subsequent subculture. Other increases reported after exposure were not startling given the obvious variability even among controls (See also Phillips et al., 1986a and b). Only 2 of 27 individual data sets in this set of experiments were found by outside experts to support the investigator's conclusions that effects were produced by electromagnetic fields. The outside experts concluded that "When the overall experience is taken into account, the data demonstrated sufficient inherent noise to rule out any conclusion (positive or negative)". Dr. Winters and Phillips may have ". . . prematurely reached a conclusion of significance from their preliminary data." (Trent and Buick, p. 5, paragraph 2, site visit report, 29 August 1984, Appendix 18). Thirteen of these "preliminary" experiments persist unchanged as the basis for Tables 43 and 44 in Dr. Winters' final report and appear to be the foundation for most of the investigator's statements to the press and in legal testimony.

Table 45 of Winters' final report presents actual colony counts as means and standard deviations in addition to standardized values. Assuming these ten experiments are new and are replicates, the increases are not so dramatic as originally claimed: 19 of the 30 values after electric, magnetic and electric plus magnetic exposures are 2-fold or less increased above controls, and 7 are at or below control values. Of the 4 higher values (6.0, 4.8, 4.6, 3.4), three occurred after magnetic exposure, indicating that if any effect exists it follows magnetic exposure. However, the effect is within the range of normal variation for unexposed colo 205 and colo 320 cells. The question is whether statistical and biological significance can be equated. Even if these results are valid they cannot be extrapolated to cancer growth in humans, because ability of tumor cells to grow in soft agar has only loose, if any, to behavior of tumor cells in the intact organism.

Dr. Trent's evaluation of Dr. Winter's final report (Appendix 18) mentions that the one new Table (45) does allow independent assessment of variability. "However, despite statements to the contrary, there remains considerable experiment-to-experiment variability, and the interpretation that this reviewer would make is that a lack of rigid quality control may have contributed to this variation. The tabular summary presentation of data excludes independent review of the data. What analysis could be done "dampens the enthusiasm of significance". However using Table 45, Dr. Trent's reanalysis of the data showed an effect of magnetic fields, suggesting the existence of a small effect. The Panel agrees with Dr. Trent that " . . .one must also consider the significance of this finding as indeterminate at present".

b. Replication of Initial Studies: A replication of the cloning in soft agar studies was performed by Drs. Cohen and Hamburger under an extension of the contract to Dr. Cohen after completion of his original study on chromosomes (Appendix 18). The two cancer cell lines used in this experiment were the same as those Drs. Winters and Phillips used (Appendix 9). These lines were not obtained directly from Drs. Winters and Phillips, but from the American Type Culture Collection, Rockville, MD. Drs. Winters and Phillips do not state the immediate source of their cells, but these all originally derived from the same two patients (Semple et al., 1978; Quinn et al., 1979). After being established, cell lines such as these are maintained in culture. Each time they are moved to new vessels for growth, they are said to be "passed". Therefore, the "fifth passage" would be a cell line closer in origin to the original patient source than the "tenth passage". Cell lines do exhibit changes over time, therefore this variable should be the same for control and exposed cultures to insure comparability. We have no information on the passage numbers of the cells used in the Winters-Phillips experiments. All the Cohen-Hamburger experiments were run within 15 passages, and were the same for control and exposed pairs.

The growth kinetics were established for both cell lines prior to running experiments. This was to insure that experiments were run in the logarithmic growth phase, so that linear responses could be expected between cell number and clone numbers. Otherwise, artifacts could be induced by different numbers of viable cells in the comparison groups at the beginning of the experiment before exposure, or artifactual responses not caused by "treatment". The number of cells used in each culture well was 5×10^5, that number providing optimum clonogenicity response.

Each experiment of the Cohen-Hamburger project consisted of a set of 4 culture wells being exposed (2 wells of each of the 2 cell types) and a concurrent set of wells in the control incubator. Four agar plates were prepared from each well, and after 7 days, colonies of >40 cells each were scored in blind fashion to avoid scorer bias, either with an inverted microscope or a FAS image analyzer (similar to that used by Winters and Phillips). Eight different exposure regions were tested, with 2-3 replicates each (38 total experiments). The authors conclude that no consistent pattern of exposure effects occurs in their data. In order to see if a "time window" exists at which length of exposure (6,24,30 hrs) had an effect, a separate set of experiments was run on colo 320 DM (selected because it had "the most consistent cloning efficiency"). There was no evidence of such a phenomena.

c. Oncogene Studies: Molecular Genetic Analysis of Tumor Cells Exposed to Electromagnetic Fields: In order to pursue further the possibility of effects of electromagnetic fields on tumor cells, colo 320 cells from Cohen's lab were shipped to Trent for investigation of the c-myc oncogene locus (Appendix 18). Colo 320 had been found to contain amplification and enhanced expression of the cellular oncogene c-myc. This means that multiple copies of the c-myc gene have been found in colo 320, and altered myc expression may contribute significantly to tumorigenesis (Alitalo et al., 1983).

No evidence of altered c-myc expression (via quantitative RNA dot blotting), c-myc gene copy number (via quantitative DNA slot blotting), or c-myc gene structure (via Southern blotting) was found. The pattern of c-myc in colo 320 reported previously was confirmed, but no field effects were detected.

Transitory effects that may have disappeared during inter-lab shipment cannot be ruled out, but the effect on clonogenicity reported by Phillips and Winters was said to be "permanent". If oncogenes caused that effect, they would have been expected to persist.

2. HUMAN EPIDEMIOLOGY

a. Introduction: Since 1979 several studies have indicated that children living in homes near power lines or other electric transmission facilities or in homes with elevated electromagnetic fields run a higher risk of cancer. There are also studies on adults reporting similar results. Several studies have reported that "electrical workers" might be at increased risk. The New York State Power Lines Project included two epidemiologic studies addressing this issue, one on adults and the other on children.

The objective of this section is to review the previous research within this area, to analyze the results of the two New York State Power Lines Project studies, and to pull together all of the epidemiologic information of relevance to this issue.

b. Previous Research

i. Residential studies: This review will start with the studies based on residential exposure. Before the two studies within the New York project were undertaken, information was available from seven previous studies; only five were published in scientific journals, but the remaining two were available as extended abstracts from a scientific meeting. A summary of characteristics of these reports is given in Table 7, which also includes descriptions of the two new studies.

A review of these studies must emphasize the potential systematic errors that might be present owing to the design or the conduct of the investigation. It is essential, however, to recognize the two possible effects that a bias can have: 1) it may give rise to a spurious effect, i.e., to make a study show an apparent effect that does not exist in reality and 2) it may mask a true effect, so that it does not appear as an effect in the study. A study showing no effects should not be criticized on the basis of systematic errors of the first type and, similarly, a study showing strong effects should not be criticized on the basis of systematic errors of the second type.

The research in this area has frequently been criticized for using crude and operational definitions of exposure. Basically, three different approaches have been employed: a) identification and coding of nearby wires, transformers and substations combined with estimations of the resulting magnetic fields ("wiring configuration"), b) field measurements at one point in time, and c) identification of nearby transmission facilities and measurement of the distances to the home. For information on the approach used in each of the studies, refer to Table 7.

The first approach, the wire coding, has been criticized on two grounds. Firstly, the wire coding does not take into account magnetic fields generated by sources other than the transmission facilities, such as unbalanced return currents or currents used for appliances. Secondly, it has been claimed that the wire-coding systems and the procedures used for estimating the fields generate results with poor correlations to the true fields.

The second approach, the point-in-time measurement, has its drawbacks because of the variations over time of the magnetic fields, which in turn are a consequence of the variation in use of appliances, heating, etc. It appears that short- as well as long-term field variations are considerable; this seems also to be true for variations between different locations within the homes.

Table 7

Characteristics of Studies on Residential Exposure to Low Frequency Magnetic Fields and Human Cancer

Study	Study Design	Diagnosis	Location	Exposure Assessment	Number of Cases
Childhood Cancer					
Wertheimer & Leeper, 1979	case-control	all	Colorado, USA	wire coding	328
Fulton et al., 1980	case-control	leukemia	Rhode Island	wire coding	110
Myers et al., 1985	case-control	all	Yorkshire, UK	calculated fields	376
Tomenius, 1986	case-control	all	Stockholm, Sweden	measured fields	699
Savitz, 1986	case-control	all	Colorado, USA	measured fields, wire coding	125
Adult Cancer					
Wertheimer & Leeper, 1982	case-control	all	Colorado, USA	wire coding	1,179
Coleman et al., 1985	case-control	leukemia	London, UK	distance	769
McDowall, 1986	cohort	all	East Anglia UK	distance	814
Stevens, 1986	case-control	leukemia	Seattle, USA	measured fields, wire coding, calculated fields	114

The third approach, using the distance between a home and an identified transmission facility as a proxy for exposure is simply a crude variant of the wire coding, using only one category for all kinds of transmission facilities.

Clearly, all these three approaches have certain limitations. However, as long as cases and controls are classified according to the same principles, these limitations represent what is termed random, or non-differential, misclassification of exposure, and they cannot give rise to spurious effects; they can only mask a true effect, if there is one. If a masking effect occurs, it is produced by means of a dilution either of the exposed group with a certain proportion of truly unexposed subjects, or of the unexposed group with a proportion of truly exposed subjects. Therefore, this source of bias seems to be of relevance for the studies showing no effects but not for the studies showing effects.

In addition to the problems mentioned above, Wertheimer and Leeper, (1979; 1982) used a design for data collection whereby the person who drew the map to be used for the wire coding knew whether the house belonged to a case or to a control. This source of bias, unlike the one discussed above, could give rise to spurious effects. The authors have made some attempts to evaluate the magnitude of this possible bias, but its importance remains unclear.

The study by Tomenius exhibits a different problem in that it is not stated in the report whether or not field measurements for cases and controls were made within the same time periods. If case and control measurements are not uniformly distributed over time, a bias could certainly arise in any direction because of time variation in electricity use.

In several of the studies (Wertheimer and Leeper, 1979; 1982; Fulton, et al., 1980; Tomenius, 1986) the homes, rather than the individuals, constituted the units of study. These were all case-control studies; indeed no one would attempt to do this in a cohort study for it would be obvious in a cohort study that if homes were used as study units, everyone who had lived in more than one home would, mistakenly, be counted more than once. Given the rationale behind the case-control design, the use of homes rather than individuals is no more justified in such studies than in cohort studies. The question remains, however, of the impact which this feature of the study design has had on the results. It seems reasonable to assume that the point estimates of relative risks are not biased in any predictable direction, but that the confidence limits appear tighter than they should, because the study size appears bigger than it is. Fortunately, all reports, except the one by Fulton, et al., also give sufficient information to allow for the calculation of some individually based results.

In none of the studies did the available information allow for control of confounding from factors other than some basic demographic variables, and it has been suggested that, for example, a socioeconomic gradient in childhood cancer incidence together with a difference in the socioeconomic distribution between neighborhoods near power lines and other neighborhoods could explain the observed associations. Other confounders have also been proposed and are certainly tenable. However, to give rise to a relative risk of 2.0, the confounder would have to show quite a close association with the exposure in question and the relative risk associated with the confounder has to exceed 2.0 by a fair amount. It is not immediately clear if there are any risk factors, known at this time, which fulfill these criteria. Indeed, for childhood cancer the etiology is generally unknown and consequently only a few reasonably well-established risk factors are available as potential confounders.

Figures 9-12 summarize the results from the available studies, including the two studies performed within this project. For all studies, relative risks

ALL CHILDHOOD TUMORS

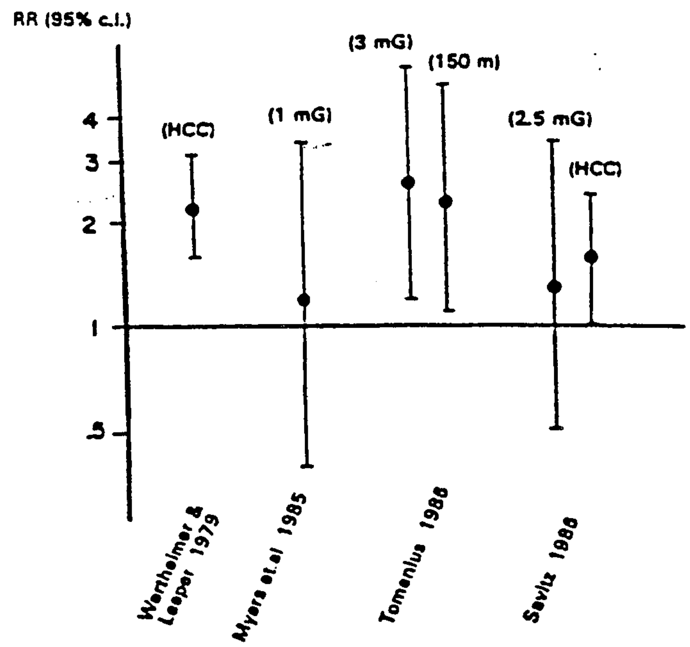

Figure 9. Results of childhood cancers in relation to magnetic fields. The studies from which the data are derived are listed at the bottom, and the method of measurement used indicated above the error bars. RR = relative risk; c.l. = confidence limits; mG = milli Gauss; HCC = high current configuration; 150 m = 150 meters from power line or transformer.

CHILDHOOD LEUKEMIA

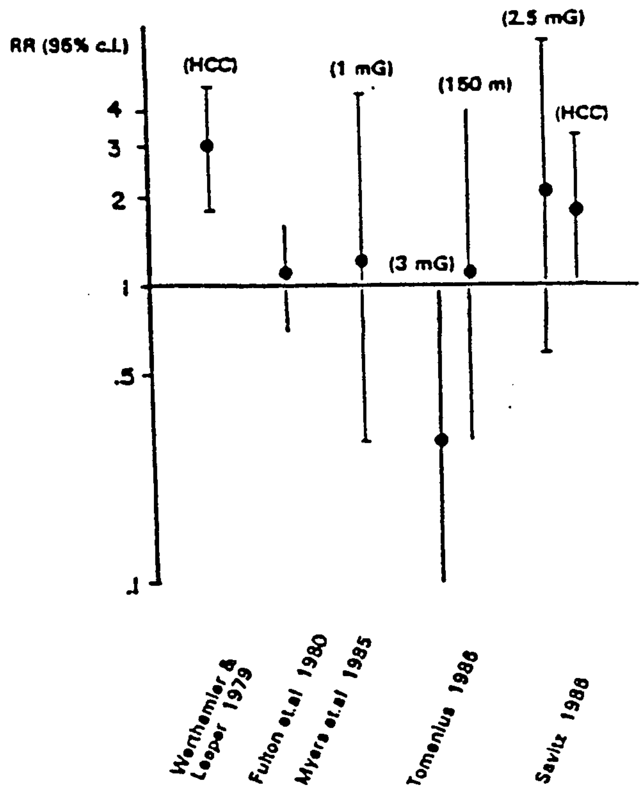

Figure 10. Results of reports of childhood leukemias in relation to magnetic fields. The studies from which the data are derived are listed at the bottom, and the method of measurement used indicated above the error bars. RR = relative risk; c.l. = confidence limits; mG = milli Gauss; HCC = high curret configuration; 150 m = 150 meters from power line or transformer. Open-ended bars indicate that calculations were based on residences rather than individuals.

CNS TUMORS

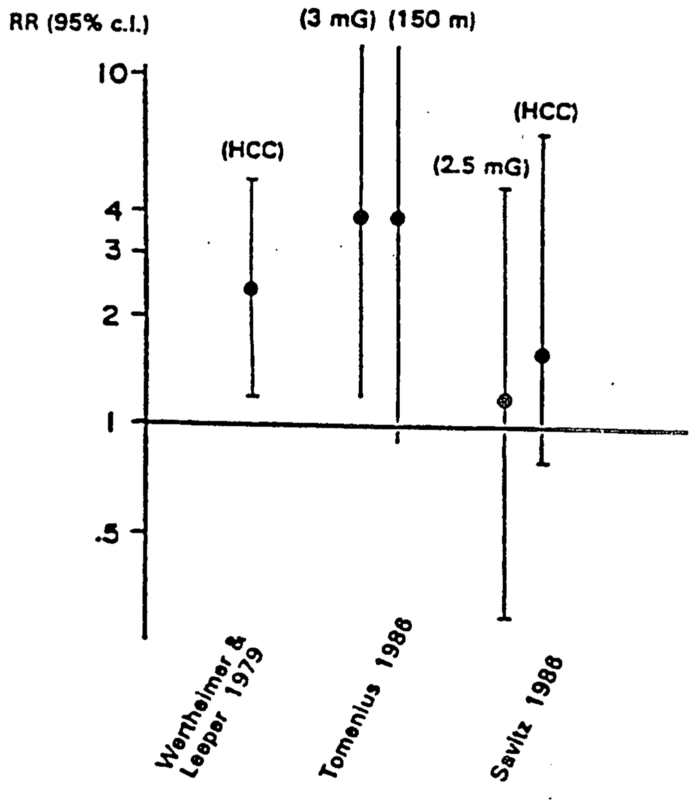

Figure 11. Results of reports of childhood CNS tumors in relation to magnetic fields. The studies from which the data are derived are listed at the bottom, and the method of measurement used indicated above the error bars. RR = relative risk; c.l. = confidence limits; mG = milli Gauss; HCC = high current configuration; 150 m = 150 meters from power line or transformer. Open-ended bars indicate that calculations were based on residences rather than individuals.

ADULT TUMORS

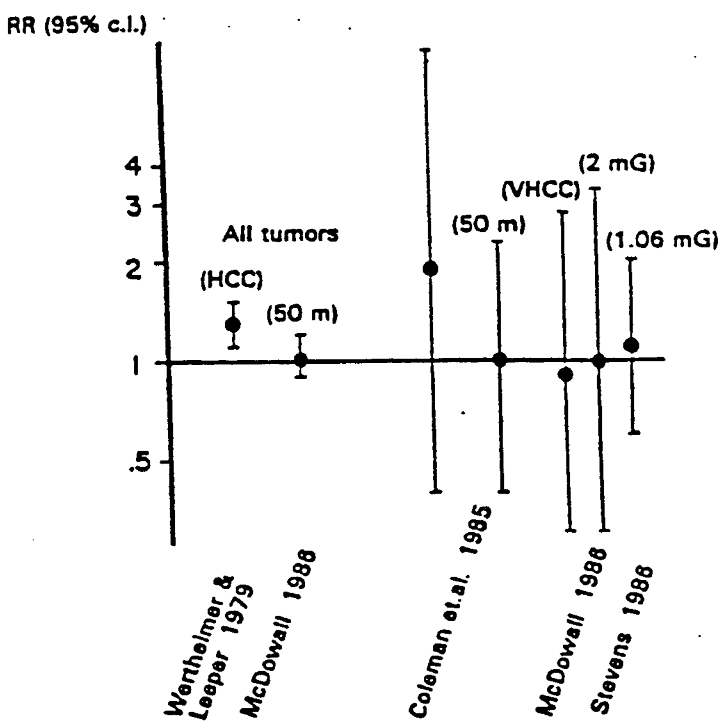

Figure 12. Results of reports of adult tumors in relation to magnetic fields. The studies from which the data are derived are listed at the bottom, and the method of measurement used indicated above the error bars. RR = relative risk; c.l. = confidence limits; mG = milli Gauss; HCC = high current configuration; VHCC = very high current configuration; 50 m = 50 meters from electric installation.

and 95% confidence limits are given for certain exposure measures at the time of diagnosis. For some of the studies, results based on more than one such measure are given. In studies where this information was not given, it has been calculated from absolute numbers presented in the reports. The open-ended bars indicate that the calculations are based on residences rather than individuals and that they are therefore uncertain and probably too narrow.

Figure 9 gives the results for the studies with data on all childhood tumors, regardless of site. Figures 10 and 11 give similar information for studies with information on childhood leukemia and childhood central nervous system tumors. Figure 12, finally, displays the results from the adult cancer studies. These results will be discussed later on, together with the findings from the two studies within this project.

ii. Occupational studies: Perhaps the earliest claim for deleterious effects of electricity in occupational health was made regarding craftsmen working with amber, where it was reported "The workmen polishing amber suffer considerably from electrical excitement, often experiencing severe nervous tremors of the hands and arms." (Williamson, 1932). Several subsequent reports have indicated that people employed in "electrical" occupations are at increased risk of developing leukemia. These studies have been reviewed by Savitz and Calle (1987). These occupations include telegraph and radio operators, power and telephone linemen, electrical and electronic engineers and electronic assemblers.

The majority of these reports are based on census information or some other kind of routinely collected register information. Hence, very limited information is available about the study subjects and only crude analysis, such as the PMR analysis, is usually presented. The major difficulty in the interpretation of the results is that so little information is available about exposure to electromagnetic fields as well as to other possible risk factors such as solvents.

Despite the obvious limitations of these studies and the erratic findings, it is difficult to avoid the conclusion that there is a certain consistency between the results. It seems more likely that these occupations are at an increased risk of leukemia than that a random phenomenon is observed or that some sort of bias is operating. If these "electrical" occupations are in fact at increased risk, whether or not the explanation is known, then it seems warranted to include long-term exposure to magnetic fields on the candidate list.

c. Research Within The New York State Project

i. Childhood cancer study: The objective of the childhood cancer study within the New York State Power Lines Project (Savitz, Appendix 15) was to repeat the original study by Wertheimer and Leeper, and also to improve and evaluate certain aspects of the study design.

Two approaches were employed for exposure assessments, namely direct point-in-time measurements within the homes and coding of wires and other transmission facilities. In both instances all assessments were made without knowledge of whether a particular home was a case or a control home. The measurements were taken under high-power conditions, with lights and appliances turned on, and under low-power conditions, with as much of the electricity as possible in the houses turned off. The purpose of the low-power-condition measurements was to measure external contribution to the magnetic fields in the house. The combination of wire coding and field measurements provided an opportunity to evaluate wire coding against actual measurements. An important finding was a correlation between magnetic field measurements and wire codes. Although there was substantial overlap in measured fields across wire code levels, there was a monotonic increase in mean field measurements over wire code levels.

Another important asset of this study is that information was collected through a questionnaire on a wide variety of potential confounders, such as socioeconomic status, smoking and x-rays. It turned out, however, that all results were basically unchanged when this information was used to control for potential confounding.

Also it is important to note that this study was designed as a population-based case-control study in the sense that eligible cases included all cases in the defined population and that the control group was selected according to a principle ensuring that it can be considered a random sample from the population. This means that, except for problems due to registration and location and non-response, the validity of the case series and the control series does not need to be questioned. On the other hand, one major difficulty with this study is the limited response rate. Of the cases, 71% were interviewed. The corresponding rate was estimated at 62% for the controls. There was also a second control group consisting of residences, and for this group the response rate was only 39%, indicating that no analysis should be based on this group. Because magnetic fields could only be obtained for interviewed subjects, the limited response rate affected not only the analyses including control for confounding, but all analyses using field measurements. Fortunately, wire coding could be performed even if an interview could not take place. Therefore, the rate of subjects with wire codes is higher but still limited.

Finally, when the results of this study are compared with those of the Wertheimer-Leeper study, it is of importance to note that there is no overlapping between the two studies, either with respect to study period or to subjects in the studies.

At the time of the diagnosis, low-power-condition magnetic fields (appliances turned off) as well as wire codes showed an association with cancer risk that was most pronounced for leukemia. High-power-condition magnetic fields (appliances turned on) did not show an association, nor did any exposure characterization at the time of birth. Some of the results are included in Figures 9-11.

Although we basically interpret this study as being positive, it is important to note that there are some internal inconsistences. The results seem to depend upon what exposure measure is used, e.g., no effect at all is seen when the high-power-condition measurements were used, and in some instances there are considerable differences between the results based on the wire coding and the results based on the low-power condition measurements. Furthermore, although the highest exposure categories display the highest relative resks, there is no clear dose-response relationship over the remaining exposure categories.

ii. Adult cancer study: The adult cancer study in the New York State Power Line Projects (Stevens, Appendix 16) was a case-control study on leukemia in adults. The rationale for choosing leukemia was the hypothesis which arose from the publication of the occupational studies mentioned previously, which showed elevated leukemia risks among people employed in "electrical" occupations.

The design of this study shares many of the features of the childhood cancer study, described above. The study is a population based case-control study. Exposure was assessed by field measurements as well as by wire codes. A refined methodology for wire coding was also developed within this project, resulting in estimated field values. This study also collected information on other risk factors, to the control for confounding factors.

Some of the secondary findings, but not the main results, agreed with those of the childhood cancer study. Again, the comparison between field measurements and the wire codes showed reasonably good agreement. The results also showed that the control for other risk factors did not affect the estimated relationship between magnetic fields and leukemia incidence. As in the childhood cancer study, the response rates were low. In fact, response rates in this study were considerable lower than usual for a case-control study performed in this area by the Fred Hutchinson Cancer Research Center, which was responsible for the field work. As for the major results of the study, regardless of how exposure was characterized, no relationship with leukemia incidence was disclosed. Some findings are included in Figure 12, together with those from the previous studies.

d. Discussion and Conclusions

i. Childhood cancer: Figure 9 summarizes the results from available studies for all childhood cancers together, regardless of site or histopathology. In most instances the precision is limited, as shown by the wide confidence limits, and the range of the point estimates is wide, but none of the estimates is below unity. In fact, given the different study designs, time periods and geographical locations, the findings appear quite consistent.

The incidence rate of childhood cancer is approximately 1 per 10,000 per person year. If the association with magnetic fields seen by Savitz is causal with a relative risk of about 2, then, depending on level of exposure, the incidence rate for the exposed group would be increased to 2 per 10,000 per person year. With the wire-code distribution that Savitz saw in Denver (the figures at other localities are unknown and may vary), and the assumption of a causal effect, this would mean that 10-15% of all childhood cancer cases are attributable to magnetic fields.

For childhood leukemia, there is more randomness and the findings are less consistent, as seen in Figure 10. The study by Fulton et al. gave a point estimate very close to unity and the study by Tomenius even indicates a considerable preventive effect of fields. The remaining three studies indicate positive effects, although the Myers study gave a relative risk as low as 1.3.

The childhood brain tumor findings are summarized in Figure 11. Only three studies provide information here, and the numbers are even smaller. Nevertheless, all three studies indicate some elevations.

Even before the study by Savitz was undertaken, available information indicated that children living near power transmission facilities or in homes with elevated magnetic fields might be at increased risk of cancer. However, so many methodological and theoretical concerns were raised against these studies that the findings had to be considered highly uncertain. The study by Savitz confirms the results of the previous studies to some extent and adds to the credibility of the hypothesis that exposure to extremely-low-frequency magnetic fields might be a cause of childhood cancer. It is important to bear in mind, however, that research in basic sciences has not revealed any mechanisms that could explain the role of the magnetic fields in the origin of cancer. Furthermore, the strengths of the magnetic fields observed in these studies are low, in the sense that one might be exposed to such fields almost anywhere in the environment; they are also low in the sense that they are approximately only 1/1000 of the strength of the fields usually used in experimental settings.

ii. Adult cancer: The adult cancer studies taken together do not indicate an excess risk either for all cancers together, or for leukemias.

Even if no data seem to indicate an effect on adult cancer of exposure to extremely-low-frequency magnetic fields, this does not, of course, rule out the possibility of an effect. Firstly, the dilutive effects might be more pronounced in adults than in children and secondly, available results have no bearing on cancers other than leukemias.

C. CELL BIOLOGY

1. General Effects On Cells: The use of cell culture techniques allows the study of homogenous populations of a single cell type to assess toxicological and environmental influences. Both tissue-culture cells and free-living organisms in culture have been used to study the effects of electrical and magnetic fields on biological processes. Specific parameters that have been examined include the synthesis of DNA, RNA and protein, rate of cell growth, cell shape, direction of cell growth, genetic alterations and responsiveness to various stimuli. Without going into detail on experiments from many laboratories which can be found in a number of reviews, it is clear that biological effects can be induced by both DC and AC magnetic and electric fields. Some of these effects, such as the cathodal orientation of nerve cell processes in DC fields, are readily reproducible in different laboratories. Other observations have been characterized by being found in one laboratory and not in a second or by the necessity of having very precisely delimited experimental conditions before the phenomena can be seen. While such limiting conditions of pulse width, waveform or necessity of modulating high-frequency carriers with low frequency might be of some general interest in attempting to determine the mechanisms by which these effects occur, they are severely limited when one tries to relate these studies to potential effects of electric power on the public health.

To avoid some of these pitfalls, the New York State Power Lines Panel has restricted the studies they supported to AC fields at 60-Hz and to field intensities which are within approximately one order of magnitude of those which could reasonably be encountered in the ambient environment. The studies commissioned have used cells derived from bone (Rodan, Appendix 13), from the nervous system (Gundersen, Appendix 5), from the anterior portion of the eye (Basu, Appendix 3) and from the canine and human immune system (Winters, Appendix 9). In each case, the design of the exposure system and its calibration were carefully monitored by the advisory panel with the assistance of DOE and NBS consultants. No attempt was made to use identical exposure systems in each situation but comparable fields were a goal of the design. This diversity was an attempt to avert a result that is specific to one experimental situation and reflected the feeling that significant findings should be obtained at similar field strengths in the face of experimental differences. Positive results from two or more sets of experiments under these conditions would be far more likely to represent specific effects of the fields rather than spurious results or effects of ill-defined confounding conditions.

While the bulk of the studies described in this section adopt in vitro approaches, three studies in particular - those of Winters, Rodan and Basu - focus on general aspects of cellular biology rather than specifically on the genetic and reproductive parameters. The studies of Winters were primarily on the immune system and the regulation of cell-surface molecules. Those of Rodan were on bone cells and those of Basu on the cells of the anterior portion of the eye. All three of the studies used normal cells. In addition, the studies of Winters and Rodan also used tumor cells. In the immunological studies, Dr. Winters found no changes in the synthesis of DNA, RNA or protein in normal canine leukocytes in response to electrical, magnetic or mixed fields. Furthermore, no changes were seen in the levels of transferrin receptors or in immunoglobulins. In human peripheral blood lymphocytes transient synthetic changes were observed. These findings argue that no normal immunological functions were perturbed by the fields. However, in vitro studies on the immune system are limited by the fact that the immune system is normally under nervous system control and that this element is eliminated in the experimental model selected in this case. An important concern with the data in the Winters' study is the very low response in the mitogen assays with Concanavalin A and the fact that quantitative plaque-forming assays were not used for the immune response. These concerns suggest that strong conclusions on the effect of fields on the immune response should not be drawn from these data and that further study is indicated.

Similarly, Rodan saw no field-induced alterations in DNA synthesis or parathyroid hormone-induced cAMP level in cultured cells from fetal rat calvarium (also see Noda et al., 1987). This finding conflicts with the results of Luben et al. (1986) who reported an increased binding of parathyroid hormone to similar cells in the presence of fields. Though these are not the same assays, one would expect that specific binding of the hormone to the receptor would increase the levels of cAMP.

Basu observed that rabbit corneal stromal cells exhibited a modest increase in tritiated thymidine incorporation into DNA in the presence of 10 μT (0.1 G) magnetic flux densities but none at 100 μT (1.0 G). No differences were seen in plating efficiency, viability or protein synthesis. Mixed magnetic and electrical fields had no effect on human corneal stromal cells. Mixed fields also had small but statistically significant effects on wound healing in organotypic cultures. A study of the combined effects of 2.7 T magnetic flux density and pulses of radiofrequency waves on the ocular tissues of rats (Sacks et al., 1986) failed to reveal any abnormalities up to two years after exposure. That study was carried out to mimic the conditions of exposure of human beings in magnetic resonance imaging equipment.

Thus it appears that in normal cells freshly derived from tissue rather than tumor cells - there is little or no effect of magnetic fields in the range up to 100 μT (1 G) and little or no effect from electrical currents up to 300 mA/m^2. On the other hand, both Winters and Rodan also included tumor cells in their studies. Winters used the colon tumor cell colo 205 and reported that under some exposure conditions there was an increase in clonogenicity in soft agar (See Section VB1), in the number of transferrin receptors on the cell surface, the amount of exposed tumor antigen and the susceptibility of the cells to killing by natural killer (NK) cells. In the case of the transferrin receptor the relative potency of the various exposures was MAGNETIC > ELECTRIC + MAGNETIC > CONTROL > ELECTRIC. In the case of susceptibility to NK cell killing the effects were ELECTRIC + MAGNETIC > MAGNETIC > CONTROL > ELECTRIC. As discussed previously, however, there were serious problems in the design of these studies.

When Rodan used osteosarcoma cells (ROS 17/2.8) he found significant increases (15-20%) in DNA synthesis on exposure to 60-Hz fields at 300 $\mu A/cm^2$. He did not find effects on the cAMP response to parathyroid hormone in the tumor cells. It is important to note that this effect on DNA synthesis was not seen in three very similar studies in our series - Livingston, Carsten and Cohen. Therefore, it is clear that this response is limited either by cell type or exposure situation. While no transcriptional changes (RNA) were found in the New York State supported experiments, Goodman and Henderson (1986) have reported increased transcription in exposed dipteran (insect) salivary gland cells. Whether this is further reflected in changes in the proteins being synthesized in these cells is as yet unanswered.

Many studies show effects of fields in increasing (*Physarum*, *Tetrahymena*) or decreasing (*Paramecium*) the mitotic cycle time. It is tempting to view these effects as being mediated by the cell membrane and specifically by the calcium ion. The calcium ion has been implicated in the control of cell division (Epel et al., 1974; Gilkey et al., 1978; Keith et al., 1985; Tsien et al., 1982) and it is interesting that the effects of fields on cell division in Paramecia are antagonized by verapamil, a calcium channel blocker. Similarly the effects of fields on the cathodal orientation of growing neuronal processes can be blocked by removing calcium from the culture medium. Calcium is also known to play a role in other cell surface events including a possible role in receptor clustering at the motor endplate of muscle in response to stimulation. While far from established fact, it is likely that membrane control of ionic calcium levels, whether from the extracellular medium or from intracellular stores, might be an important way in which electrical and magnetic fields affect cells.

2. Electrical Stimulation Of Bone Repair: Currently many orthopedic surgeons surmise that electrical stimulation procedures simplify the treatment of fracture nonunions. Though the procedures now in vogue appear to be relatively simple, the means by which they accomplish this remains a complex issue in the field of bone repair. Electrical stimulation has been hypothesized to initiate a delicate interplay between exogenous electrical energy and the complex mechanical, electromechanical and biological processes that naturally occur during bone formation. Understanding this interplay may aid in the selection and development of methods and technologies to stimulate the natural process of bone repair.

As an organ, bone shows complex interrelationships between physical and biological processes, the very architecture of bone being a response to the mechanical demands placed upon it. This is one manifestation of Wolff's Law which was defined almost 100 years ago. In addition, the known electrochemical and electromechanical properties of bone are thought to play an essential role in its growth and remodeling. Recent studies suggest that an electrokinetic (streaming) mechanism is primarily responsible for the endogenous electrical potentials produced by mechanical strains in vivo (Frank and Grodzinsky, 1987; Gross and Williams, 1982; Pollack, 1984), hypothesized to be a signal that may modulate cellular response.

Several studies have also helped to quantify the endogenous bioelectric currents and potentials produced by injury to soft and hard tissues (Borgens, 1984; Friedenberg and Brighton, 1966). The existence of such endogenous potentials generated by electromechanical or electrochemical means has led to many animal experiments to discover whether exogenous electric currents could stimulate bone growth and healing. The early experimental work of several groups focused on the use of direct current (2-20 μA) applied by means of implanted electrodes (Lavine and Grodzinsky, 1987).

The three modalities most commonly used in the electrical stimulation of delayed union, nonunion, and congenital pseudarthroses involve currents delivered internally be means of implanted electrodes, or by externally mounted devices that inductively or capacitively couple currents to the appropriate site. The first attempts to use electrical stimulation to enhance bone healing were performed on cases of nonunion of fractures and congenital pseudarthrosis of the tibia using DC current with implanted electrodes. Electrical stimulation was used in congenital pseudarthrosis because the risk-benefit ratio was highly favorable to the patient. Of the semi-invasive methods, the electrode-sensitive method has been used in many cases of fracture nonunion (Brighton et al., 1981; Heppenstall, 1983), incorporating four stainless steel cathodes, each delivering 20 μA direct current via a commercially available power pack.

Inductive coupling was the first of the non-invasive methods to have extensive clinical use (Bassett, 1984). Time-varying magnetic fields ("PEMFs") are produced by means of external coils driven by a time-varying current pattern. The magnetic fields penetrate the limb and induce electrical currents within the region of the fracture. Various pulse shapes have been studied (Bassett, 1984; Downes and Watson, 1984) and are used for different treatment modalities. The resulting currents are induced in an extremely complex manner both spatially and temporally, because of the highly complex, anisotropic, nonhomogeneous conduction, dielectric, and structural properties of wet, living bone. Because of these complexities, it is extremely difficult to model and compute the exact magnitude and distribution of the current that will be induced by the PEMFs at the site of treatment. While most investigators believe that PEMF treatment does not cause tissue heating, the question has been raised that local tissue heating may occur to an extent that would not be predicted by oversimplified models that are based on the assumption of electrically homogeneous tissue properties. About 70-85% percent of the nonunions, and about 65 percent of the congenital pseudarthroses treated in this manner have been reported to achieve union (Bassett, 1982; De Haas and Beaupre, 1986; Downes, and Watson, 1984; Mulier and Spaas, 1980).

The next commercially available non-invasive method was that of capacitive coupling (Brighton and Pollack, 1985), in which a time-varying electric field is applied to the limb by externally placed capacitor plates located on the skin overlying the treatment site. All of the commercially available techniques, both invasive and non-invasive, are reported to give about the same overall success rate for fractures of the tibia. All techniques emphasize the importance of high-quality orthopedic fracture care, a factor which has been suggested as partly responsible for some of the success attributed to this approach (Barker et al., 1984).

The exact mechanisms by which various electrical stimuli induce an osteogenic response are still unknown. Interpretation of some of the experimental data in animals which have been ascribed to electrical stimulation has sometimes been complicated by other variables, such as the presence of mechanical stresses resulting from the stimulation apparatus. The different experimental models used in different laboratories has further complicated the issue of repeatability.

It is likely that very different mechanisms would be associated with the invasive techniques as compared to the noninvasive methods, due to the presence of the implanted electrodes. When current is passed across an electrode/electrolyte interface such as that at an implanted electrode, chemical electron-transfer reactions must occur at the interface. (This enables the current to bridge the junction between electron transport in the external metallic circuit and ion transport in the tissue/fluid space within the limb). In establishing the mechanisms by which current from implanted electrodes elicits a biological response, it is essential to distinguish between the effect of the electrical current per se and the effect of these accompanying chemical reactions and reaction products.

Recent evidence suggests that electrode chemical reactions may be the primary stimulus for the osteogenic response observed in some studies. For example, the reaction at a stainless steel cathode results in consumption of dissolved oxygen and an increase in local pH (Brighton et al., 1981; Renooij, 1983). Brighton et al. (1981) summarized previous studies showing that low tissue oxygen tension and a slightly alkaline environment favor bone formation. Baranowski et al. (1983) used microelectrodes to measure pH and pO_2 in the tibial medullary canal of rabbits that received DC stimulation currents of 1-50 μA at that site. They found an association between decreased pO_2, increased pH, applied current, and osteogenesis in the vicinity of the implanted cathode. Direct observation of an osteogenic response induced by similar local changes in pH and pO_2, but without applied currents, would further serve to validate this hypothesis.

The cellular mechanisms that may be associated with the noninvasive (capacitively and inductively coupled) techniques have been even harder to identify. An extensive number of in vitro studies have focused on the effect of electrical currents on bone and cartilage tissue and cell preparations. A wide range of cellular processes have been examined, including protein and glycosaminoglycan synthesis, cell proliferation and differentiation, growth of bone and cartilage rudiments, and accumulation of cyclic nucleotides (see Fukada et al., 1985 for a recent review). While many positive effects have been reported, a clear understanding of the basic mechanisms relating to osteogenesis has yet to emerge. Some of the physical mechanisms that may play a general role in cellular response to electrical currents have been reviewed (Robinson, 1985), and include modulation of membrane potential and membrane transport, current-induced motion of membrane-bound receptors and cytoskeletal elements, and other indirect effects of fields on membrane channels.

Resolution of the issue of mechanism is central to understanding the validity of the fundamental hypothesis that endogenous currents produced by deformation of bone in vivo act as a signal to bone cells.

D. NEUROBIOLOGY AND BEHAVIOR

1. Brain and Neuronal Development: An extensive literature has accumulated on putative biological effects of extremely-low-frequency electric fields, especially in the areas of animal behavior and physiology. In contrast, very little is known about extremely-low-frequency field effects on developing nervous systems, although theoretical arguments exist for such effects. Initial

reports, including those indicating adverse effects, need much further verification in order to determine how, if at all, neural development may be vulnerable to an environment increasingly filled with extremely-low-frequency fields.

Although possible mechanisms of biological interactions are only a matter of speculation at this time, cellular activities that are critical in neural development might be affected by extremely-low-frequency fields. Although extremely-low-frequency fields at environmental intensities possess too little energy to break covalent and hydrogen bonds so prominent in living organisms, they may well change the three-dimensional structure of ions and molecules existing as either temporary or permanent dipoles (Adey, 1981). Molecular conformation is of the utmost importance in biological membranes, in which the fluid-mosaic model of Singer and Nicholson (1972) stresses the importance of noncovalent interactions. Furthermore, neurons maintain at their membranes a 70 to 90 millivolt potential difference which - across a membrane only 75 Angstroms thick - represents field strengths of about 10^7 V/m. Such a potential difference, whose maintenance requires a significant portion of cellular energy, could be altered by exogenous electric fields. Also, magnetic fields may affect cellular activities involving paramagnetic ions, such as iron, or reactions with free radical intermediates. Animal tissues permit penetration of magnetic fields not much differently than air.

The field of neural development has attracted considerable attention in the recent past. It is a difficult field of study because of the unique complexity of the final products, especially in mammals. However, a number of basic mechanisms of neural development have been proposed. Some of these mechanisms may be vulnerable to extremely-low-frequency fields (Jacobson, 1978).

Neuronal proliferation, migration, and selective death are critical in neural development, and may be regulated by receptor-mediated factors taken up at cell membranes (Liu, 1981). Steroids, including sex hormones, also play a role in neural development by acting via noncovalent interactions with cytoplasmic receptors, which are then translocated to the nucleus (McEwen, 1983). Long journeys of neurons and their processes may involve poorly understood interactions with extracellular guiding proteins, such as fibronectin and laminin (Liu, 1981). Formation of the correct synaptic connections seems to depend on the disposition of membrane macromolecules inserted via Golgi-derived coated vesicles and then left to find their appropriate location in the post-synaptic cell membranes (Altman, 1971).

Therefore, various activities in neural development depend upon conformation of molecules and their noncovalent interactions with each other - any or all of which may be affected by extremely-low-frequency fields. Experimental support for the effects of extremely-low-frequency fields on membrane associations in non-neuronal cells has come from a long series of work on fungi by Marron and colleagues (Marron, et al., 1983). These authors exposed Physarum polycephalum amoebae to sinusoidal 60-Hz fields, at 1 V/m, applied via stainless-steel electrodes placed directly in the growth media. Perpendicular magnetic flux densities were 0.1 mT (10 G). Centrifuged cells were placed into an aqueous liquid-liquid polymer two-phase system containing dextran and polyethyleneglycol (PEG). Cells were withdrawn from the PEG-rich upper phase and counted to determine their concentration. Exposed cells were then compared with control cells. This allowed analysis via cell concentrations independently of cell numbers. Exposed cells showed a significant change in their partitioning behavior between the two liquids. Presumably, this change in partitioning can result from either a change in membrane molecular composition or surface charge. Such an in vitro system, which had previously detected mitotic delays and reduced oxidation in amoebae exposed to 60-Hz fields (Marron, et al., 1978) allows numerous advantages of experimental design which may be applied to work on extremely-low-frequency field effects on neural development.

The rat cerebellum was chosen as an experimental model for neural development because neuronal development here is very clearly outlined in the literature and development sequences are similar in man, monkey and rodents (Jacobson, 1978). In addition, Hansson had reported startling changes in the cerebellum of rabbits exposed in a switchyard to 50-Hz electric fields. Hansson (1981) could justifiably say in his report that "No morphological study has been published on the possible structural effects on the nervous system (by electric fields)." In an outdoor setting, Hansson exposed female albino rabbits to 14 kV/m lines, at 50-Hz. This is approximately equivalent to 1.5 - 2 kV/m in humans. Incidentally, this is also the electric field strength at the edge of a 365-kV line right of way. A second group was placed next to an open disconnecting switch (presumably to assess corona effects), a third group was surrounded by a Faraday cage, and a fourth group of rabbits was placed outside a measurable electric field. Exposure of females began some time (unspecified) after mating, and offspring were subsequently exposed for the first two and a half weeks after birth.

Exposed rabbits reached just over half the weights of animals kept away from any electric field, did not keep their coats clear, and "appeared slow in movement". This motor deficit led to histological analysis of the cerebellum and revealed ultrastructural changes of startling magnitude in the exposed rabbits: reduced arborization of dendrites, reduced number and size of Nissl bodies (rough endoplasmic reticulum), reduced numbers of microtubules and mitochondria, and increased microfilaments. No actual numbers or percentages for these changes were given. However, the most dramatic effect was the existence in Purkinje cells of 500–1,200 lamellar bodies which were never found, in any number, in control animals. These lamellar bodies appeared to be stacks of tubular profiles of plentiful smooth endoplasmic reticulum. In contrast, only a few profiles of normally plentiful rough endoplasmic reticulum, as noted above, could be found.

Hansson suggested that malnutrition could be the ultimate problem. This explanation is plausible in light of the severe weight reduction noted in experimental animals, but food intake records were not available for substantiation. The outdoor exposure of these rabbits also raises serious questions regarding effects of uncontrolled temperature, humidity, etc. There is almost no quantification of results or, indeed, of the total number of animals or electron micrographs examined. The claim that "marked neuronal alterations were observed in several (other) parts of the brain and retina" was made without presentation of any evidence.

Hansson's work (1981) does represent a beginning in the study of the ultrastructure of developing nervous systems, in spite of its methodological difficulties. The cerebellar cortex, including Purkinje cells, represents an excellent model for studying possible neural developmental effects, since the basic outline of its development is well researched (Altman, 1972). In an effort to confirm Hansson's findings Albert, et al. (1984) exposed pregnant rats throughout gestation at 100 kV/m [see Kaune (1979) for exposure details]. They were unable to confirm Hansson's results (Albert et al., 1985a). Electron microscopic examination of Purkinje cells in these studies showed that lamallar bodies were found in both experimental and control groups, and were present in both cell bodies and dendrites. Some animals in both groups were totally devoic of lamallar bodies.

In their 1984 study Albert and colleagues used electron microscopy to quantify synaptic contacts in the developing rat cerebellum, but no statistically significant differences were found between exposed and controls. They also did not observe weight reduction or other changes in motor control. Hansson attributed the motor deficits he observed in exposed rabbits to the presence of lamallar bodies, but the Albert results in rats make this explanation unlikely. It is possible that the presence of lamallar bodies is an artefact resulting from excessive handling or is a function of variations in exposure conditions.

In order to resolve these discrepancies in results it would be necessary to standardize exposure conditions and periods of recovery. The issue of recovery is critical. Subtle cerebellar deficits were found by Sikov et al. (1984) to be recoverable within a week, for example, and slight morphological changes may be associated with such physiological deficits as decreased righting reflexes and geotropism.

Because of the potential significance of these studies, the New York Power Lines Project funded Gona to investigate the effects of 60-Hz fields on the development of rat cerebellum (Appendix 11). Gona and his co-workers exposed pregnant and postnatal Sprague-Dawley rats to electromagnetic fields at three field parameters: 100 kV/m and 1 mT (10.0 G), 100 kV/m and 100 μT (1.0 G) and 1 kV/m and 1 mT (10.0 G).

Cerebellar Purkinje cells differentiate, migrate, and form their synaptic connections during postnatal life, so Purkinje cell differentiation and maturation were studied by exposing newborn pups for 1, 2 and 3 weeks. Since the cerebrum develops primarily during gestation, cerebral experimental studies were conducted by exposing pregnant dams continuously from days 5-20 of pregnancy. The pups from these prenatally exposed or sham-exposed dams were then sacrificed 1, 2 and 3 weeks after birth. Gona studied several other parameters of body and brain development, including measurement of gross body and brain weight, biochemical analysis of brain, including DNA, RNA, total protein and cerebroside, and electron microscopic investigation of ultrastructural changes of the cerebellum.

In this investigation Gona, in contrast to Hansson, did not observe differences in weight, motor activity and eye opening time between the control and experimental groups at the combinations of electric and magnetic fields cited above.

Electron-microscopic examination of cerebellar neurons (particularly Purkinje cells) showed no abnormalities. However, Gona did see membranous stacks resembling lamellar bodies, but these were found in both control and exposed animals. A number of biochemical parameters were also measured by Yu, co-principal investigator with Gona, but no significant differences existed between exposed and sham exposed groups. One can conclude that cell numbers as judged by DNA content, cell size (DNA/protein ratio) and myelination (cerebroside levels) were unaffected by electromagnetic fields during pre- and postnatal development. It should be noted that Gona reported that some transient increase in cerebellar DNA concentration was observed at 100 kV/m and 100 μT (1 G) on postnatal day 8 but not at other field parameters or ages. Further, at 1 kV/m and 1 mT (10 G) total protein at postnatal day 6 and DNA/protein ratio were lower. Both values reached normal levels by postnatal day 13 and 20 respectively, indicating no permanent effect. It appears that these may be chance findings or, like the cell degeneration normally seen in cerebella, may have some relation to DNA and protein levels since these macromolecules represent cell numbers and sizes.

On the basis of Gona's results, which morphologically are similar to those of Albert, et al. (1984), it is reasonable to conclude that there are no morphological alterations produced in Purkinje cells because of exposure to fields. It is more likely that Hansson observed artifacts since the animals were exposed outdoors under a substation where temperature and humidity varied widely over the lengthy duration of exposure.

2. Sensation and Perception

The association between sensation/perception and 60-Hz electromagnetic fields exists as two separate problems. The first issue is the sensation and perception of electromagnetic fields; the second issue is the effects of these fields upon sensations and perceptions. Both problems require the differentiation between the terms sensation and perception. Sensation refers to the proximal detection of a stimulus; perception refers to the response to a sensation that is based upon the learning or conditioning history of the organism. A stimulus may be sensed but not acknowledged depending upon its perceptual characteristics, whether positive, negative, or irrelevant.

For the New York State project, the initial question involved the simple question: Can people perceive electromagnetic fields? The answer is complicated. For human beings, introspection is the method of choice for the detection of a stimulus. However, a stimulus can influence human subjects without their awareness. Whether or not this is defined as "implicit detection" or an "effect" is an arbitrary definition. When non-human animals are used to test responsiveness, detection must be determined alternatively by one of two methods. Responding for reward is either contingent upon the presence (or absence) of the field or the field is used as a component of a learning sequence. In the former instance, if the animal responds during the presence of the field (but not when it is absent), detection is assumed to have occurred.

In the latter instance, detection is inferred when the field can elicit a behavior after the field is paired temporarily with an unconditioned stimulus that is known to elicit the behavior.

Detection of electromagnetic fields per se is often replete with confounding variables because both experimentally- and transmission-line-generated forms are accompanied by a multitude of other stimuli that include infrasonics, vibrations, and ions, or blatant artifacts such as electric shocks. Human subjects often attribute their experiences to the detection of electromagnetic fields simply because the label is readily available to them. However, the degree to which these concomitants contribute to "power-line effects" in the field has not been addressed.

In the present project, the Graham experiments were the major sensory perception study. Human subjects were exposed for brief periods (less than 6 hours) on two successive days to electric fields between 0 and 16 kV/m and to magnetic flux densities 0 and 40 μT (0.4 G). Detection of fields as defined by verbal (subjective) experience occurred at or above 9 kV/m when the subjects were seated. However, the threshold was variable and was influenced by a variety of expected psychophysical factors such as the rate of field strength intensification (gradual vs sudden offset), and habituation (after 3 to 21 minutes of continuous exposure). There was no detection of the magnetic field component when it was presented singly.

Despite testing on a wide variety of cognitive tasks that effectively sample all of the major psychological systems, only a few weak changes were noted. Performance on a task that required selective attention and estimations of time intervals were significantly (but weakly) facilitated during field presentations. In the former case, detection of mismatched (odd) stimuli was improved. The only significant electrophysiological change involved the P300 component of the evoked potential measure. This event occurs 300 msec after a modality-specific stimulus is delivered. It is frequently associated with the "meaningfulness" and infrequency of a stimulus. The occurrence of the effect is compatible with the enhancement of the specific type of selective attention (the increased accuracy of mismatched stimuli). The effect of the field was to maintain the "detection" or the mismatched stimuli particularly during the second day of exposure.

The results of these studies do not agree with results from other studies. Stollery (1986) passed 500 μA of 50-Hz current by electrodes through 66 male volunteers for about six hours. Each subject served as his own control. Subjects were tested on a variety of memory, attention and verbal tasks. Although there was no significant differences for these measures between field and sham conditions on the first day, on the second day the field group required more time to solve complex problems on a syntactic reasoning test. According to Sweetland et al. (1986), a singular one-hour exposure to a NMR device reduces digit span and increases anxiety. However, in both of these studies, the mode of exposure was quite different from that employed in the Graham study.

From a practical point of view, the magnitude of the reported effects is extremely small for all three studies. In the Graham study, the alteration in the P300 amplitude and the accuracy in selective attention would be less than the peak to peak change in the normal phasic arousal that occurs every 90 minutes. There was no evidence that the normal absolute peak or trough of the values changed. Similarly the alteration in syntactic reasoning reported by Stollery (1986) is within the same magnitude. The magnitude of the reduction in digit span and the increased anxiety were comparable to what might occur during a test-retest of the same average subject on a "good day" and "bad day". However larger changes in the P300 components of auditory evoked potentials have been produced by stronger 60-Hz magnetic fields [5 mT (50G)] presented near the temporal lobe (Kuzendorf, 1987)

The absolute 60-Hz detection thresholds from the Graham study are similar to those found for other species. A study by Stern et al. (1983) demonstrated that pigeons could accurately detect electromagnetic fields as cues for reward. The threshold for the 100% detection was about 8 kV/m, with a range between 4 kV/m and 10 kV/m. Rats have also been shown to discriminate field presence when gradients of this level are present. Detection of weak 60-Hz magnetic fields when behavioral criteria are used is not consistent for mammalian species. However, detection of weak power-line magnetic fields by birds is well documented.

The effects of 60-Hz fields upon the detection of intrinsic sensations is the second major problem of this research. Anecdotal reports of nociceptive threshold changes have been frequently associated with field exposures. This question is perhaps even more relevant than frank detection of fields since alterations in pain thresholds can significantly alter the quality of life in the human population. Pain detection can be influenced further by the person's personality profile.

Ossenkopp, Cain and their colleagues (Ossenkopp, et al., 1983; 1985) have demonstrated on several occasions that magnetic field (0.5-Hz) exposures can block the analgesic effects of morphine. Their typical paradigm is to expose the animal to a magnetic field for about an hour, inject the animal with morphine and then determine pain thresholds—usually under blind procedural conditions. The magnetic-field-induced blocking (1) is maximum when the animal is tested at night, (2) is similar to a few minutes of exposure to bright light during the dark cycle, and (3) is influenced by the amount of geomagnetic activity (magnetic storms) at the time of experimentation. The effect is apparent with primary opiate receptors (mu, delta) but not with other opiate receptors (sigma). The mechanism seems to be calcium-mediated (Kavaliers and Ossenkopp, 1986b).

For the present project, Ossenkopp and his group exposed mice to various intensities of 60-Hz fields; the magnitudes were similar to those that might be experienced very near power lines. An intensity-dependent effect of the 60-Hz magnetic field exposures on morphine analgesia was noted. Exposure to the power-line frequency during the night period reduced the effectiveness of the morphine analgesia for painful stimuli. As noted in the previous studies, the blocking effect of the 60-Hz field on the analgesic effects of morphine wase not observed when the animals were tested during their daylight cycle. Similar results were obtained by Ossenkopp et al. (1985 a and b) in a study in which mice were exposed in a magnetic-resonance-imaging apparatus.

That brief (less than 10 hours) exposure to power-line- frequency electromagnetic fields has effects on sensation, perception and related behaviors suggests three major conclusions: (1) accurate detection of the presence of an electric field by subjective means begins around 9 kV/m but the threshold is quite variable depending upon a variety of physical parameters, (2) 60-Hz fields can influence pain thresholds, particularly if the noxious or nociceptive experiences occur during nocturnal periods (3) 60-Hz fields do not radically alter cognitive activities in a manner that is obviously associated with processes that might affect higher intellectual functioning. The caveat is that these conclusions apply to normal subjects.

3. Cellular Neuroscience and Calcium

Much of the literature on electrical field effects on the nervous system has focused on the physiologically important calcium ion. For example, Bawin and Adey (1976) claim that efflux of radiocalcium from chick neonatal cerebrum is reduced by electric fields. These results were contradicted by Blackman et al. (1979; 1982) who claimed an increased efflux under similar conditions. Neither of these studies dealt with any physiological parameter which might be calcium dependent nor did they look specifically at intracellular ionic calcium - which is the "active" form of calcium in the cell though quantitatively only a very small fraction of the total cellular calcium. This differentiation is important since the calcium efflux studies measure the amount of radioactive calcium, previously introduced into the tissue, that washes out of the tissue after exposure to a given experimental protocol. The source of the calcium is not readily identified. It could be calcium which is exported from the inside of the cell or, more likely, may represent calcium bound to fixed charge sites in the extracellular matrix.

In the study of Gundersen (Appendix 5), spinal cord neuron-muscle cultures were exposed to circularly polarized fields of 100 μT (1 G) and electrical fields of 30 kV/m (air equivalent) (See also Gundersen and Greenbaum, 1985). No changes were found in calcium efflux from these cultures with electric, magnetic or combined fields. These studies were not comparable to the Bawin and Adey studies in that Gundersen labeled for 72 hrs in contrast to the 20-minute period used by Bawin and Adey. In shortened labeling times much more of the calcium would be bound to extracellular cell surface glycoproteins and matrix and to peripheral intracellular compartments from which it might be more readily affected by the applied fields. Neither of these measures would give an adequate measure of intracellular calcium or of physiologically important calcium currents. On the other hand, Gundersen found that linearly polarized magnetic fields increased the frequency of miniature endplate potentials (mepps) at the neuromuscular junction while circularly polarized fields were without effects. The effect was seen at 60-Hz, but not at 70-Hz. These differences are as great as 23% when perpendicularly polarized fields are used. These results reflect an increased quantal release of packets of acetylcholine from the presynaptic neuron. This release is known to be affected by calcium and it is possible that the effect might mirror calcium ion changes or changes in membrane responsiveness to calcium ion in the presence of magnetic fields.

The physiological implications of this increase in mepp frequency are hard to evaluate, though if a global phenomenon it would require an increased cellular synthesis of acetylcholine. As long as the number of mepps did not reach the threshold needed to trigger an action potential in the muscle, there would be no effect on muscular activity.

4. Biological Rhythms

A diurnal or approximately 24-hour variation in functional amplitude is characteristic of all systems within the human body. This variation is usually called the "circadian rhythm". It is not a singular phenomenon but a complex of separate rhythms that are normally phase-locked. In addition, they often share exogenous "zeitgebers" or timegivers that synchronize the daily peaks and troughs of the cycles. Three major types of dysfunctions can occur: (1) alterations of cycle duration, (2) shifting (lagging) of the peak of the cycles, or (3) an uncoupling between cycles.

Dysfunctions in circadian rhythms are important because they can profoundly affect psychological and biochemical processes. Alterations in phasic attention and concentration following sudden shifts in circadian rhythms increase the risk of industrial accidents. Subtle seasonal shifts in the amplitude or the hour of the daily peaks in circadian cycles are major correlates of a clinical subtype of psychological depression and are also frequently associated with a compromise in immunocapacity.

The effects of electromagnetic fields upon circadian cycles have focused upon two major areas: behavioral measures and the biochemical activity of the pineal organ. Typical behavioral measures have included diurnal variations in activity, body temperature, and consumptive activity. The biochemical activity of the pineal organ has been studied because of its well known role as a modulator of neuroendocrine function. One of its constitutents, melatonin, is a special metabolite of serotonin. The two synthesizing enzymes for melatonin are uniquely found within the pineal organ. Both the concentration of melatonin and the activity of the synthesizing enzymes demonstrate a conspicuous diurnal variation.

The pineal organ has a ubiquitous control over the gonads, thymus, adrenal gland, and thyroid. A sudden decrease in (nocturnal) melatonin has been suggested as a factor that initiates puberty. Increases in melatonin level tend to promote periods of decreased vigilance or to extend the duration of normal sleep. Disruptions of melatonin are associated with dyssomnia.

The relevance of melatonin to the 60-Hz problem is highlighted by recent observations that the pineal organ is sensitive to near-natural magnetic fields in pigeons and rats (Semm, 1983). Moreover, sensors in the retina may mediate the effect of magnetic fields to pineal structures (Olcese, et al 1985) either via paraoptic fibers to the intrinsic pacemaker of the brain (the suprachiasmatic nucleus) or through more general descending sympathetic pathways. Recent evidence suggests that the magnetic-field effect upon melatonin synthesis may be amplified by weak ambient red light (Reuss and Olcese, 1986). This unusual observation may help explain why in the Ossenkopp study magnetic fields block morphine analgesia only at night when the animals are exposed to a 100 μT (1 G) magnetic flux density.

The problem of effects of power line intensities on behavioral indices of circadian rhythms was studied by Sulzman and Murrish (Appendix 7). This study had several important characteristics. Three levels of electric field intensity were employed: 2.6 kV/m, 26 kV/m and 39 kV/m, each accompanied by a 100 μT (1 G) magnetic field. This design allowed the possible detection of at least rudimentary intensity-dependent effects. In addition the animals were exposed for substantial periods (two weeks) to the fields during direct measurement of the behavior; this allowed potential detection of both acute and chronic changes. Finally, because the same animals ultimately received the different field conditions following an initial baseline period, residual effects could also be detected.

The physiological model involved the use of free-running circadian rhythms; this means that the primary zeitgebers, light/dark cycle, temperature and noise, were held more or less constant during the experiment. The advantage of free-running compared to entrained rhythms is the former's susceptibility to influence by subtle environment effects; both electric and magnetic fields have been shown to influence free-running rhythms in mice and man (Dowse and Palmer, 1969; Wever, 1974). Entrained rhythms, which means that the animals are exposed to a driving, light-dark cycle while the fields are applied, appear to be relatively resilient to significant disruption.

Specific beh..iors measured by Sulzman and Murrish included oxygen consumption and feeding as defined by the number of lever presses per unit time during the day. The advantage of these two measures is their synchronicity and potential for "uncoupling". The disadvantage of these two measures is their dissimilarity to the activity and body temperature measures used by Wever. This prevents a direct comparison of the two studies despite the similarity of the human and squirrel monkey models.

The methods of analysis involved the use of both nonparametric and parametric statistics. The use of both methods reduced the risk of missing phenomena that were not linear or masking phenomena that were very weak. However, if a phenomenon was weak and non-linear it could have been still overlooked. The specific measurement was the absolute temporal shift in the peak of activity (acrophase) over real time during the period of exposure.

The results showed an intensity-dependent effect. None of the monkeys exposed to the 2.6 kV/m fields demonstrated any change in the free- running periods of lever pressing (feeding) or oxygen consumption. On the other hand, 33% of the monkeys exposed to the 26 kV/m fields and 75% of the monkeys exposed to the 39 kV/m electric fields showed a significant lengthening of period. Although the number of animals in each treatment was small and variable, the intensity-dependence appears reliable. Interestingly, even though the monkeys exposed to the lowest intensity did not show a significant increase in periodicity, the values were longer than the free-running periods during non-exposures.

Sulzman and Murrish also reported apparent chronic or long-term effects from exposures to the higher intensity electric fields. This conclusion was based upon the failure of the animals to return to pre-exposure free-running values when the animals were followed for several fortnights (post-exposure) under ambient fields. The validity of this observation was supported by the relative absence of its occurrence in the history of their laboratory. In addition, the "irreversibility" of magnetic field effects (in particular) has a relatively long history. It was most recently reported by Wolpaw and Seegal (Appendix 17) for monkeys that had been exposed chronically to either 3 kV/m, 10 μT (0.1 G) or 30 kV/m 90 μT (0.9 G) fields for 21 days. Whereas the metabolites of serotonin and dopamine were both suppressed in the cerebral spinal fluid, only the latter returned to normal after removal from the fields. The metabolite of serotonin remained depressed.

The results of the Sulzman study differ from Wever (1974) in one important aspect: field exposures were associated with an increase in free-running rhythm duration rather than a shortening. However, Wever used a 10-Hz, 2.5 V/m square-wave field compared to sine-wave 60-Hz fields with both magnetic [100 μT (1 G) and electric (26 kV/m or 39 kV/m) components. In addition Wever measured body temperature and activity in ambulatory humans (living in an underground bunker) while Sulzman and Murrish measured the oxygen consumption and lever pressing of relatively restrained monkeys.

Two other differences occurred between the two studies. First, Wever reported that a reduction in free-running rhythms occurred in all of his subjects; the effect was duration dependent (i.e., the greater the time of free-running, the greater the effect of the field). The present study showed that some animals did not show any significant changes, and those that did did not exhibit a duration dependence of their response. Secondly, Wever reported clear uncoupling of the two rhythms (activity and temperature) while Sulzman and Murrish reported no uncoupling.

The effects of 60-Hz electromagnetic fields on melatonin synthesis *per se* was not addressed in the New York State projects. However, several recent studies have indicated that a variety of field conditions inhibit melatonin production. Alteration in the normal geomagnetic field (Olcese and Reuss, 1986), application of a 100 μT (1 G) field in the presence of red light (Reuss and Olcese, 1986), and electric fields of about 8 kV/m or greater have been shown to suppress pineal activity. Recently, even weaker electric fields (1 kV/m) were shown to suppress melatonin synthesis (see Wilson et al., 1986).

In summary, the major results of these studies concerning the effects of power-line fields on circadian-related systems suggest that long-term exposure to electromagnetic fields can shift or induce a lag in intrinsic rhythms. These shifts may be chronic once they appear. On the other hand, power-frequency electromagnetic fields tend to affect melatonin synthesis within minutes; however, the effect is transient and reversible within a few hours to days.

5. Seizures, Evoked Responses and Neurochemistry

Research into all aspects of epilepsy has expanded rapidly in recent years, and the extraordinary diversity and complexity of epilepsy research has been recently reviewed (Delgado-Escueta, et al., 1986). There is now an impressively long list of physical and chemical agents that can alter seizure likelihood and expression. The studies of Ossenkopp & Cain (Appendix 12) indicate that magnetic fields must be added to the list. Specifically, the mortality of pentylenetetrazol-induced seizures in rats is significantly decreased with flux densities of 100-150 μT (1.0-1.5 G) for 1 hour and the development of kindled seizures and electrical after-discharge in rats are decreased with flux densities of 100 μT (1.0 G).

The results do not indicate possible mechanisms producing these effects. Although these data suggest the possibility of salutary effects in human patients with epileptic disorders, it cannot be inferred that there are no conditions of exposure which would make seizures worse.

The fact that magnetic field exposure changes seizure susceptibility even after the exposure has been terminated argues for a mechanism involving alteration by the fields of brain hormones. Ossenkopp suggests that opioids may be responsible. His studies on alteration of morphine-induced analgesia by magnetic fields (Kavaliers and Ossenkopp, 1986 b and c) clearly point to the endogenous opioids under those conditions, and make the presumption of opioid mechanisms in the epilepsy experiments more attractive. The epilepsy model is, however, inherently much more complex, in that the involvement of many more naturally occurring substances has been postulated. Investigations into electrical and chemical kindling have shown evidence for participation by a wide variety of substances including catecholamines, serotonin, dopamine, opioids, cyclic nucleotides and calcium-dependent proteases in the pathogenesis of the kindled focus.

The data from Ossenkopp & Cain, however, do not suggest a hazard to people, with or without seizure disorders, who are exposed to magnetic fields. The apparent beneficial effect is, however, an interesting clue to mechanisms of both seizures and field effects, and as such deserves further study.

Wolpaw and colleagues (Appendix 17) studied the effects of electric plus magnetic fields on 10 pig-tailed macaques (Macaca nemestrina). They demonstrated attenuation of the late components of the somatosensory evoked potentials (SEP) recorded from stimulation of the median nerve. Auditory (AEP) and visual (VEP) evoked responses were normal, but a smaller number of stimuli were required for the AEPs and VEPs than for the SEPs and the authors suggest that, since components of the late peaks of the evoked potentials relate to mechanisms of attention, abnormalities might have been noted only after a large number of stimuli (and therefore, in their studies, for SEPs only). They point to evidence for the importance of opioids in attention mechanisms and postulate a connection between these results of decreased amplitudes of late SEP components and the findings of Ossenkopp on field effects on morphine analgesia, also felt to relate to changes in endogenous opioids.

In the Wolpaw studies, a great many measures of well-being of the macaques were recorded, including weight, blood-cell counts, blood chemistries and tests of motor skill, and no significant effects of the fields were encountered. In addition, there were no changes in the gross neuropathology in the brains of the 5 autopsied animals. The only consistent effect of the fields, except for the decrease in the late components of the SEP, was in the amount of homovanillic acid (HVA) and 5-hydroxyindoleacetic acid (5HIAA) in the cerebrospinal fluid (CSF). In both cases, there were significant decreases and since these substances are major metabolites of dopamine and serotonin, respectively, the question of effect of fields on metabolism of these important biological amines is raised. After a period of recovery following field exposure, the CSF HVA returned to normal, but the 5HIAA remained depressed. Wolpaw's studies leave unresolved the important question if the effects of fields on biologic amine metabolism correspond to abnormalities in learning or other behavior.

The electroencephalogram (EEG) per se was not studied in any of the New York projects. There is evidence that magnetic field intensities of current magnetic resonance imaging (MRI) equipment produce no changes in the EEG power spectrum in human subjects receiving brain MRI imaging (Bartels, et al., 1986).

6. Learning and Memory

Learning and memory are two complex processes that allow a person to adapt to the environment as a consequence of experience. Learning refers to the dynamic state during which time information is acquired, processed and consolidated. Memory refers to the capacity to display evidence that learning has occurred once the learning situation has been removed. Direct measurements of either learning or memory are difficult because they are manifested as performance variables. Performance can be influenced by motivation and emotional behaviors.

Two questions have been asked: (1) can electromagnetic fields affect learning and (2) can electromagnetic fields be integrated into a learning sequence? Two basic approaches have been employed to answer the first question.

One approach involves the consequences of short-term exposures to electromagnetic fields upon adult learning. A second approach involves exposure of the developing organism to fields and the later determination of learning or memory deficits. Answers to the second question utilize procedures by which the electromagnetic field is tested as a cue. The most typical model involves "state-dependent memory" whereby responses occur only in the presence of a field because they were acquired when the field was present.

Three separate projects addressed these problems. The Thomas and Liboff (Appendix 8) study evaluated the effects of brief exposures on adult learning; (2) the Salzinger study (Appendix 14) evaluated the effects of prenatal 60-Hz field exposures on adult learning, and (3) the second part of the Ossenkopp and Cain study (Appendix 12) determined the efficacy of the field as a learning cue.

The original Thomas protocol was composed of two phases. The first involved exposures to 50, 100, 300 or 500 μT (0.5, 1, 3, or 5 G) 60-Hz magnetic flux densities with and without a 1 kV/m electric field for 30 minutes. Some of the exposure combinations were extended to one hour. The second phase involved intraperitoneal injections of either amphetamine (1 mg/kg) or chlordiazepoxide (10 mg/kg) just before the 30-minute exposures to the fields. This procedure allowed the potential discrimination of three potential levels of synergism or non-linear interaction: (a) between the magnetic field and the electric field, (b) between the magnetic field and the drugs, and (c) between the magnetic field, electric field and the drugs.

Selection of the specific parameters for the field conditions and injections had the following advantages and disadvantages. The four magnetic flux densities allowed the detection of potentially intensity-dependent behavioral responses. The single electric field value was a limiting feature of the study as well as the single dosage for each of the drugs. However, higher electric field values may have compromised the design limits of the apparatus and the drug dosages were well within concentration range of maximum interaction with other substances.

As a consequence of some theoretical considerations and after there had been no obvious detection of field effects in the first two phases, a third phase of the study was conducted that involved reduction of the ambient static geomagnetic flux density from 40 to 26 μT (0.40 to 0.26 Gs) and the superimposition of a 60-Hz magnetic field of 50 μT (0.5 G). This design was considered to be important because of theoretical models and empirical studies with tissue preparations (Blackman et al., 1985).

The measurement involved an operant procedure with the animal learning to respond to obtain a reward that is presented as a function of the number of responses or the time of not responding. Operant procedures have the advantage of generating discrete, multiple measurements and data can be collected under relatively controlled conditions. A disadvantage is that a substantial amount of learning history is required for each animal before the treatment is begun, so that the behavior can become so conditioned that a particular procedure may be relatively insensitive to weak effects.

The specific method of measurement involved a multiple fixed ratio (FR) and differential reinforcement of low rate of responding (DRL) reinforcement schedule. In this instance, the FR was a FR 30 which means the animal had to display 30 responses (bar presses) before a reward was delivered and the DRL value was 18 which meant the animal could not respond for at least 18 seconds before a single response resulted in the delivery of reward. If the animal responded prematurely, the option for reward was delayed another 18 seconds. The animal had to further associate specific chamber cues (the color of a light plus the presence or absence of a tone) with the particular schedule. The FR schedule generates high rates of responding while the DRL generates low rates of responding. An additional complexity of this procedure required the rat to not respond when all of the chamber cues were removed; a response at that time delayed the onset of the next schedule of reinforcement.

This multiple FR/DRL procedure is far superior to the single-schedule techniques that were used previously (de Lorge & Marr, 1974; Persinger, 1974). By the intrasession sequencing of schedules that facilitate high rates of responding, daily artifacts coupled with motivational factors can be reduced. In addition it allows for the differentiation of a general effect on behavior (both schedules being influenced) versus a specific effect on behavior (only one schedule being influenced). This distinction provides the first step for pursuit of mechanism. Whereas the FR schedule has been used to infer such conceptual processes as "perseveration" or schedule-induced "drive", the DRL is considered to be one of the best measures of the inferred process of "inhibition".

The selection of the FR/DRL schedule had a second major advantage that complemented the selection of two antithetic drugs along the stimulant-relaxant continuum. In addition to producing two distinct but common physiological states, these drugs influence behavior by separate but general agonist-receptor mechanisms. Thus not only the interaction between drugs and magnetic fields could be detected by this model but also the differential effects of this interaction on one of the two schedules could be detected.

The method of assessment of any treatment effect was intersession comparisons. This means that the behavior following a field exposure day (usually either a Tuesday or Friday) was compared to that of the other sessions. The advantage of this procedure is that a putative effect must exceed daily baseline oscillations. The primary measurement was response rate. The advantage of using response rate (usually responses/minute) is its numerical values; its disadvantage is the effects of averaging and neglect of variable responding within the time frame. However variable responding can be observed by noting the inter-response times which are the times between responses. When the time between successive responses is plotted on the X axis and the numbers of responses with those times are plotted on the Y axis, a spectrum is obtained which allows the experimenter to perceive the composition of the temporal properties of the responses that composed the average measure (response rate). Both measures were used in this study.

The criterion for acceptance of a treatment effect was based upon the "systematic" change of behavior following field and/or drug treatments compared to baseline days. The advantage of a systematic change criterion is its reliability and simplicity. The disadvantage is that treatment effects that emerge as interactions from hidden factors are ignored. In addition, even an effect that occurs once every three times can be excluded. A systematic criterion usually excludes statistical analyses because the effects are blatantly observable.

The results of the exposures to the 60-Hz magnetic fields with and without the electric field and these conditions with and without either of the two drugs did not show either direct or interactive drug/field effects. The baseline and dispersion measures for the daily variations of responding for each of the two schedules were within acceptable ranges. The response rates and percentage change in response rates for the effects of the two drugs were comparable to results from the literature and indicated that the rates and the effects of drug dosage that were used in this study were representative of the normal population.

By far the most profound effect was the change in DRL behavior but not FR responding in rats that were tested after 30 minutes of exposure to a 60-Hz magnetic field plus a reduced orthogonal magnetostatic flux density of 26 μT (0.26 G) (about half of the background static earth's field). The major effect was an increase in response rate and a shortening of the inter-response time. This meant that the rats responded more quickly as if there had been an impairment of temporal discrimination; however an alternative hypothesis is a transient failure in some inhibitory process. The phenomenon was brief because it was present for at least an hour during the test period but not present 24 hours later (the next test period).

The empirical validity of the effect is suggested by its specificity to one schedule (DRL); this suggests the influence was not a general effect on behavior. The discriminate validity is also suggested because the effect was found only with the presentation of the 60-Hz field plus the reduced magnetostatic field and not with either the static field or the oscillating field when presented separately.

There are two levels of reliability. The first involves the occurrence of the effect in 5 of the 5 animals tested, although a conservative criterion would involve 4 of the 5 animals. Calculations from Appendix 8 showed that the mean relative increase in response rate following the 60-Hz plus reduced field exposure for all 5 exposures for each rat and for all 5 rats was 29%; the range of response facilitation (or "breakdown in inhibition") was 9% to 44%. Within each rat's performance the increase of response rate was similar to that of the group. In other words, the distributional characteristics within each animal were similar to the distribution of the group. This is a strong indicator of the robust nature of a phenomenon.

The lack of single source magnetic field effects upon DRL and FR schedules found in this study is similar to that reported by other major researchers over the last decade. Although the effect of the 60-Hz fields plus the reduction in the geomagnetic field appears to be new, it is not without conceptual replication (Blackman et al., 1985; Leal et al., 1986; Smith et al., 1987). In addition, Persinger (1974) showed that rats who were maintained on a DRL 20 schedule and who were exposed to an 0.5-Hz field also showed an increase in response rate over baseline values; the effect only lasted for about 24 hours despite continuous exposure. The type of equipment used to generate the fields was also shown to attenuate the local static field component. Both Rocard (1964) and S.W. Tromp in his classic text, Psychical Physics (1949), emphasized the importance of interaction between background magnetostatic field intensity and oscillating fields for their "detection" by human volunteers.

The Salzinger study (Appendix 14) emphasized the effects of preperinatal exposure to 60-Hz fields upon adult behavior in a specific operant paradigm. The term 'preperinatal" defines the time of exposure: about one day after conception to 8 days after birth. The pregnant mothers were exposed to either 30 kV/m electric fields plus 100 μT (1 G) magnetic flux densities, 10 kV/m electric fields plus 33.3 μT (1/3 G) magnetic flux densities or sham fields. Because there were only two exposure devices and the design was based on a reference group (groups that developed in one apparatus compared to other), the experimenters used either the full-field condition in one apparatus and no field in the other (sham condition) or the full field in one apparatus and the 1/3-field condition in the other.

The basic measure was behavioral. Each rat learned to press a lever for food reward that was delivered intermittently in time. The intermittent delivery was random, such that despite the animal's display of responses, only one response was followed by food reward every so often. For example, if the schedule was a random interval (RI) 10 sec, the animal received a response contingent reward on the average every 20 seconds although the time between rewards varied between 1 and 40 seconds. This type of reinforcement schedule generates a relatively smooth and consistent response rate and has been used extensively in studies that require a "smooth baseline" or slope for measurement.

Salzinger's group utilized a sequence of random intervals that ranged from 10 sec to 180 sec. The change in random interval schedule was cued in the appropriate number of shifts such that there was little "carry-over" between random schedules (i.e., the animal's responses on the different schedules were similar to the behavior they would have displayed if they had been only trained on one of the schedules). This allowed a type of "dose-dependence" of schedules by comparing different rates of the presentation of rewards in time. The procedure effectively increases the operational number of measurements for each animal plus allows determination of any interactional or differential effects from power-line field treatments. This is useful for isolating mechanisms.

Salzinger began testing his preperinatal animals at 90 days of age. The occurrence of the significant field-attributed effects did not appear reliably until after the 20th session and remained relatively stable for at least another 30 sessions to the end of the study. The largest discrepancy between the sham-field animals and the field-exposed animals occurred with the shortest intervals of intermittent reinforcement (RI 10 and RI 20). However, the absolute magnitude of the effect was not greater than 20%. The response rates of animals exposed to extremely-low-frequency fields were about 20% less than that of the sham-field controls. A sensible explanation for the lag in the occurrence of the effect is not clear.

The possibility that electromagnetic fields could be used as "cues" for the occurrence of a physiological state was eloquently shown by Ossenkopp and Cain (Appendix 12). They preexposed mice to a 0.5-Hz magnetic field before daily morphine injections for about 10 days. Normal tolerance appeared. When the animals were exposed to a non-field condition before the morphine injection, sensitization to the drug returned. A similar dependence between the environment of morphine injection and the "learning" of tolerance has been blamed for some "accidental" drug overdoses. Ossenkopp and Cain found that a 60-Hz field could also act as a weak "cue" for the development of tolerance although it did not seem to influence the tolerance directly.

In summary, power-line-intensity electromagnetic fields do not appear to influence even the most complex operant schedules during adult learning situations. However, interactions between background geomagnetic field conditions and the 60-Hz magnetic component can influence behavior. The effect is transient and reversible. On the other hand, prenatal exposure to these fields produces more or less permanent changes in response activity. The meaning of the effect is obscure and its onset requires a long history of testing. Finally, 60-Hz fields can become cues that control the occurrence of behaviors, including those that involve tolerance to drugs.

7. Nerve Regeneration

Axonal growth is one of the most fascinating research areas in developmental neurobiology. Though the precise mechanism of axonal growth is still unclear, some biological aspects regarding the matter are being revealed. Axonal growth can be modulated by altering cationic flow through neuronal cell membrane. The neurite growth in pheochromocytoma cells (PC-12 cells) is affected by various extracellular concentrations of Ca^{++} and Mg^{++} (Koike, 1983). Higher concentration of Ca^{++}, however, may inhibit neurite growth as seen in isolated molluscan neurons (Kostenko et al., 1983). Other monovalent cations, like K^+ and Na^+, also play a very important role in modifying ionic flux through neuronal cell membranes of chick and mouse sympathetic ganglia and dorsal root ganglia (Skaper and Varon, 1980; 1981, 1983). Grinvald and Farber (1981) have demonstrated calcium action potentials at or near the growth cone of neuroblast cells. These findings indicate that axonal growth may be regulated by electrochemical phenomena (like ionic binding and membrane transport) involving neuronal cell membranes.

a. Cellular Growth: Axonal and/or neurite growth can also be modulated by artificially induced electromagnetic (especially DC) fields. It is now apparent that several cell types in addition to neuronal cells, respond directionally to electromagnetic fields. These cells under normal conditions of development travel from their point of origin to their final destination and apparently do so in response to endogenous electromagnetic fields. Examples of such cells are neurons (Jaffe and Poo, 1979), myoblasts (muscle cells) (Hinkle et al., 1981), fibroblasts (Erickson and Nuccitelli, 1984) and epithelial cells (Luther et al., 1983). As observed by Jaffe and Poo (1979), muscle and fibroblastic cells move towards the cathode more than the anode. Not surprisingly, the field strengths that can alter the directional migration rates of cells are very small (~ 7 V/m).

It should be made clear that migration of growth of neurites and other cells towards the cathode is a quantitative phenomenon involving static (DC) electric fields. It is also becoming apparent that minute electric fields stimulate neuronal cells to differentiate into neurons and promote neurite growth. Sisken and Smith, (1975) reported that not only do neurites of trigeminal ganglia grow towards the cathode but also that electric fields enhance neuronal survival time in cultures. Patel and Poo (1982) observed that pulsed electromagnetic fields had effects on neurite growth similar to direct currents. The mechanisms underlying these observations are not fully known, but clearly calcium ions play an important role. This in part can be substantiated by eliminating extracellular calcium ions or adding calcium ion-channel blockers such as lanthanum.

Pilla (1979) has championed the view that pulsed electromagnetic fields perturb the electrochemical properties of cell membranes. With the application of pulsed electromagnetic fields, enhanced healing of recalcitrant bone fractures (Bassett et al., 1982), DNA uncoiling, inhibition of bone-cell responses to parathyroid hormone (Luben et al., 1982) and RNA transcription in salivary gland chromosomes (Goodman et al., 1983) have been reported. Albert et al. (1985b) have observed that 7-Hz pulse-train-type fields affect neuronal and neurite attachment and length of neurites. These appear to be an interplay between pulsed electric fields and exogenous nerve growth factor. Based on the above discussion, one can conclude that static and pulsed electromagnetic fields do affect cell growth, differentiation, survival and directional migration. Furthermore, calcium ions play an important role in this phenomenon. However, much more research needs to be conducted before the issue of mechanisms and hazards, if any, can be rationally discussed.

b. Peripheral Nerve Regeneration: Great interest has developed recently in the possibility of enhancing peripheral nerve regeneration by exogenous electric fields including extremely-low-frequency fields. While nerve regeneration differs at least in some respects from the original development of the peripheral nervous system, regeneration is thought to depend on some of the same processes, including directed axonal migration, Schwann cell direction, and interaction with muscle-fiber membrane proteins (Seil, 1983). During the last two decades investigators have cut a motor nerve, sutured it in place, and attempted to monitor regeneration by histological analysis of the nerve or the performance of the reinnervated muscle. While some of the investigators, using various electromagnetic parameters, have had varying successes, their explanation of experimental conditions has often been so ambiguous as to defy analysis. Two recent reports - with quite different results - have more clearly specified experimental conditions, including the frequencies and wave-forms of fields used.

Ito and Bassett (1983) cut and re-sutured both sciatic nerves in female Sprague-Dawley rats. The animals were placed in body casts, and placed either inside magnetic coils (exposed animals) or at least three meters away (control animals). After prolonged exposures they studied both the histology of the nerve and performance of reinnervated muscles (gastrocnemius and soleus) for the success of regeneration. Distance traveled by viable axons past the cut stump was also recorded. Intracellular content was evaluated qualitatively. The mean load lifted by both hind legs was also determined by fixing the hind legs into a standard position and placing a load cell on the feet.

Ito and Bassett claim that, in comparison to control rats, animals exposed for either 12 or 24 hours per day had superior nerve regeneration. Experimental nerves had a greater migration of fibers past the distal stump; strangely, the actual distance was greater in rats given 12-hour daily exposures than in those given continuous exposures. While distances traveled by the regenerating nerves were significantly greater in both experimental groups than in controls, there was no significant difference between the experimental groups. Axon numbers and diameters were larger in the experimental rats, but the actual figures were not given. Similarly, interaxonal collagen was simply stated as having "appeared greater" in exposed animals. Functional tests showed no differences in mean loads until 12 weeks of exposure, when the exposed rats' hind limbs supported more than double the mean loads of controls. The four rats that were not operated upon but were placed in casts had less ability to lift loads than untreated rats, but the differences were not significant.

While these results seem clear-cut, certain aspects of Ito and Bassett's technique are prone to error. However, these criticisms may be directed at all attempts to study nerve regeneration in an in situ system. Specific details and raw data on axon counting are not given, and the histological examination of each cross-section did not appear to be complete. Muscle testing was prone to errors in exact positioning of hind legs; and measured strengths may depend on factors other than the extent of nerve regeneration, such as animal size, age and pre-experimental activities. Cutting both sciatic nerves in each animal gives the investigators more data for each animal, but prevents one from having a control muscle or nerve in the same animal, which could be useful in both functional testing and neuronal histological evaluations. It might be more revealing to cut only one nerve and, instead, use the uncut nerve and muscle as a control rather than another animal.

A similar study by Orgel, et al. (1984) failed to find any enhancement of peripheral nerve regeneration by electromagnetic fields. These authors note, however, species differences and important differences in frequencies and wave-forms. In this study, rats were exposed to 15- or 72-Hz fields for a total of 12 weeks. To measure the extent of regeneration in the single nerve cut in each animal, Orgel et al. did histological analysis of the nerve as well as the ability of the nerve to conduct the retrograde transport of horseradish peroxidase (HRP), a substance whose reaction product can be visualized with light and electron microscopes. Also, electrophysiological recordings were made of the reinnervated muscles, comparing them with preoperative recordings.

In contrast to Ito and Bassett (1983), Orgel et al. found no significant differences in nerve regeneration between either exposure group and controls or in axon diameters or densities, HRP transport to the spinal cord, or muscle compound action potentials.

Species differences, as well as differences in frequencies and wave-form, may explain the discrepancies between investigations as may the details of experimental techniques. In addition more needs to be learned about standardizing the actual field strengths of extremely-low-frequency fields experienced by the animals or tissues of interest.

VI. SUMMARY

In this section we focus on effects that have been found in the New York-funded projects and which seem worthy of further consideration because of their possible implications for human health.

A. MAGNETIC FIELDS

It is clear from the results of the studies sponsored by the Project, as well as from many other recent studies, that both 60-Hz electric and magnetic fields can affect certain biological systems. Magnetic field effects were found in a number of the projects in this program. However, the mechanisms responsible for these effects are unknown. Many effects have been observed at magnetic flux densities in the neighborhood of 100 μT (1 G) or greater. These levels are similar in magnitude to the maximum magnetic flux density directly beneath power transmission lines. Lower magnetic flux density thresholds for most observed field effects have not been determined.

The epidemiological studies raise the possibility that magnetic flux densities one one-thousandth of those shown to have effects in laboratory studies may be a health concern. For several reasons, including the fact that a causal relationship between weak magnetic fields and cancer has not been established and that methodological uncertainties associated with quantifying magnetic field exposure levels exist, we cannot offer a recommendation based on the epidemiological studies. Except for houses close to power transmission lines, the major sources of magnetic fields in homes are the ground return currents from distribution systems and fields in the immediate proximity of appliances.

B. NEUROBIOLOGY AND BEHAVIOR

At the onset of this project there was serious question as to whether there were demonstrable neurobiological or behavioral effects of exposure to electrical and/or magnetic fields. Data accumulated by our contractors as well as a rapidly building literature on retinal magnetoreceptors in birds and mammals leave little doubt that such effects can be observed in well designed experiments.

In contrast, our knowledge of the mechanisms by which these effects are mediated has not advanced significantly. One hypothesis is that several of these effects are mediated via endogenous opioids. However, no data have been obtained to either support or deny this hypothesis. Other effects could be mediated or modulated by changes in the levels or intracellular localization of ionic calcium. The alterations in miniature end plate potential frequency by magnetic fields could be due to small changes in internal ionic calcium. Efflux of calcium from multicellular nervous system preparations reported by other laboratories reflects effects on extracellular calcium, and the physiologic relevance of this calcium store is unknown.

The reliable and specific effects of brief exposures to 60-Hz magnetic fields within a decreased geomagnetic background deserves further attention. Interactions between 60-Hz magnetic fields and the intensity and direction of the static background fields have been suspected by many authors and may be an important source of the variability in occurrence of magnetic field effects. The magnitude of the effect from exposure to the combination of 60-Hz magnetic fields and a reduced geostatic field suggests that geomagnetic fields may interfere with inhibitory behaviors. They would be displayed in situations that required dependence upon subjective estimates of timing and the suppression of impulsive responses.

Our studies have not shown any structural neuropathology in either developing or adult animals. We do not feel that there is a significant risk of structural change at the field intensities normally produced on the ground by power-lines.

Accepting that biological effects result from field exposure we are faced with deciding whether these effects might lead to adverse health effects. For most of the findings it must be emphasized that the changes are relatively small. However, some changes, such as the depression of hydroxyindole acetic acid levels in the cerebral spinal fluid seen by Wolpaw and Seegal, are extremely long lasting. The alterations in circadian rhythms are interesting in that such alterations can be associated with alterations in mood and behavior of subtle types. It is possible that these changes could underlie some of the rather "non-specific" changes which have been reported in the occupational literature in electrical switchyard workers. Certainly, circadian rhythms might be much more suitable parameters to monitor in occupational studies than the more vague subjective responses. A more dramatic effect of fields was the demonstration of a persistent deficit in the response rates of adult rats that had been exposed before and just after birth.

In our studies, no neurobiological effects were seen at field intensities lower than those encountered within the existing right-of-ways of 345- or 765-kV lines. Even those effects encountered were of reasonably small amplitude and could not be said with confidence to indicate health hazards. Our studies are limited in that many of them did not explore weaker magnetic fields or obtain adequate data to determine dose-response characteristics.

C. CANCER

Previous epidemiologic studies on adult and childhood cancer have been questioned because of serious methodological shortcomings. The results of the Savitz study on childhood cancer changes the situation considerably because it was designed to minimize flaws in previous studies, and because it was conducted under the supervision of a panel of independent scientists. Even though the Savitz study also has certain limitations, it indicates an excess risk for childhood cancer, in particular leukemias, associated with high current wiring configuration near the homes. Although this study basically confirms the results of the previous studies, the causal relationship is still no more than an hypothesis. However, the basis for this hypothesis is now stronger. The reasons why this is still only a hypothesis are 1) we still only have one well designed study, 2) there are unresolved questions in the Savitz study, and 3) there is no basic mechanism known to explain a causal relationship. If future research confirms a causal association between 60-Hz magnetic fields and childhood cancer public health considerations would have to be developed from 1) baseline risk of childhood cancer, 2) risk increase due to field exposure, and 3) distribution of exposure in the population.

On his own initiative, one of the Project investigators undertook studies of the effects of field exposure on the growth of cultured cells in soft agar as measured by the number of clones (colonies) formed. Normal cultured cells do not grow in soft agar unless they are "transformed," and field exposure did not produce transformation. However, the two cancer cell lines tested, which have the inherent ability to grow in soft agar, were reported by the investigator to form more clones after exposure.

Because of the possibility that these results were artifactual, that is, were related not to field exposure but to the inherent variability of the cloning assay, clonogenicity of these same cancer cells lines was examined in a second laboratory. Dr. Hamburger, who participated in the replication study, was the originator of the cloning assay for evaluation of chemotherapeutic agents. In their final report Drs. Hamburger and Cohen report no consistent effects related to field exposure. In the replication study several significant findings are reported but these findings are not reproducibly observed and do not always occur in the same direction, that is in some experiments there are more clones in the control, in other experiments the converse is true.

We conclude that further replications of the influence of fields on the ability of cancer cells to form clones in soft agar are not warranted because: (1) electric and magnetic fields have not been observed to induce transformation in normal cells, (2) exposure of two cancer cell lines in two different laboratories do not provide convincing evidence of an effect of biological significance, and (3) extrapolations from the behavior of cancer cells in soft agar to intact organisms cannot be made. Extrapolation of possible field effects on cancer should be done with more relevant assays.

Previous studies were not strongly suggestive of either genetic mutations or chromosomal damage caused by electric or magnetic field exposure. Several independent investigations within the New York State Power Line Projects also failed to find evidence of genetic or chromosomal damage. In light of the epidemiology results future studies on chromosomes should focus on mechanisms of leukemiagenesis for example oncogenes and promotion. There is currently no convincing evidence for field effects on fertility or growth. Further animal studies would not seem warranted for these variables. Our studies on fetal development have shown no gross morphologic changes. However, the Salzinger results showed persistent changes in performance of rats that had been exposed <u>in utero</u> and immediately after birth. These results may reflect subtle but important alterations of nervous system development that are not reflected in gross morphology.

VII. RECOMMENDATIONS

Research sponsored by this project and related research has demonstrated variety of effects of electrical and magnetic fields. These findings do not readily translate into concrete regulatory recommendations on width of right-of-way, line heights, or location of lines near homes. They do, however, lead us to the recommendations which follow:

1. There should be a major research effort on means of power delivery and use that would reduce magnetic field exposures.
2. Further study should be made of the interactive effects of the earth's geomagnetic field and 60-Hz fields.
3. The determination of the existence of thresholds for biologic effects of magnetic flux densities should be pursued.
4. The experiments on field effects on learning ability should be replicated.
5. The possible association between cancer (especially leukemias) and magnetic fields must be further investigated. Several avenues of study should be pursued.
   a. There should be further epidemiology study of residential exposure, conducted at more than one site with careful measurement of exposure.
   b. Attempts should be made to correlate cytogenetic and diagnostic subgroups of cancers with exposures.
   c. Further investigation of occupational exposure and cancer incidence should be conducted with improved documentation of actual exposures.

d. Animal models should be developed and laboratory investigations designed to explore possible mechanisms of field-induced carcinogenesis. If an effect is documented, then the dose-response relationship should be investigated.

6. Further research on the biologic effects of electromagnetic fields is very important. It should be administered by an agency, preferably federal, which is credible by virtue of being clearly independent of partisan influence.

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IX: Appendix 1

Engineering Instructions for Contractors:

Exposure Systems and Dosimetry Section from RFP, 1981. pp. 1-2.

Phase Relationship Between Electric and Magnetic Fields for Projects in the New York State Overhead Powerlines Program. (Document distributed to all contractors in March, 1984). pp. 3-5.

The Chattanooga Times, Thursday, July 9, 1987

Ordinary overhead power lines linked to leukemia in children

By Darren Dopp
The Associated Press

ALBANY, N.Y. — Children who live near ordinary overhead power lines are twice as likely to develop leukemia as children raised away from the magnetic fields associated with the lines, a scientific panel reported Wednesday.

The panel also estimated that 10 to 15 percent of all childhood cancer cases may be due to the magnetic fields generated by such power lines.

State health officials say the panel's report is the first time an impartial group of scientists has concluded that magnetic fields may be a danger to human health.

The director of the project, Dr. David Carpenter, dean of the State University of New York's Albany School of Public Health, called the finding "disturbing" and urged immediate follow-up studies.

"There is nothing in this study that should cause anyone to do anything dramatic, like selling their home," the author of the study, Dr. David Savitz, said Wednesday.

The childhood cancer link was reported in a 154-page study by the New York Power Lines Project. The project had commissioned 16 scientists from universities throughout the nation to study a range of possible effects on humans and laboratory animals caused by both high-intensity and low-intensity power lines.

[illegible] incidence may be increased by power fields," Carpenter said. "But this is clearly a dramatic finding."

Other studies examined the effects of power fields on living cells and on animal reproduction. One study found that epileptic mice living in a magnetic field had fewer fatal seizures than a control group living outside the field.

One of the studies conducted in the Denver area between 1978 and 1983 found that children with leukemia and brain cancer are more likely to live in homes close to typical neighborhood power lines.

A team of researchers led by Savitz, an epidemiologist at the University of North Carolina, coded all the homes in a suburban community according to their proximity to overhead lines, transformers and substations.

The cancer risk to children living closest to the power lines was 1.7 times higher than for children who lived away from the lines. The risk of developing leukemia in children was 2.1 times higher.

The general incidence of childhood cancer is one in 10,000 per year.

The final report of the panel differed significantly from an earlier presentation by its top scientist. In April, Dr. Michael Shelanski, chairman of the Department of Pathology at Columbia University College, announced there were no clear health hazards from power lines.

The Chattanooga Times, Thursday, July 9, 1987

People

Parking ticket coming to town

BUCKLAND, Mass. — Ever since the horseless carriage arrived in this little town that clings to a slope rising from the Deerfield River, you could park anyplace you could find a spot. But no more. The parking ticket is coming to Buckland, population 1,800. Police Chief James Basile said Wednesday it was a fine solution to tie-ups in front of the general store. "I don't appreciate it," said Rosemary E. Egan, manager of the Buckland Bar & Grill. "There's no parking around here anyways." Basile said there was room for 60 cars. Previously, anyone who parked in front of one of the few 'No Parking" signs, a fire hydrant or the spot marked "Police Car Only" would receive a warning ticket saying "Please don't do it again."

Adopted woman

summon conductor Herbert von Karajan, 79, for a medical test in a paternity suit filed Jan. 8 by a woman who claims the famed maestro is her father. Karajan's office in Salzburg had no comment. Ute de Doncker, 43, who lives in Sunderland, England, claims that she was adopted and spent years trying to find her real parents. She says she found her mother in Berlin and was told that von Karajan was her father.

Israeli boys mob British singer

JERUSALEM — British sex symbol and rock singer Samantha Fox arrived in Israel on Wednesday and was mobbed at the airport by scores of teen-age

Tel Aviv before she leaves Friday. Police rushed the star out a back airport gate and into a waiting car, but screaming teenagers reached the car and temporarily prevented it from moving by

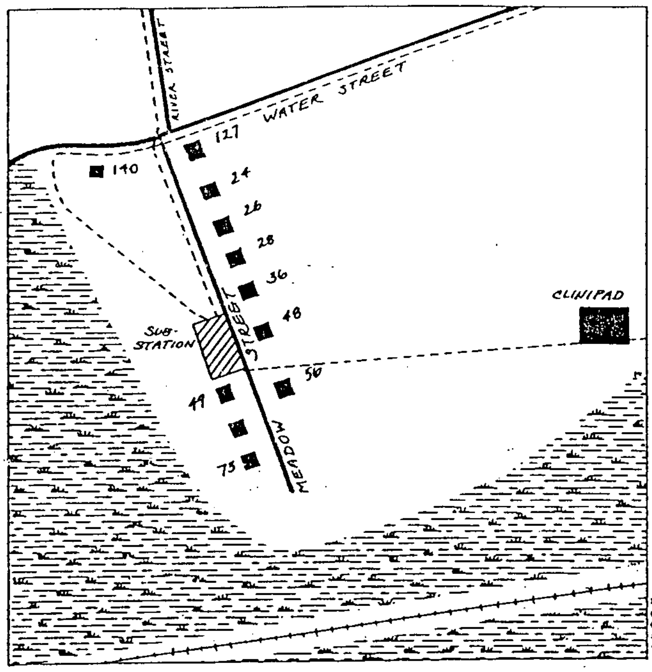
Skating low

Eric Snell, 12, goes low on his ska[...] his way through some obstacles a[...]

ANNALS OF RADIATION

CALAMITY ON MEADOW STREET

ON a Friday evening in mid-January of this year, Edna and Robert Hemstock received a visit at their home, in Guilford, Connecticut—a town on Long Island Sound about fourteen miles east of New Haven—from their friends Loretta and Fred Nelson, who also live in Guilford. Edna Hemstock, a vivacious woman in her middle forties, who is Robert's second wife, works as an office manager for a manufacturing firm; Robert Hemstock, a red-haired, forty-nine-year-old man of Irish ancestry, is a free-lance consultant for machinery design and product development. Loretta Nelson, a slender, sombre woman in her early forties, works at a nearby electronics plant; and Fred Nelson, an affable, wiry, gray-haired man of fifty-four, is an oil-burner serviceman. The two couples had become acquainted a year or so earlier, when the Nelsons' seventeen-year-old daughter, Joyce, and Charles Hemstock, Robert's twenty-year-old son by his first marriage, who had been living together in the Nelsons' house, on Meadow Street, learned that Joyce was pregnant. This was a cause of some concern to both sets of prospective grandparents, because in 1982 Joyce, who is called Missy by her family and friends, had been found to be suffering from the extremely rare combination of glomerulonephritis—a disease of the kidney capillaries, which resulted in her losing thirty-five per cent of the function of both kidneys—and partial lipodystrophy, a disorder that has caused a severe loss of fat under the skin around her face, neck, shoulders, and chest. Because of her kidney condition, Joyce was carefully monitored during her pregnancy by physicians at Yale University's School of Medicine; they did not expect her to be able to carry the baby for more than six months. Happily, however, Joyce carried her baby for a full nine-month term, and gave birth on October 23, 1989, to a healthy seven-pound-three-ounce girl. Sitting at the Hemstocks' kitchen table nearly three months later, Loretta Nelson made a point of remarking on how lucky they were to be grandparents, considering the threat that Joyce's kidney ailment had posed to her pregnancy. She added, "And considering all the other illness there's been on Meadow Street," which caused Bob Hemstock to sit up and take notice.



"That was the first time I'd heard anything about a lot of illness on Meadow Street," Hemstock said recently. "Edna and I had visited the Nelsons on several occasions while Missy was pregnant, and we had met their neighbor Suzanne Bullock, whose seventeen-year-old daughter, Melissa, had been operated on for brain cancer earlier that year, but neither of us knew about any other unusual incidence of disease down there. So I asked Loretta what she meant, and she proceeded to tell Edna and me a story that we found astonishing and disturbing."

To begin with, Loretta told her hosts that Joyce had been a healthy child of eight when the family moved to 36 Meadow Street from the neighboring town of Branford, in 1979, and that within a year she had become sickly and begun to lose weight. Loretta said that the doctors at the Yale School of Medicine had informed her and Fred that the causes of Joyce's glomerulonephritis and lipodystrophy were unknown but that her lipodystrophy might be the result of genetic vulnerability and of some type of environmental insult. She went on to say that she and Fred knew of no other case of either disease in either one's family. After reminding the Hemstocks that Melissa Bullock, who lived next door, at 28 Meadow, had developed brain cancer, she told them that Jonathan Walston III, who had lived at 36 Meadow as a child and young man, had developed a brain tumor in the late nineteen-seventies, when he was living at 48 Meadow—the house next door on the other side. She then said that Jonathan's father, Jonathan Walston, Jr., who was born at 36 Meadow and had lived there most of his life, had died there of brain cancer in 1975. She also said that a woman who had lived at 24 Meadow—three houses over—until she died of asthma, in 1989, had developed a brain tumor in the early nineteen-seventies.

Hemstock was flabbergasted by what he heard, because Meadow Street, which runs north to south and terminates at a salt marsh lying between Guilford and Long Island Sound, is only about two hundred and fifty yards long and has only nine houses on it. He said, "Good God, Loretta, do you realize how odd it is to have that much brain cancer on one small street?"

Loretta replied that she and some of her neighbors were concerned about the situation but didn't know what to do about it. She also said that she and Fred had begun to suspect that the disease on Meadow Street might be caused by an electric substation that stood diagonally across the street from their house.

Over the weekend of January 13th and 14th, Hemstock mulled over what Loretta had told him, and the more he thought about the situation on Meadow Street the more concerned he became about it, and the more certain that he should try to find out what lay behind it. He looked up "nephritis" in his Merck Manual and learned that it was a kidney disease of various origins, one of which could be connected with exposure to mercury salts. That rang a [illegible] with him, because he thought he [illegible]d read somewhere that transformers were often coated with mercury. He then looked up "transformers" in an electrical-engineering textbook and learned that they are used to either step up or step down electric voltage.

"First thing Monday morning, I called up the Connecticut Light & Power Company, in New Haven," he recalls. "I asked for customer service and went through four or five people until I got a lady who was some kind of supervisor in the customer-service complaint department. I told her I was calling about a health problem on Meadow Street in Guilford. I told her there had been a lot of brain cancer there, and I asked her if she knew about it and if it might be connected with the company's substation. 'Absolutely not,' she said. 'There have been a lot of foolish studies that don't prove any connection whatsoever between electromagnetic fields and illnesses.' She went on to say that you could get more exposure to electromagnetic fields from [illegible]aster or a coffeemaker than from substations or power lines. I thought it was very strange how quickly she had brought up the subject of electromagnetic fields, only to deny that they could be a hazard. At that point, I knew almost nothing about electromagnetic fields, and I had certainly never heard that they might be connected with illness—yet here she was alerting me to the possibility even as she assured me that it didn't exist. I told her I was shocked that she had given me such a quick answer. I said I was calling about a serious matter and was looking for real answers, not rhetoric. With that, she got kind of huffy. 'Well, I'm sorry you feel that way,' she replied. 'I'm just telling you what our studies have shown.' This got my Irish up. I told her I was going to research the problem and find out the answer on my own. I also told her to take down my name. 'I'm Bob Hemstock,' I said, 'and you're not going to forget it.' "

That afternoon, Hemstock went to the library in Guilford and, with the [illegible] of a computer index, spent an hour [illegible]o looking up references to electromagnetic fields. He then went to the libraries in Branford and North Branford, to the west of Guilford, and did the same thing. By the end of the afternoon, he had made a list of more than a dozen articles, published in various magazines, medical journals, and newspapers around the nation, about the association of electromagnetic fields from power lines and other sources with cancer and other diseases. At the same time, he decided to investigate other possible causes of the disease on Meadow Street, such as chemicals being used at the Clinipad Corporation's factory, on High Street—about a quarter of a mile east of Meadow—which manufactures antiseptic medicinal pads. At about 5:30 P.M., he called Loretta Nelson, who had just returned home from work, and told her about his conversation with the supervisor at Connecticut Light & Power, his research at the three libraries, and his decision to investigate the chemicals being used by Clinipad. He then suggested that she get in touch with some of her neighbors on Meadow Street and hold a meeting toward the end of the week so that he could present his findings to them and learn how they might want to proceed.

THE following morning, Hemstock called WTNH, Channel 8, the ABC television station in New Haven. He said he wanted to speak to someone about a health problem on Meadow Street, and was asked to leave his name and telephone number. An hour or so later, he received a call from Becky Morris, the assignment editor at the station, to whom he related the essential elements of Loretta Nelson's story. Morris was interested—not the least of the reasons being that in December Channel 8 had broadcast a human-interest piece about Melissa Bullock's recovery from surgery for brain cancer and her return to Guilford High School, where she had been a star player on the girls' basketball team—

but she appeared reluctant to cover the Meadow Street story without seeing medical records and talking to some of the doctors who had been involved. Hemstock told her about the articles he had come across, linking exposure to electromagnetic fields with brain cancer and other diseases, and his suspicion that the substation and power lines on Meadow Street might be related to the unusual occurrence of illness there. Morris said that she would consider doing a segment on the situation, and would call him back.

Later that morning, Hemstock drove to the hiring office of the Clinipad factory, and, in the course of inquiring about a job, asked for a catalogue of the company's products. A woman in the hiring office handed him an employment application but refused to give him the catalogue. Hemstock drove home, called the factory, and told a sales representative that he was thinking of putting together an industrial first-aid kit that the company might wish to manufacture. The sales rep agreed to compile a list of the company's products and their chemical components. The list included acetone, alcohol, iodine, and a dozen or so other chemicals, and Hemstock picked it up that afternoon. In the evening, he looked them up in his Merck; although acetone was described as toxic, none of them were listed as actual or suspected carcinogens. He spent much of Wednesday, Thursday, and Friday at the Guilford library, looking up the toxicity of the chemicals and reading articles in various publications about the biological effects and disease-producing potential of the sixty-hertz alternating-current electromagnetic fields given off by power lines. (Current for industrial and household use is known as sixty-hertz alternating current, because it flows back and forth, first in one direction and then in the other, sixty times a second.)

On Friday evening, a group of people joined Loretta and Fred Nelson at their home: among them were Jonathan Walston III, who is called Jack; his wife, Leah; Suzanne Bullock; and Bob Hemstock. After Hemstock introduced himself to Leah and Jack Walston, who had moved away from Meadow Street in 1983 and now live a mile or so to the east, he told the group about his research.

"I started out by saying that there

had been far too much illness on Meadow Street for us not to acknowledge the existence of a major health problem, and that I was concerned about the well-being of my son and granddaughter, and of everyone else who lived there," Hemstock recalls. "I showed them the list of chemicals used at Clinipad and said that, while I didn't want to rule them out as a possible cause of the problem, my research had so far provided no evidence that any of them could produce cancer, or that any Meadow Street residents had been unduly exposed to them. In connection with that, I pointed out that the town's drinking water, which is from deep artesian wells and is pumped into a holding tank several miles away, had been tested in September and found to be safe. I also talked at some length about the possibility that polychlorinated biphenyls, or PCBs—chemicals that were once widely used in transformers and are known to be toxic—might have leaked from the Meadow Street substation, or been dumped in a manner that might have exposed the residents. I then told them what I had learned about the cancer-producing potential of electromagnetic fields from power lines, and handed out copies of some of the articles I had read on the subject."

AT THE CLASSICS TEACHER'S

You gave us phlox, blue-rose, burst on the marble
table in the back yard, the word in bloom like the sound
fire makes when it leaps—*phlox*—into being.

Our friend has gone to sleep, blue-white, this evening
on the black grass. Beside him, a pine-green spotlight falls
where, torchlight, the kerosene shines. There are no clouds.

Cloud-gray phlox in front of us, though. Not everything's lost,
not everything's shaken. Your clean, safe-surrounded house
has a back door into its garden. Your pinks have blue-gray

leaves. Your broken porch has a strong false floor. There's a place
to hide just behind the trellis covered in larkspur. Across
two rivers and fifty miles, our tiny great city is crowned

in acres of gray-pink light. It smokes, it could be on fire,
with all its division and anger. Night is making it loud
even now, but we don't hear it. In the garden tonight we're turned

to another city—cities: How the ex-queen Hecuba cried *oimoi* over
captured daughters and two dead sons. How Troy was flicked from its
pyre of ashes and became Rome. How S. Weil proved that hounding

force, like hounding charity, turns its object to stone. Our friend
turns over and wakes up, mentions the stars. He laughs aloud: "Found
it." He's forgotten, he says, the whole sky except for the Bear,

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Included in the information that Hemstock gave his listeners was the fact that several epidemiological studies—all of them published in peer-reviewed medical journals—showed that children living near high-current electrical-distribution wires giving off relatively strong magnetic fields were developing cancer or dying of it at twice the rate of children who lived in homes that were not near high-current wires. Also included was the fact that a large number of epidemiological studies and surveys showed that men whose occupations expose them to electric and magnetic fields, such as electricians, electrical engineers, electric-utility workers, power-station operators, and telephone and power linemen, were developing cancer—particularly brain cancer and leukemia—at a rate significantly higher than that of other workers. He specifically cited a study showing that electric-utility workers in Maryland were suffering a higher than normal incidence of brain cancer, and a survey showing that electric-utility workers in East Texas were developing brain cancer thirteen times as often as expected. Hemstock went on to tell his audience about experimental studies showing that low-level electromagnetic fields, such as those given off by some power lines, could suppress the immune system, and thus suggesting how such fields might lead to the development of cancer, and about studies demonstrating that such fields could adversely affect the central nervous system, alter the chemistry of the brain in test animals, and cause birth defects and miscarriages.

"When I finished sharing what I had learned about the harmful effects of electromagnetic fields, I said that although I had not completed investigating the possibility of chemical contamination, my suspicions were very strongly directed toward the substation as the source of the disease on Meadow Street," Hemstock recalls. "I said that if that proved to be the case we would be taking on Connecticut Light & Power—a huge entity—and would be in for a long, hard battle. For that reason, I advised everyone to gather together the pertinent medical records, and I said that we ought to think about hiring a lawyer to represent us."

During and following Hemstock's presentation, there was a good deal of give-and-take between him and his listeners. Leah and Jack Walston said they were convinced that the substation was a factor in Jack's brain tumor and in his father's brain cancer, and also in a tumor that had developed on the left leg of their daughter, Ann, when she was thirteen years old and they were living at 48 Meadow—directly across the street from the substation. A number of stories and anecdotes were told. Jack Walston remembered that at the age of three Ann had been playing in front of the house at 48 Meadow on a summer day when the substation exploded and a Connecticut Light & Power engineer, who had been working on one of the transformers, was severely shocked and blown high into the air. He went on to say that Ann had been credited with saving the man's life, because she had run into the house to tell her mother, and Leah had called the police and an ambulance. Fred Nelson remembered standing in his kitchen, holding a cup of coffee, one morning, when a squirrel short-circuited one of the transformers, causing the substation to blow up and fill the

the Dipper, after all this time. "Look." We look, we gaze, we stare
at the ones we see and the ones we cannot see. You laugh, and send
us looking for Cassiopeia on her visible chair. We allow

as she might be somewhere. Those poor sailors, believers, swimming
cousins, their stars arranged into patterns they could understand—
how they longed, like fossils in water, to stay in mind,

their impression buried in mud of a certain kind.
We debate their conjugations, their words like men and women,
yoked to sense. How is it that the word "to bear," as in pounds

of burden, in the present (*fero*) was not at all like the word
"to bear" in the past (*tuli*), the "perfect"? We do not know,
but we can guess. And how are the slaves who bear our peace?

If we do not know, we do not know. We can guess, at the very least.
You were positing how to move a kind of knowledge into the world,
how Virgil, off on his farm in wartime, reported the sounds

of bees, soil, reaping. You stepped indoors for something: "Wait
right here." Our friend (you should know) said some words about
you. Then you came out with water, ice, sugar, lemons.

Catullus and his supper guests who had to bring their own provisions
didn't drink like this. All nose and mouth, we inhaled, we drank
what only in your buried garden tastes whole and round.

—Elizabeth Macklin

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kitchen with a bright-red flash of light. He added that people living on Meadow Street had always had to reset their electric clocks three or four times a week, because the relays in the substation were forever being tripped, interrupting the electric service. That observation reminded Jack Walston that light bulbs had continually been burning out when he and his family lived at 48 Meadow—that they sometimes went through half a dozen bulbs a week. Loretta Nelson pointed out that practically everyone on the street suffered from severe headaches, and that the problem had become so acute in the Brunelle family, who now live at 48 Meadow, that Kevin and Mercedes Brunelle had recently taken their nine-year-old son, Kevin, Jr., to the Yale University School of Medicine's Yale-New Haven Hospital for a complete checkup and a brain scan.

DURING the week of January 22nd, Hemstock continued to visit the Guilford library and read up on the biological effects of low-level electromagnetic fields. He also received a number of telephone calls from Becky Morris, of Channel 8, who said she was still interested in doing a story about Meadow Street. At 9 A.M. on Thursday, January 25th, he telephoned Dr. John Brogdan, a general surgeon, who is the Guilford health officer. "I called Dr. Brogdan because I thought he should be alerted to the situation on Meadow Street, and because I thought he might be able to give me some advice," Hemstock recalls. "The first time I called, he hadn't come in yet, but when I telephoned again, shortly after ten, his secretary put me through. 'Dr. Brogdan,' I said, 'I'm Bob Hemstock. I'm calling about a health problem on Meadow Street.'

" 'Do you live on Meadow Street?' Dr. Brogdan asked.

" 'No, I don't,' I said.

" 'Then what business is it of yours?' he inquired.

"I was really taken aback by that question. For a second or two, I didn't know what to say. Finally, I said, 'I'm a member of the human race, Dr. Brogdan, and I'm interested in humanity. I thought doctors were, too.'

" 'Are you a doctor?' he asked.

" 'No, I'm not,' I said. At that point, he suggested that I gather up the medical records of the people on Meadow Street and bring them over to his office so that he could look at them and see if there was a problem. I told him I thought that that was an absurd idea. 'That's not my job,' I said. 'That's your job. You should be looking into the situation.'

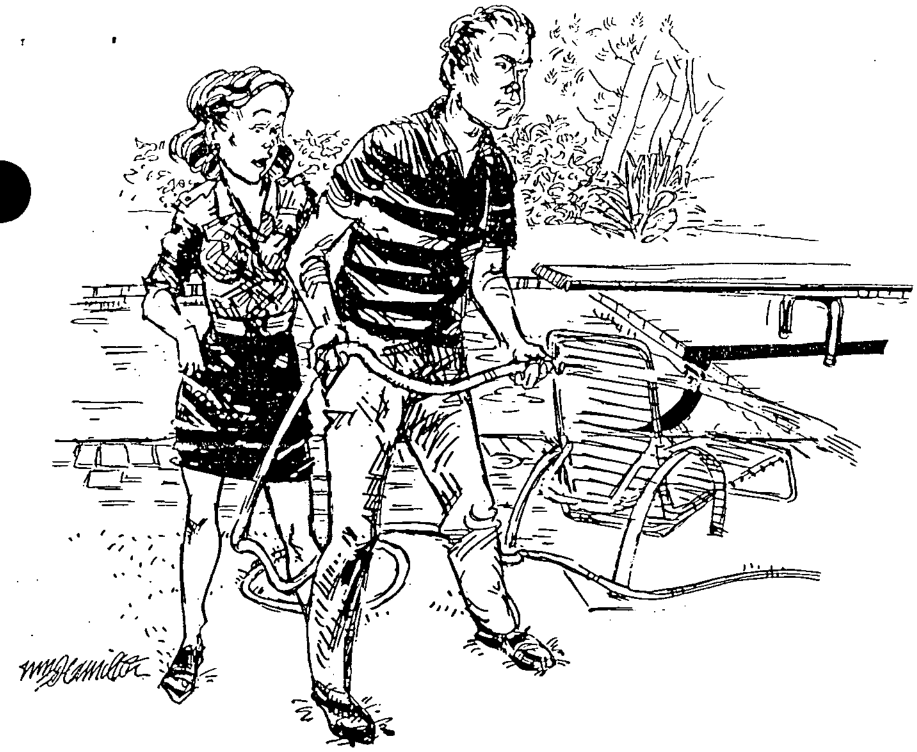
" 'Listen, I've received a call from one of the neighbors over there that you're a troublemaker and don't even live in the neighborhood,' Dr. Brogdan replied.

"That really got my Irish up. I said, 'Well, my name is Bob Hemstock, and you're not going to forget that name.' And I hung up."

The next day, Becky Morris called Hemstock to say that Channel 8 had decided to do a story on the Meadow Street cancer cluster for that night's eleven-o'clock news broadcast, that she would arrive at the Meadow Street substation at four-fifteen, and that Kevin Hogan, a reporter, would interview him and some of the residents.

"Hogan asked a lot of questions and the camera crew shot a lot of tape," Hemstock recalls. "Most of it got left on the cutting-room floor, but some of it did make the Friday-night eleven-o'clock news."

The news segment started out with Loretta Nelson standing in the yard beside her house and expressing concern about the health problems in the neighborhood. It then showed Fred Nelson also voicing worry, and he was followed by Hemstock, who stood in front of the substation and said it appeared that the substation was involved. Next, the camera turned to Kevin Brunelle, Jr., the nine-year-old boy who lives directly across the street from the substation, and he described his illnesses and the CAT scan he had been given at the Yale-New Haven Hospital, which had been negative. Then the program showed Jack Walston, talking about the brain tumor he had suffered. Finally, John Gustavsen, a spokesman for Northeast Utilities, the parent company of Connecticut Light & Power, gave the company's assessment of the situation. "It's a terribly unfortunate coincidence, and nobody to our knowledge has contacted our company, at least more than once," Gustavsen said. "If it's electromagnetic fields we are talking about, we are aware of studies that show a correlation statistically



"You know what I like about L.A.? We don't have to be interesting anymore."

only. They don't demonstrate cause and effect."

On the morning of Monday, January 29th, yellow trucks bearing the logo of Northeast Utilities were to be seen everywhere in Guilford. Three trucks, together with a supervisor's sedan, were parked on Meadow Street in front of the substation, and half a dozen men were working inside. Another yellow truck, carrying three workers, was parked beside a utility pole in front of a house at 140 Water Street, just around the corner from Meadow. Two of the workers were standing on the sidewalk by the pole, and the third worker had climbed the pole and was examining the wires strung from its crossbar. A Northeast Utilities sedan was parked farther east on Water Street, toward the center of town, and a young man and a young woman who had got out of it were walking slowly along the sidewalk. The young man was calling out the serial numbers of distribution transformers that were mounted on utility poles, and the young woman, who was carrying a clipboard, was writing them down. Still farther along the street, a yellow van belonging to Northeast Utilities and bearing the sign "INFRA-RED SURVEY" was parked beneath the wires, and a worker wearing coveralls and carrying some kind of instrument in his hand was standing beside it. Hemstock, who was driving along Water Street at the time, parked on Meadow, got out, and walked back toward him.

"As I approached, he put the instrument in the back of the van, where there were a lot of gauges and equipment, and closed the door," Hemstock recalls. " 'What're you guys doing?' I asked, and he said, 'Oh, we're just looking for energy loss—heat loss—so we can improve the electrical service.' "

On Thursday, February 1st, the New Haven *Register* ran a story about the situation on Meadow Street, beneath a headline saying "POWER STATION STIRS FEARS OF HEALTH RISK." The story was by Judith Lyons, a staff writer for the newspaper, who had interviewed several of the residents.

"Something is very wrong here," Kevin Brunelle told her. "My son and I are experiencing terrible headaches. Four people who have lived on this street have had brain tumors."

Brunelle's wife, Mercedes, told Lyons that brain scans and other tests had not been able to determine the reason for their son's headaches. "I'm scared," she said. "We have two other young children, too, to worry about."

Suzanne Bullock talked about her daughter Melissa's brain cancer, and said that the substation had not been ruled out as a possible cause. She also commented upon the unusual number of utility-company trucks that had been seen at the substation during the previous week. "We are glad they are there," she said. "We just want to see something done."

Henry Prescott, a spokesman for the utility, denied that any special measures were being taken in response to the residents' complaints. He said that workers had been sent to the Meadow Street substation to install devices that minimize short circuits.

Two residents of the street expressed skepticism that the substation was the cause of any illness. So did Robert Adair, a physicist at Yale University, who was described as an expert on electromagnetic energy. Adair had written in the November 15, 1989, issue of the *Journal of the National Cancer Institute* that anyone who believed that electromagnetic fields could promote cancer "would believe in perpetual motion or cold fusion." Not surprisingly, he supported the position of the Connecticut Light & Power Company that there was no evidence that the substation had contributed to any illness. He dismissed a much publicized recent study conducted by Genevieve Matanoski, an epidemiologist at Johns Hopkins University's School of Hygiene and Public Health, and two colleagues; they had studied New York Telephone Company cable splicers, who are exposed to electric and magnetic fields from power lines, and found a significantly increased incidence of cancer—including seven times the rate of leukemia and almost twice the rate of brain cancer that was found among the company's office workers. He told Lyons that the electromagnetic fields produced by substations were "extremely weak," and that the currents going into and out of substations tended to cancel each other out.

The fact is that substations are known to produce very strong electromagnetic fields, and also transient high-frequency electromagnetic pulses. Moreover, because the currents carried by high-voltage lines going into a substation and those carried by lower-voltage distribution wires leaving a substation are almost never in balance, the magnetic fields they produce—invisible lines of force that readily penetrate virtually anything that happens to stand in their way, including the human body—almost never cancel each other out. They certainly did not at the Meadow Street substation, where measurements taken at various places near the peripheral fence of the facility shortly after Adair made his statement showed magnetic fields ranging from twenty to several hundred milligauss. (A gauss is a unit of measure for magnetic-field strength; a milligauss is one-thousandth of a gauss; and levels of between two and a half and four and a half milligauss have been associated in several epidemiological studies, including the Matanoski study, with the development of cancer in human beings.) Adair, however, declared that a television set would have a greater biological effect on Meadow Street families than the substation would. Yet magnetic-field levels given off by the average television set fall off to biologically negligible strengths within two to three feet of the appliance, whereas strong magnetic fields can often be measured within a hundred feet of a distribution substation, such as the one on Meadow Street, and within the same distance of the high-current distribution wires leading from it. Adair concluded by telling Lyons that he found it "inconceivable" that the substation could have "anything to do" with illness among nearby residents.

On the same day that the *Register* ran its story about Meadow Street, several residents received telephone calls from Dr. Brogdan's secretary, to tell them that on February 5th town officials were planning to meet with officials of Connecticut Light & Power and discuss the health problems that had been reported. The meeting between officials of Guilford and Connecticut Light & Power was soon cancelled, however, and not rescheduled. Over the six weeks following the broadcast and the news story, the utility's yellow trucks and vans kept showing up at the Meadow Street substation with such unusual frequency that some residents of the street began to jot down their license numbers. The residents not only observed power-company employees working on the equipment in the substation but also noticed that a number of them were carrying instruments similar in appearance to gaussmeters—devices used to measure the strength of a magnetic field. They concluded that the company was engaged in an effort to reduce the amount of power being handled by the substation. One indication that this may indeed have been the case came in March, when an official of the Connecticut Department of Public Utility Control, in New Britain, told Hemstock that the Connecticut Light & Power Company had recently informed him that the Meadow Street substation was then receiving only twenty-two thousand six hundred volts—a substantial reduction, considering the fact that the facility had previously been fed voltage from several hundred-and-fifteen-thousand-volt lines. Another indication was that the loud and constant hum given off by the vibration of the laminated iron sheets of the substation's transformers—a sound most Meadow Street residents had grown so used to that they'd ceased to notice it—suddenly diminished.

A SUBSTATION is an assemblage of equipment—circuit breakers, disconnecting switches, transformers, and the like—that is designed to change and regulate the voltage of electricity. At power-generating plants, alternators produce medium voltages—typically, twenty thousand volts, or twenty kilovolts. The transformers at generating plants raise these to higher voltages—typically, a hundred and fifteen thousand volts, or a hundred and fifteen kilovolts, or else two hundred and thirty thousand volts, or two hundred and thirty kilovolts—which are required to transmit electrical energy economically over long distances to cities, towns, and other load centers. At those centers, distribution substations step down the transmission voltages to lower voltages—typically, 13.8 kilovolts or twenty-seven kilovolts—which then carry electric current to neighborhoods. There pole-mounted transformers step down the voltages further, to the two-hundred-and-forty-volt and hundred-and-twenty-volt levels required to operate household lights and appliances. In this respect, electric current—a flow of charged particles which always produces an electromagnetic field—can be likened to water flowing in a pipe, and voltage can be thought of as the pressure that pushes current through a circuit.

Like other distribution substations, the one on Meadow Street, which was built in 1932, was fed high voltage by a transmission line from Branford, and it sent out strong current at lower voltages on primary wires for distribution to various load centers in the Guilford area. (Stepped-down voltage invariably results in increased current, and the stronger the current the stronger the magnetic field.) As the demand for electricity grew in the region, the substation was required to handle and distribute an increasing amount of energy, and during the late nineteen-fifties and again in the sixties it was enlarged to accommodate additional high-voltage lines brought in from Branford, until it had grown to more than twice its original size. By the spring of 1972, the demand for electricity in the rapidly growing shoreline communities of Connecticut was such that Connecticut Light & Power proposed to run a hundred-and-fifteen-kilovolt transmission line from Branford, through the northern sections of North Branford, Guilford, Madison, Clinton, and Westbrook, to Old Saybrook—some fifteen miles to the east—and to construct a bulk-supply substation in Madison for distributing electricity to load centers throughout the region. At the time, company officials estimated that a second substation would have to be built in Guilford in 1978, and another hundred-and-fifteen-kilovolt line would have to be brought to the proposed substation by 1985 to supply the growing loads expected in the town. They told officials and residents of the affected towns that burying the proposed transmission line would cost at least six times as much as stringing it aboveground.

Strong opposition from citizens' groups and zoning boards tied up the power company's proposal in regulatory proceedings for several years, and it was not finally approved by the Connecticut State Power Facility Evaluation Council until 1979. Meanwhile, the Meadow Street substation, which started out as a relatively small distribution facility, had begun to serve as a bulk-power substation for most of Guilford. One set of high-current distribution wires crossed Meadow Street between the house at 48 and the house at 56, and traversed an adjacent salt marsh in an easterly direction, toward Madison. A second set of distribution wires ran north from the substation on telephone poles along Meadow Street, crossed Water Street, and continued north up River Street to the Boston Post Road, about a mile away. A third set of distribution wires ran over the salt marsh in a northwesterly direction to Water Street near the West River, and then east along Water Street toward the center of Guilford, passing beneath the second set of wires at the corner of Water and Meadow. (High-current distribution wires are thick, large-gauge wires that are attached to utility poles with large glass or porcelain insulators.) These three sets of distribution wires were carrying very strong current—enough to supply the electrical needs of a wide region—and by 1974 they were creating magnetic fields powerful enough to interfere with television reception in the neighborhood.

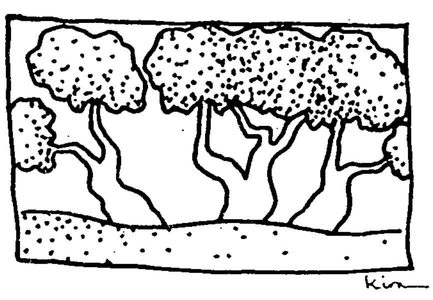
During 1975, Robert Bryden, who lives at 140 Water Street, began to observe drastic warping and blurring of his television picture, and to experience pain and swelling in his eyes; his wife was suffering from swelling of the face and numbness and nerve tingling in one of her arms. He then wrote more than a dozen letters of complaint to Guilford and Connecticut officials; to the Federal Communications Commission, in Washington, D.C.; to the representative for his congressional district; and to Senator Abraham Ribicoff. As a result of requests from the F.C.C., whose officials clearly believed that power lines were creating the interference, Connecticut Light & Power on several occasions sent representatives to Bryden's neighborhood to investigate the problem. However, after trying to correct the interference by working on the power lines, the company decided that its equipment was not to blame, and recommended that the problem be solved by the F.C.C., which informed Bryden that it had more important matters to deal with. Early in 1976, Bryden gave up and arranged to have cable television installed in his home. Many of his neighbors had already done so. Apparently, neither he nor they were aware that, just as someone can distort the lines of a drawing by jiggling the elbow of the artist who is making it, strong magnetic fields given off by power lines can distort a television picture by interfering with the path of the electron beam that forms the picture on the screen. Nor were they aware that in 1973 the members of a seven-scientist committee convened by the United States Navy had found the results of several Navy-financed studies of the biological effects of extra-low-frequency electromagnetic fields in human beings and animals so disturbing that they had recommended unanimously that the Navy (which suppressed their recommendation) warn a Presidential advisory panel of possible danger "to the large population at risk in the United States who are exposed to 60 hz fields from power lines and other 60 hz sources."

MEANWHILE, in September of 1975, Jonathan Walston, Jr. (whose physician was Dr. Brogdan), died of brain cancer, at the age of fifty-four, at his home, at 36 Meadow. He had lived there from 1920, when he was born, until 1939, when he married a young woman named Marian Peck, and moved to North Street, about a mile away. His father, Jonathan, Sr., died, of a bleeding ulcer, in 1947, at 36 Meadow, and, shortly thereafter, Jonathan, Jr., Marian, and their three children—Jonathan III (Jack), Emily, and Wanda—moved there to live with his mother. During the next dozen years, Jonathan, Jr., worked as an iceman, as a firewood carter, and in construction; in 1960, when he was forty years old, he turned to lobster fishing. A few years later, he bought the house next door at 48 Meadow for twelve thousand dollars from a builder who had converted it into upstairs and downstairs apartments during the late nineteen-fifties. Jonathan, Jr., rented out both apartments at 48 Meadow and continued to live at 36 Meadow, and in May of 1971 he rented the downstairs apartment at 48 to his son, Jack, who moved there with his family.

Jack was born in 1942, while his father and mother were living up on North Street, and he went to live at 36 Meadow in 1947, after his grandfather's death. He quit high school at sixteen to work as a laborer, laying water mains in Guilford, and later went lobstering with his father. He lived at 36 Meadow until 1968, when he married Leah Craven, who was working as a secretary-receptionist for Guilford Pediatrics. During the first three years of their marriage, she and Jack lived up on Church Street, near the center of town, and their daughter, Ann, was born there in 1969. A few weeks after they moved to 48 Meadow, Leah gave birth to their son, Jonathan IV.

The year Ann was born, Jack's twenty-five-year-old sister, Wanda, who had recently married and was living in Branford, developed a nonmalignant ovarian tumor; it was removed by surgery. She was born on North Street in 1944, and had lived at 36 Meadow for almost twenty-three years. She was the first of four members of the Walston family to develop a tumor, either malignant or nonmalignant, while or after living at 36 Meadow or 48 Meadow. The second was her father, Jonathan, Jr.; the third was her brother, Jack; and the fourth was Jack's daughter, Ann.

Jack Walston is a heavyset man with dark eyes, dark hair falling over his brow, long dark sideburns that give him a rakish look, and an impish sense of humor. In the middle of his forehead is a tablespoon-size depression extending up to his hairline, where surgeons at Yale-New Haven Hospital removed a tumor from his olfactory groove, in the front part of the brain. In 1972, about a year after he moved back to Meadow Street—he was then working as a mechanic and welder for the Guilford Septic Tank Company—he experienced a blackout while driving to Branford for National Guard duty. A year or so later, he blacked out again, in a bathroom at the National Guard armory. Early in 1979, he became irritable and began to experience terrible headaches and blurred vision—"It got so bad I couldn't see the welds," he says—so he went to a local eye doctor, who prescribed new glasses, which didn't do any good. In June, he went to another eye doctor in Guilford. This one told him that he had something growing on his optic nerve, and referred him to an eye doctor in nearby Middletown. The Middletown eye doctor said he had developed optic neuritis, and sent him to Dr. Thomas Walsh, a neurologist and ophthalmologist at Yale-New Haven Hospital.



"By that time—September—things had got so bad that whenever I lay down on my side to watch TV I went blind on that side, whichever it was," Walston recalls. "I had also lost most of my ability to smell and taste. Dr. Walsh gave me a CAT scan that showed a large mass in the olfactory groove, and recommended that I go see Dr. Dennis Spencer, a neurosurgeon, who is the head of Neurosurgery at Yale-New Haven. After examining me, Dr. Spencer told me that I had a large tumor in the front part of my brain, and that I had to get it operated on as soon as possible, so I went into the hospital the following week, and on September 28th he operated on me for seven hours. He removed my forehead bone in two pieces and took out a meningioma—a generally nonmalignant but often fatal tumor—which was the size of a small grapefruit and had got entangled in my optic nerves and stretched them out as fine as ribbon. In order to take out the tumor, he had to sculpt out a small piece of my brain—about five centimetres' worth of the right frontal tip—which the tumor had been pushing against. Then he patched my upper sinuses with tissue taken from a muscle on my skull, put the two pieces of forehead bone back in place, and sewed me up. I got out of bed the next day, because they wanted me to get my lungs working, but some kind of fluid began running out of my nose. It turned out that the tissue patch had come loose and I was leaking brain fluid, so they did another CAT scan and found out I was getting air into my head when I inhaled. They put gauze under my nose and told me to lie flat, so my brain would heal, but my lungs weren't working right, and I developed double pneumonia and got put on a respirator and went into a semicoma for about a week and a half. When I came out of it, in early October, they set me up for another operation, during which they drilled a hole through my forehead bone and syringed out the air. However, they still had to replace the tissue patch, so I had to undergo still another seven-hour operation, in which Dr. Spencer took out my forehead bone all over again, and repatched my sinuses with more tissue, from my thigh."

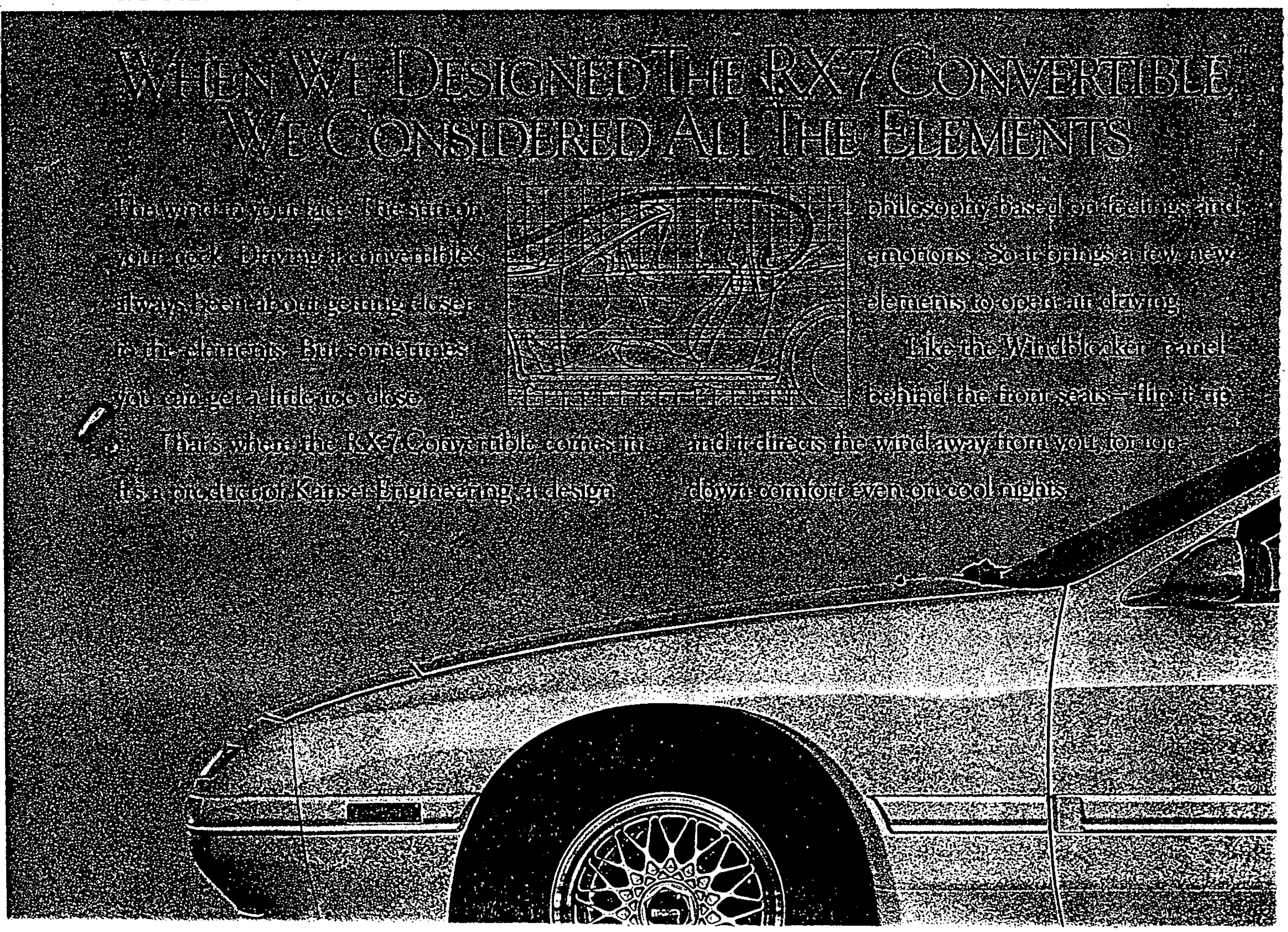
Leah Walston is a calm, forthright woman. She says that since the operation Jack has been on Dilantin to prevent brain seizures, and that his short-term memory has been impaired. "If someone were to ask him his telephone number, he might give the number at 36 Meadow when he was a boy," she said not long ago. "He gets irritated when he can't remember recent dates and things."

Looking back on events, Leah realizes that there was an unusual series of health problems on Meadow Street all during the nineteen-seventies. "It's hard to know how many of them were related to the substation, which often blew up in those days, but, taken all together, they make you wonder," she said. "In 1972, I lost our third child because of a miscarriage. At about the same time, the woman who lived four houses over from us, at No. 24, developed a meningioma just like the one Jack had later except that hers was attached to her skull bone, so she had to have part of the bone replaced with a steel plate. Then there was the time the substation blew up in the summer of that year. My sister, Brooke, was visiting us, and we were all over at Jack's parents' house, next door, in the evening, when a thunderstorm came up. I started back to our house with Ann, and Brooke and Jack came behind me with little Jonathan. While they were walking along the street, a bolt of lightning hit the substation. Brooke grabbed up little Jonathan, and she and Jack made a dash for the house, and while they were running there was a loud hum from the substation, and it got louder and louder until there was an explosion, as if a bomb had gone off. A huge flash lit up the neighborhood with all the colors of the rainbow—gorgeous blues, greens, and yellows—and hung over us for a second or two. The lightning bolt had put the substation out of commission and knocked the power out in the whole town.

"A month later, when Brooke was vacationing up on Cape Cod, she had a grand-mal seizure in the kitchen of the house where she was staying. She fell down and cut herself on the head, but she came straight home to Connecticut without seeing a doctor. Then, in 1973, she had two more seizures, so she did go to a doctor. He diagnosed the problem as epilepsy—an electrical disturbance in the brain—and put her on Dilantin. She stayed on Dilantin for a couple of years, and then weaned herself from it and never had any more seizures.

"Meanwhile, Jack's father had died of brain cancer, and when Jack developed his meningioma, in 1979, Brooke said there had to be something in the air on Meadow Street that was giving people cancer—first of all, Jack's sister Wanda, and then the woman at 24, and then Jack's father, and now Jack himself. Brooke said we should look into the substation, because she felt there must be some connection, but we resisted the idea. About that time, we learned that little Jonathan had Osgood-Schlatter Syndrome—a condition in which the knee tendons don't grow properly, and the kneecaps don't join with the tendons. Then, in 1982, Ann, who was thirteen, developed a nonmalignant tumor, on her left tibia, just below the knee. She had first started to have pain in the knee and leg that winter, but our local doctor said that that was normal for growing females, so we didn't pay much attention. In late August, however, a lump the size of a marble developed below her knee, and the skin around it turned brown. We took her to Dr. John Ogden, an orthopedic surgeon at the Yale School of Medicine, and he X-rayed her and made the diagnosis. When Dr. Ogden operated on her, in September, the tumor was embedded so deep in the shinbone that he had to go through almost to the last quarter inch. Ann wore a full hip-to-ankle cast for a month, and she was on crutches for another month. Brooke got angry when she learned what had happened, and insisted that we do something about the substation. She and I quarrelled about it until she finally gave up."

Leah continued, "In 1983, we moved from Meadow Street up to North Madison Road, near Guilford Lake. Around that time, we found out that Ann had developed a mild case of scoliosis, which is curvature of the spine. A year or so later, she developed blurred vision. Like little Jonathan, she had had bad headaches practically the whole time we lived at 48 Meadow. We took her to Dr. Laura Ment, a pediatrician and neurologist at Yale-New Haven. She gave her an EEG and said Ann was suffering from temporal-lobe epilepsy. Dr. Ment put her on Dilantin, and although she had one epileptic seizure—in October of 1984—she was able to graduate from high school in 1987 and then from the hairdressing academy in Branford. In 1985, she developed a ganglion cyst in her left wrist. We took her to Dr. Kendrick E. Lee, an orthopedic surgeon at the Yale School of Medicine, and he removed it. The cyst has recurred three times, and it has now affected the nerves of her hand so badly that she can't work as a hairdresser. Back in 1980, I had developed some very large and incredibly painful keratinous cysts under my arms and in my groin. The doctors at Yale-New Haven said it was because my sweat glands were plugged up, so they operated on me and removed the cysts from under both my arms. Then, about the time Ann developed her ganglion cyst, my face swelled up terribly, and Dr. J. Cameron Kirchner, an ear-nose-throat surgeon at Yale-New Haven, had to remove the parotid gland from my left cheek, because it had become grossly inflamed and wasn't functioning prop-



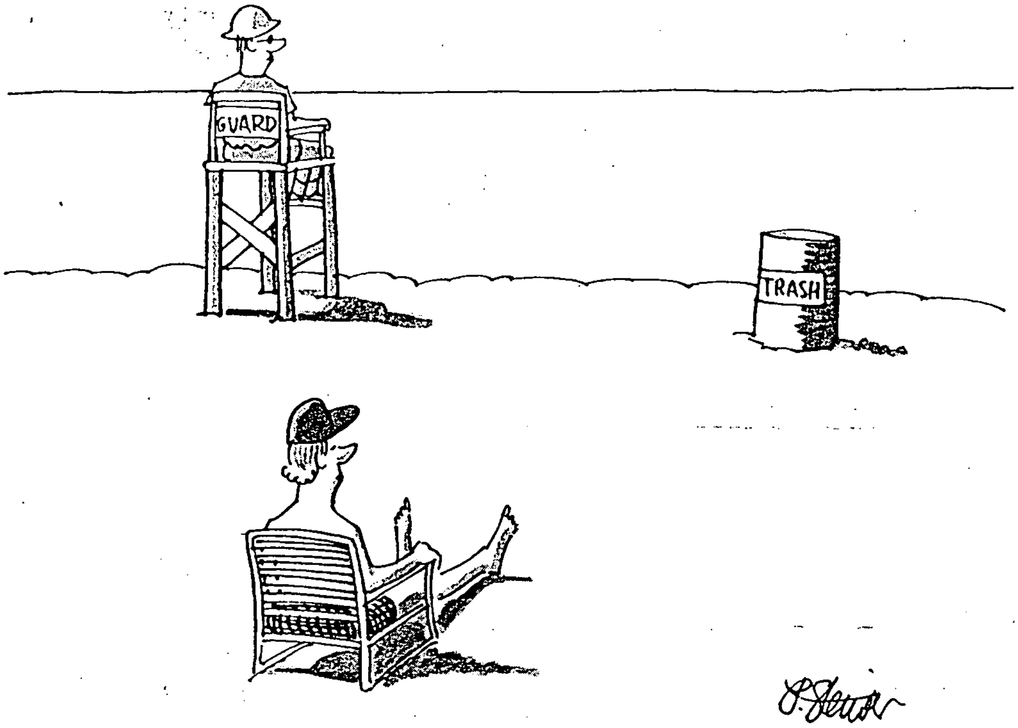
erly. When you think of all the trouble we had—just one family—it makes you wonder."

Jack Walston said, "The builder who sold the house at 48 Meadow to my father had bought it from a couple whose son was born crippled and was never able to walk. They also had another son and a daughter, who were normal. The builder, who had three children, too, lived in the house only briefly, and moved away soon after he converted it into upstairs and downstairs apartments. All the bedrooms in both apartments faced the substation, just across the street. The upstairs apartment was rented to a couple, and they lived there for several years. They had three children. One was born with a deformed spine, and it was corrected by surgery at Yale-New Haven Hospital. After my father bought the house, he rented the upstairs apartment to a couple who had one son. The husband worked for a local company that manufactured electrical equipment for boats, and he had a steel plate in his head, because of a wound he had suffered during the Second World War. He later committed suicide with a gun. After that family moved away, my father rented the upstairs apartment to a couple who had a son who was born mentally retarded in 1967 and had epileptic-type seizures as he grew, and was treated at Yale-New Haven Hospital. My father rented the downstairs for several years to a couple who had two sons during that time. One was born with hypospadias—a defect of the penis—and the other was born with a hole in his heart. Both defects were repaired by surgery at Yale-New Haven. After those people moved away, another couple rented the apartment until, in 1971, Leah and I moved in."

"How were any of us to know that the substation might have caused all that trouble," Leah said. "One of the doctors who operated on Jack came to dinner at our house in 1980, and he didn't say anything to us about the substation being across the street. All the doctors who later treated Ann were told about Jack's brain tumor and the fact that his father had died of brain cancer, and none of them seemed to think there was anything unusual. Only my sister, Brooke, made the connection between the substation and what had happened to us, and we didn't believe her."

JACK WALSTON's mother, Marian, whose sixth child was born dead in 1954, because of a premature separation, sold the house at 36 Meadow to a builder in 1976, soon after Jack's father died. The builder remodelled the house and rented it to a family. They lived there from 1977 until 1979. Then the builder sold the house to Loretta and Fred Nelson. Loretta and Fred have two children—Fred, Jr., who was born in 1968, and Joyce (Missy), who was born in 1972—and they bought the house at 36 Meadow for thirty-seven thousand dollars in September of 1979, just at the time Jack Walston's brain tumor was diagnosed.

"About a year after we moved here, Joyce began to lose her face," Loretta recalls. "Her face was shrinking and hollowing out. In the spring of 1981, she developed a strep throat and a high fever, and her urine turned a dark-brown color. I was working at the electronics plant, so Fred took her to our pediatrician. He said she had a kidney problem, and sent us to



SUMMER READING

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Dr. Norman Siegel, a nephrologist at Yale-New Haven Hospital. Dr. Siegel performed a biopsy on her in May, and that's when he told us that she had glomerulonephritis and had lost thirty-five per cent of her kidney function. Other physicians at the hospital then diagnosed her lipodystrophy—the breakdown of fatty tissue that was causing her to lose her face. The combination of the two is extremely rare. In fact, Joyce was only the second case they had ever seen at Yale-New Haven. The doctors told us they didn't know what caused it, and we had no reason then to think that it might be associated with the substation here on Meadow Street, but now that we look back and think about all the cancer and headaches in this neighborhood we've begun to wonder. All of us—Fred, Sr., and Fred, Jr., and Missy and me—have had fierce headaches since we came to live here. A lot of other people on the street have them, too. The Brunelles, next door, for example, and a family who live up on the corner of Meadow and Water. And that's not all. Six months ago, Fred, Sr., developed a bump the size of a quarter on the back of his left hand, which got sore and caused him to lose the grip in his fingers. It turned out to be a keratoacanthoma, which is a benign tumor, and it had to be removed by a plastic surgeon. I'm afraid of the substation now. I keep remembering the couple who used to live next door to the big substation in Branford, in a frame house on Mill Plain Road, where the brick apartment buildings are now. The husband lived there in the middle nineteen-sixties, and when he was in his late twenties he died of cancer. It was all over his body. His wife also got cancer. I found out when I met her in the early nineteen-seventies at the hairdressing academy, while I was getting my hair cut. She told me she'd had chemotherapy. One of my biggest worries these days is Fred, Jr. He joined the Airborne two years ago, when he was nineteen. He was stationed at Fort Bragg, North Carolina. Last year, when he was at Edwards Air Force Base, in California, they gave him an X-ray and told him he had either a tumor growing in his side or an extra rib. My other worry is little Amber, Missy's baby. When my friend Jane Harrison, who works with me at the electronics plant, heard that Melissa Bullock, next door, had brain cancer, she said we ought to get the baby off the street."

Loretta had become friends with Melissa's mother, Suzanne, when both were living in Branford during the nineteen-seventies. When Suzanne and her husband, Marshall, and their two children, Melissa and Corey, moved to Meadow Street, in the winter of 1979, Loretta came to visit them on several occasions. "I wish I had a house of my own," she used to say, and eventually Suzanne and Marshall persuaded her and Fred to buy the house next door.

Neither Melissa nor Corey encountered any unusual health problems while they were growing up on Meadow Street. By the time Melissa was sixteen, and a junior at Guilford High School, she had become an exceptionally beautiful young woman, almost six feet tall, who was a star player on the girls' basketball team. She was also a straight-A student, played the flute and piano, and had plans to go to college and ambitions to become a model. However, on the night of December 29, 1988—a day before her seventeenth birthday—she suffered a grand-mal seizure on the high-school basketball court during a game against Plainville. She was taken by ambulance to the emergency ward at Yale-New Haven Hospital, and was given a CAT scan and examined by a neurologist on staff duty. He said that what he saw looked like "an old injury," and prescribed Tegretol to forestall any further seizures. She was back home in her bed in Guilford at one in the morning. The next day, Suzanne called her pediatrician, in Branford, and he referred her to Dr. Isaac Goodrich, a neurologist and surgeon in New Haven. On January 5, 1989, Dr. Goodrich sent Melissa to an outpatient radiology clinic for a magnetic-resonance-imagery examination. The M.R.I. showed a mass consistent with a low-grade tumor in the posterior lateral portion of the brain beside her left ear. Dr. Goodrich told Suzanne that it was a fairly common tumor, and was probably Grade One—that is, small—and nonmalignant, but that it should be removed as quickly as possible.

On January 19th, Dr. Goodrich operated on Melissa at the Hospital of St. Raphael, in New Haven, and removed the tumor, which was so close to the optic nerve controlling right-side vision that he warned Suzanne that Melissa's sight on that side might be impaired. He sent tissue samples from the tumor to the hospital's pathology laboratory for testing, and when the final result came back, a day later, he didn't believe it, so he sent a sample to Yale-New Haven Hospital for another opinion. The report that came back from Yale-New Haven was the same as the report from the first lab: Melissa had developed a Grade Three astrocytoma—advanced malignant tumor of the brain.

"Dr. Goodrich was real shook up when he told me the news," Suzanne recalls. "He took it very badly. The tumor had become encapsulated, and that may have made the original CAT scan and subsequent M.R.I. diagnoses difficult. In any event, the cancer had spread far enough into the brain so that the prognosis for Melissa now had to be guarded. Late in January, Dr. Goodrich recommended that she begin radiation therapy, and starting in February she received two hundred rads in each of twenty treatments—five days a week for four weeks—at Yale-New Haven's Department of Therapeutic Radiology. She never got sick from the radiation, but she lost all her beautiful blond hair. Then, on March 27th, she went back to Yale-New Haven, and Dr. Joseph Piepmeier, a neurological surgeon, drilled two burr holes in her skull around the tumor site, inserted plastic tubing in each of them, and placed three seeds—tiny metal balls containing radioactive iodine—in each tube. The idea was that the iodine seeds would radiate outward and kill any cancer cells that remained in her brain. While she was in the hospital recovering from the operation, she suffered a full focal seizure, and they had to give her a huge dose of phenobarbital to pull her out of it. She also had trouble breathing and had to go on a respirator, but she was in top physical shape, because she's an athlete, so she bounced back quickly, and in two days she was able to come home.

"Dr. Goodrich had recommended that she undergo chemotherapy as well, and in June we went to Dr. Leonard Farber, an oncologist in New Haven. He gave her the first of two doses of an anticancer drug called CeeNU. She missed half a year of school, but, thanks to the homebound-studies program, she was able to start her senior year last fall. Since the operation, however, she has had trouble reading, and has gone from a Level One student—someone who gets straight A's—to Level Two. What happens is she'll get stuck on a word and lose the context of a sentence. She also has trouble understanding abstract concepts, such as irony. She often misuses words that have a similar sound—for example, 'pole' for 'pool.' In addition, she has lost part of her vision. In fact, from about one to four-thirty on the right side of both eyes she has a total blackout. She's back on the basketball team, though, playing first string and compensating amazingly well, considering her handicap.

"The strange thing about all this is that my mother, who's a retired registered nurse, never wanted me to move to Meadow Street. She was suspicious of living so close to a substation. Around the time Melissa's tumor was diagnosed, Loretta and I talked about the unusual number of cancer cases there had been on the street, so I asked Dr. Goodrich about it. I asked him if there was any chance that the substation was causing it and if the same thing could happen to Corey. In fact, I wanted Corey to have a CAT scan, but Dr. Goodrich said there was only a one-in-a-hundred-thousand chance of anything like that happening to him. Later, I read an article in a women's magazine about a study showing cancer in children who lived near high-current power lines. And recently I heard about a Vietnamese boy who got leukemia while living up on River Street, on the other side of Water, near the same high-current wires that come past our house here on Meadow. A few months ago, I developed a cyst in my breast, which my doctor tells me is going to have to be monitored with mammography every three months from now on. It seems there's no end to the disease around here, so if it isn't the substation that's causing it, what can it be?"

MALIGNANT brain cancer is a rare disease in the United States, striking about one in every twenty thousand people each year. Nonmalignant meningioma is even rarer, occurring in about one in a hundred thousand people annually. The rates for brain cancer and meningioma in Connecticut are approximately the same as for the rest of the nation. Thus, to have two brain cancers and two meningiomas occurring in a span of twenty years among a handful of people living on a street of nine houses in Connecticut, or, for that matter, anywhere else in the United States, would be highly unusual—indeed, extraordinary—in and of itself. But the situation on Meadow Street is probably even worse than it appears, for the simple reason that when a thorough investigation of the health experience of its residents over the past thirty or forty years is conducted the cancer rate will undoubtedly have to be revised upward. Good reason for thinking so comes from the fact that just a few weeks ago it was learned that still another resident of the street, Mrs. Judith Lehman Beauvais, had developed cancer. She was born in 1941, and she lived at 56 Meadow, within a few feet of the high-current wires that cross over from the substation, from the time she was seven until she was twenty-one. Then she married and went to live on Mulberry Point Road, in Guilford. Five years ago, at the age of forty-four, she developed a malignant tumor of the optic nerve behind her left eye. It was treated with radiology at Yale-New Haven Hospital, leaving her partly blind in that eye and with limited vision in the other.

The fact that two malignant brain tumors, a malignant eye tumor, and a nonmalignant brain tumor have developed in people living in four adjacent houses on Meadow Street which are situated across from the substation and close to its high-current wires, together with the fact that the other nonmalignant brain tumor occurred in a woman who lived just a few houses away, speaks for itself. The fact that one of the brain cancers has been found in a seventeen-year-old girl, whose chances of developing such a neoplasm are only about one in fifty thousand, makes the substation additionally suspect. So does the fact that a nonmalignant ovarian tumor occurred in a twenty-five-year-old woman who had lived most of her life at 36 Meadow, and that her niece—a thirteen-year-old girl, who had lived for eleven years at 48 Meadow—developed a nonmalignant tumor on her tibia.

Moreover, these tumors are simply some of the more serious afflictions that have beset the inhabitants of the dwellings at 28, 36, 48, and 56 Meadow over recent years. Ann Walston not only developed the tibial tumor at the age of thirteen but suffered brain seizures when she was fifteen, and has since developed—and been operated on for—painful and disabling ganglion cysts of the wrist. Her mother, Leah, who had suffered a miscarriage while living at 48 Meadow during the early nineteen-seventies, underwent surgery for painful and debilitating cysts during the early nineteen-eighties, and, more recently, had to have an inflamed parotid gland removed from her cheek. Leah's sister, Brooke, suffered brain seizures during the early nineteen-seventies, when she was in her late twenties, and shortly after visiting the house at a time when the substation was struck by lightning, causing it to blow up and send powerful transient electromagnetic pulses throughout the neighborhood.

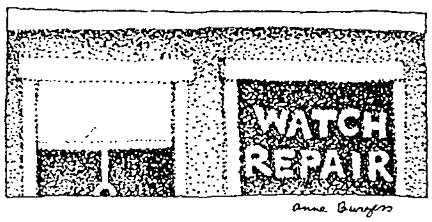
Fred Nelson, who has lived at 36 Meadow for the past ten years, recently developed a disabling growth on one hand, which had to be removed by surgery. By the age of sixteen, his daughter, Joyce, had developed glomerulonephritis and partial lipodystrophy—a kidney disease and a fatty-tissue disorder—which are extremely rare in combination and may be the result of some environmental insult. And Suzanne Bullock, the mother of Melissa, has been found to have a suspicious-looking cyst in one of her breasts.

Also disturbing is the extraordinary incidence of birth defects in children who were conceived and carried at 48 Meadow. Serious birth defects occur in about one in every twenty children who are born in the United States. However, no fewer than five of the nine children who were born to parents living in this house during the ten-year span from the middle nineteen-fifties to the middle sixties—it was during that time that the substation across the street was enlarged to handle higher and higher voltages—were afflicted with serious congenital anomalies. Two other children—Ann Walston and her brother, Jonathan Walston IV—developed either spinal or ligamental disorders as they grew. Additionally unsettling is the fact that a great majority of the residents—both children and adults—of 36 and 48 Meadow during the past twenty years have experienced excruciating and recurring headaches.

During the past thirty-five years, the fifty or so children and adults who were living in the four adjacent houses on Meadow Street which are opposite the substation have been seen hundreds of times for their various ailments by local physicians and pediatricians in Guilford and Branford, and those doctors have sent most of the patients whom they found to be suffering from serious illness, or disease they could not identify, to the Yale University School of Medicine's Yale-New Haven Hospital for examination, diagnosis, and treatment by a battery of oncologists, neurologists, nephrologists, geneticists, anesthesiologists, neurological surgeons, orthopedic surgeons, pathologists, radiologists, and chemotherapists —specialists who, depending upon the individual case, have proceeded to question them about their symptoms and family medical histories; to give them CAT-scan, X-ray, and EEG examinations; to delve into their brains and innards; to excise their malignancies, tumors, and other growths; to suture their wounds; to give them postoperative radiology and chemotherapy; to prescribe all manner of drugs and medicines; and to conduct follow-up examinations, without asking any of these patients about the neighborhood in which the patient lived. However, even if the cluster of malignant and nonmalignant tumors of the brain among the residents of Meadow Street had come to the attention of the doctors at the Yale School of Medicine, or if local health officials had become curious enough to stick pins denoting malignant neoplasms, nonmalignant tumors, and serious birth defects into a detailed street map of Guilford and thus been confronted by a forest of pins on Meadow Street near the substation, the physicians might have ascribed it to chance statistical variation—the rubric under which members of the nation's medical and scientific community have long chosen to file away (and avoid dealing with) cancer clusters. As for the particular cancer hazard posed by electromagnetic emanations from power lines and substations, the physicians are for the most part keeping silent until it appears safe to speak out—just as they did with the asbestos-cancer epidemic that will end up killing hundreds of thousands of shipyard and construction workers, and as they have done with the ongoing destruction of the ozone layer by chlorofluorocarbons, which, by significantly increasing the amount of harmful ultraviolet radiation reaching the earth, will inevitably result in a greatly increased incidence of malignant melanoma. In short, before the physicians and the scientists feel free to acknowledge that substations and high-current power lines constitute a serious public-health hazard, it will undoubtedly be necessary to identify some additional Meadow Streets.

Unfortunately, this turns out to be not difficult to do. For example, in May of 1989, Dr. Sorrell Wolfson, a sixty-three-year-old physician, who is the director of the Salisbury Radiation Oncology Center, in Salisbury, North Carolina—a city of twenty-five thousand inhabitants about forty miles north of Charlotte, in Rowan County —had four brain-tumor patients referred to him for treatment in a single week. Wolfson, a native of Tampa, Florida, received his medical degree from the Vanderbilt University School of Medicine, in Nashville; did a two-year residency in pediatrics at the University of California Medical School in San Francisco; and then had a year's fellowship in pediatric oncology and hematology at the Memorial Sloan-Kettering Cancer Center, in New York City. After completing his training, he returned to Tampa and spent the next twenty-two years treating children who had developed cancer and various blood diseases. During that time, he was a professor of pediatrics at the University of Florida, in Gainesville, and at the University of South Florida, in Tampa, where he became chairman of the Department of Pediatrics.

Discouraged because he was seeing many of his young patients die, Wolfson gave up his pediatric practice in 1980 to study radiation oncology, and since 1983 he has specialized in treating cancer with radiation therapy —first in Tampa, and then, starting in October of 1988, in Salisbury. Because he had treated only a few brain-tumor patients during the five years he practiced radiation oncology in Tampa,



and only one brain-tumor patient during his seven months in Salisbury, he was naturally surprised to have four cases referred to him in a single week. He became concerned when he learned that all four patients lived near the small town of China Grove, which is in the southwestern part of Rowan County, about ten miles from Salisbury, and he became even more concerned when his interviews with them revealed that six other people from that area had also developed brain tumors in recent years. At that point, Wolfson called the Rowan County Health Department, and was referred to Dr. C. Gregory Smith, an epidemiologist with the Environmental Epidemiology Branch of the North Carolina Department of Human Resources, in Raleigh, and Dr. Smith sent him a set of cancer-cluster-investigation forms to fill out.

After verifying the ten brain-cancer cases in southwestern Rowan County through the medical records of hospitals in which they had been treated, Wolfson returned the cancer-cluster forms to Dr. Smith on June 21st. The ten cases went back to 1978, and all ten were primary brain cancers; that is, they had originated in the brain, and not metastasized there from elsewhere in the body. On July 5th, Smith wrote back to say that he planned to discuss the cases with an epidemiology intelligence officer from the Centers for Disease Control (C.D.C.), in Atlanta, who was scheduled to join the state's epidemiology branch on August 1st. Wolfson was elated to hear this, and two days later he gave a long interview to Rose Post, a reporter and columnist for the Salisbury *Post*. She then wrote a two-part series on the cancer cluster, which appeared in the newspaper on July 9th and 10th.

In the first article, Post quoted Wolfson as saying that since the incidence of brain tumor was one in twenty-five thousand in the general population each year, four brain cancers were "a huge number for anybody to see in a week's period of time." Dr. Smith, for his part, told Post that the cluster "could be coincidence," and that the basic question to be answered was whether it had occurred by statistical chance or because of specific risk factors.

In the second article, Smith was even more cautious in his remarks to Post. He told her that his organization received reports of "perceived clusters" each week but did not investigate all of them. After noting that one out of every four people develops some form of cancer in his or her lifetime, Smith said that because there were so many retirement communities in North Carolina "you can go door to door and find lots of cancer." He went on to tell Post that his office was interested in the cluster that Wolfson had reported because it "involves a relatively rare type of malignancy over a relatively short period of time." He said that the state study would require statistics on brain cancer in Rowan County and in the surrounding counties, but that North Carolina's cancer-incidence registry was only two years old, so "unfortunately, all we have in the way of cancer statistics at this time are death certificates." He assured Post that the state investigators would look into the life styles and occupations of the brain-cancer victims and also into any family history of cancer.

On July 12th, a third article by Rose Post appeared. She wrote that Dr. Wolfson had learned about twenty-four new brain-tumor cases in Rowan County that week, including another possible cluster of cases in the Trading Ford-Dukeville area—two small communities about five miles northeast of Salisbury, near the Duke Power Company's Buck Steam Plant, on the Yadkin River. The next day, she wrote that four additional cases—all of which, like the twenty-four previous ones, were unconfirmed—had been reported, bringing the total to twenty-eight. Dr. Smith said he was not surprised by this. "That's not uncommon," he told Post. "Many times that's what happens when a cancer cluster is reported to the media." Smith went on to say that the state would investigate and verify all the newly reported cases, and take special note of whether they were primary brain cancers. "It's very common for many other types of cancer to metastasize to the brain," he said. "Most lay people don't realize that." Smith advised Post against going out and interviewing any of the cancer victims herself, observing that untrained people asking questions might provide patients with information that "becomes part of their knowledge base and part of their answers," and "may be woven into their recollections of their own life experiences." He also pointed out that cancer-cluster reports "can turn into a firestorm pretty quickly," with the result that "everybody gets upset and makes urgent demands for things to be done, sometimes unreasonable demands."

After the publication of this fourth article, Post was unable to make further contact with Dr. Smith; he informed her that the epidemiology branch was receiving so many requests for interviews from television reporters, radio stations, and other segments of the news media that she would henceforth have to go through the Department of Human Resources' public-relations office. Meanwhile, other researchers joined him in expressing doubt that the pending investigation would turn up anything of much importance. "It's extremely rare that a study of what appears to be a cluster comes up with any likely cause," Leslie Boss, an epidemiologist at the Centers for Disease Control, told Pam Moore, another writer for the Salisbury *Post*. Boss went on to say that such studies "consume a tremendous amount of time and a tremendous amount of money," but that "from a political point of view" they had to be carried out. Boss noted that three or four people could be expected to die of brain cancer each year in Rowan County, but that "we don't get as excited about" the fact that there were thirty to thirty-five deaths from lung cancer and about thirteen deaths from breast cancer in the county each year. Dr. Glyn Caldwell, who said that he had participated in studies of more than a hundred cancer clusters during eighteen years he had spent at the C.D.C., agreed with the tone of Boss's remarks. He told Moore that he had never worked on a brain-cancer cluster, but that he was unaware of any such cluster in the United States which researchers had been able to authenticate. He went on to suggest that the new doctor in town (Wolfson) "may be the cause of the cluster"—meaning that the cases could have existed for some time and it was only Wolfson's own discovery of them that made them appear significant.

On July 18th, the *Post* ran a story by Rose Post about the reported link between exposure of electric-utility workers to electromagnetic fields and the development of brain cancer and leukemia. On this subject she interviewed David Savitz, an epidemiologist at the University of North Carolina, in Chapel Hill. He told her that he and some colleagues were conducting a study to determine whether power linemen and power-station operators were more likely to be afflicted with brain cancer and leukemia than other utility workers, such as office personnel and truck drivers, who do not have the same exposure to electromagnetic fields. (The study was being financed by the Electric Power Research Institute, or EPRI—an organization in Palo Alto, California, that is, in turn, financed by major utility companies across the nation. For nearly twenty years, EPRI has sponsored research on power-line health effects which has advanced the proposition that the electromagnetic fields given off by power lines do not pose significant health hazards.) Savitz had previously conducted a study for the New York State Power Lines Project, which confirmed an earlier finding, by the epidemiologist Nancy Wertheimer, of Boulder, Colorado, that children living near high-current wires developed cancer (including brain cancer) at twice the rate of children who did not live near such wires. However, he did not tell Post that just a few weeks earlier, at the annual meeting of the Society for Epidemiologic Research, he and a colleague had presented disturbing findings about deaths from brain cancer among electrical workers. Savitz and his associate, who subsequently published their results in the *American Journal of Epidemiology*, had analyzed 410,651 deaths—among them 1,095 deaths from malignant brain tumors—occurring in sixteen states that participate in an industry-and-occupation-coding program of the National Center for Health Statistics, and had found that electrical workers had a fifty-per-cent greater rate of death from brain cancer than other workers.

In gathering material for her July 18th article, Post also interviewed Michael Mullen, a spokesman for the Duke Power Company, in nearby Charlotte. He told her that Duke Power was affiliated with EPRI, and that the weight of evidence of studies done during the past few decades "gives us confidence that we are providing electricity to our customers in a safe manner."

Post devoted a major portion of this article to the cluster of brain-cancer cases that Dr. Wolfson had reported from the Trading Ford-Dukeville area, near the Duke Power Company's Buck Steam Plant. That section read:

> Two people who grew up as neighbors in the Dukeville community adjacent to the Buck Steam Plant have raised questions since members of both familes died of brain cancer.
>
> Bill Gilland's mother, Edna Gilland, died of primary brain cancer in January, 1988. "When she died," he said, "we started thinking of the people in that community who had died of the same thing."
>
> He listed seven people. Two died 10 or more years ago, but the other five have died within the past three years.
>
> Those names have been turned over to Dr. Sorrell Wolfson, director of the Salisbury Radiation Oncology Center. Wolfson prompted the study here when he contacted the Environmental Epidemiology Branch, State Division of Health Services, after he became concerned about four current brain-tumor cases in southwestern Rowan. Those four led to information about six others in the same area. All 10 cases have been verified.
>
> OTHER CASES
>
> The Post asked Duke Power about the study after questions were raised by relatives of people with brain cancer in China Grove and Trading Ford. The New York Times reported last week that accumulating scientific evidence had convinced many that there is cause for concern.
>
> On that [the Dukeville] list is Walter Koone, who died of a brain tumor in March, 1986, right after his 50th birthday.
>
> Koone's sister, Margaret Koone Murphy, who now lives in Las Vegas, Nev., believes there's enough evidence of a connection to warrant further study.
>
> "It's kind of amazing," she said, that so many people with brain tumors can be counted who worked at the power plant and lived in a community that had—at most—300 people.
>
> "I don't know what caused it," she said, "but I think there has to be something, whether it's food, water, or the electromagnetic field. I just feel like the numbers are too high." If the normal incidence of brain cancer is one in 25,000, "and you have that many brain cancers, not considering other types of cancer that people in this area have, it's a high number."
>
> Mrs. Murphy and her two brothers grew up in Dukeville village. Their father, who died Aug. 23 with cancer of the lung, worked at Buck Steam Plant all his life.
>
> "And I'm home now," she said, "nursing my mother back from cancer of the breast."
>
> Her brother, Walter, lived in the village until he graduated from high school. After four years in the Army, he moved to Belmont where he worked at the Allen Steam Plant until he died. Her other brother lives in Mount Holly and works for a Duke Power plant.
>
> "My mother still lives on Dukeville Road," she said, "about a mile from the plant. Mrs. Gilland was my mother's closest friend."

Since health officials in North Carolina had been playing down the importance of the initial brain-cancer cluster, reported by Dr. Wolfson, it may not seem surprising that neither Dr. Smith nor anyone else at the state epidemiology branch apparently made any attempt to follow up the information about the incidence of brain cancers in the Trading Ford-Dukeville area which had been provided by Rose Post in the Salisbury newspaper. Somewhat more surprisingly, no other North Carolina newspaper, and no television or radio station, picked up Post's story. On January 6th of this year, however, the Charlotte *Observer* ran a long piece about the controversy over whether electromagnetic fields can cause cancer and other disease. The article quoted a review, prepared in 1989 for Congress's Office of Technology Assessment, stating that "the emerging evidence no longer allows us to categorically assert that there are no risks" entailed in exposure to electromagnetic fields, and that there was "some evidence to support the possibility that exposure can act as a cancer promoter." The *Observer* piece also cited the findings of the study recently conducted by Genevieve Matanoski, the epidemiologist at Johns Hopkins; namely, that the incidence of brain tumors among forty-five hundred New York Telephone Company cable splicers—men whose work near power lines and substations exposes them to electric and magnetic fields—was almost twice as high as that of the company's office workers, and that their leukemia rate was seven times as high. Nancy Wertheimer told the newspaper that a majority of the scientific studies conducted since 1979 showed that there was an association between exposure to electromagnetic fields and the development of cancer. However, Dr. Philip Cole, the chairman of the Department of Epidemiology of the University of Alabama, who had appeared at a 1987 congressional hearing to support the position of EPRI that power-line fields did not pose a health hazard, said that the findings of the studies were inconsistent, and added, "My own conclusion is that there's nothing going on here." David Savitz, for his part, declined an invitation from the newspaper to advise people to reduce their exposure to electro-

"Sorry, Chief, but Bianca Jagger is here to check on human-rights abuses."

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magnetic fields. Doing nothing "may not be irrational," he told the *Observer*. This seemed an unusually sanguine observation from the author of a study that reported finding nearly twice the expected number of cancer cases among children living near high-current wires; and, as it happened, Savitz was about to publish a new analysis of data from the same study, showing four times the expected rate of brain cancer in children whose mothers used electric blankets in their first trimester of pregnancy, as well as higher than expected levels of leukemia.

In any event, the members of the North Carolina Environmental Epidemiology Branch had been doing essentially nothing about the cluster of brain cancers in Rowan County which had been reported more than six months earlier. Dr. Smith's plan to turn the cases over to the epidemiology-intelligence officer from the C.D.C. in August of 1989 apparently had not worked out, because at the end of this March—ten months after Dr. Wolfson reported the first ten brain cancers in southwestern Rowan County, and eight and a half months after Rose Post wrote about a second brain-cancer cluster, in the Trading Ford-Dukeville area—Dr. Peter Morris, a state epidemiologist, went to Salisbury and spent two days interviewing the families and the surviving victims in nine of the initial ten cases.

A week or so before Morris conducted these interviews, he told Post that the state had already studied mortality rates for Rowan and the surrounding counties, and that "nothing out of the ordinary is going on in the area as a whole, for brain cancer, at least." He said that he intended to ask for detailed occupational and residential histories in the nine cases, "to see if there is anything these people have in common, or that a large proportion have in common." He went on to say that it could be significant, for example, if many or all of the brain-cancer victims had worked in the same plant twenty years ago. He also said that he did not expect the interviews to provide any definitive information, because cluster studies generally provide only suggestive information. During his stay in Salisbury, Morris did not visit Trading Ford or Dukeville, and when he was asked if he had reviewed the reported cases of brain cancer that Dr. Wolfson had sent to the epidemiology branch from that area he said he had not.

If Dr. Morris and his colleagues at the epidemiology branch had investigated the brain-cancer cluster reported among residents of the Trading Ford-Dukeville area, they would have discovered that all seven victims of the disease had indeed had something in common: they had worked at the Buck Steam Plant or had lived in Dukeville, a village of eighty-six houses, for married workers and their families, and a dormitory, for single workers, which the Duke Power Company had built near the plant, so that its employees could walk to work. Indeed, Dukeville was situated not only close to the plant but also adjacent to a large substation, where the medium voltages produced by the plant's alternators were raised to two hundred and thirty thousand volts and sent out over more than half a dozen transmission lines radiating from the plant, to carry electrical power throughout the central Piedmont.

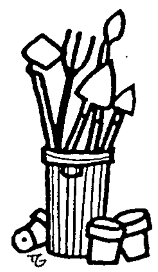
The Buck Steam Plant—it was named for James Buchanan (Buck) Duke, who died in 1925—was built in 1926. At that time, the company constructed forty-two four-, five-, and six-room houses for its employees, and those who occupied them paid no rent and were provided with free coal for heating. Twenty-two more houses were built in 1942, when Duke Power was called upon to produce extra electricity for the war effort, and another twenty-two were built in 1945, just after the war ended. In 1955, however, the company decided to sell its real estate in Dukeville, giving the resident employees the opportunity to buy their houses for between a hundred and a hundred and fifty dollars a room. The company offered the purchasers a number of lots on either side of Dukeville Road, at the top of a hill about a quarter of a mile away, for three hundred dollars apiece. About thirty of the houses were moved to the top of the hill, which is about midway between the power plant and Trading Ford, an old riverside supply post, and most of the other houses were moved elsewhere in the vicinity.

Today, almost nothing is left of the original village of Dukeville, but the Buck Steam Plant, which was partly shut down during the nineteen-fifties and sixties, is being renovated and is scheduled to go back into operation soon. As for the three hundred or so people who lived in the village or worked at the plant (or did both), what is known of their health experience indicates that it has been unfortunate, to say, the least. In addition to the seven people who have died of brain cancer, four others, who simply lived near the plant or the high-voltage transmission lines radiating from it, have also died of the disease. Moreover, a preliminary inquiry among people living on Dukeville Road reveals that there have been at least eight deaths from leukemia, lymphoma, and other cancers among people who had either lived in the village of Dukeville or worked at the Buck Steam Plant—including the death from lung cancer of a man who never smoked. By assigning this cancer cluster to the category of chance statistical variation, the North Carolina authorities seem to have overlooked an extraordinary hazard that—like the one on Meadow Street which confronted the physicians at Yale-New Haven Hospital for so many years—has been right in front of them. As for the likelihood that the inhabitants of Dukeville and the residents of Meadow Street were exposed to similarly powerful electromagnetic emanations from the substations near their homes, it is interesting to note that, just as Jack Walston remembers going through half a dozen light bulbs a week while he and his family were living at 48 Meadow, a former resident of Dukeville recently recalled "going through light bulbs down there like crazy."

IN April of 1989, several weeks before the first brain-tumor cases were referred to Dr. Wolfson, a parent living in the neighborhood of Santa Rosa Lane, in Montecito, California—an affluent community of nine thousand people near Santa Barbara—got in touch with officials of the Santa Barbara County Department of Health Care Services to report a cluster of leukemias and lymphomas among children and young people in the area. When Dr. Alan Chovil, who is the director of Preventive Medical Services for the county, asked the California Department of Health Services, in Sacramento, to verify the report, the parent's concern was confirmed: six cases of leukemia and lymphoma—including one case of leukemia in a three-year-old child who had died earlier in the year —were diagnosed between 1981 and 1988 among residents of Montecito …teen years of age or younger. According to researchers at the state environmental-health-hazards section, that was almost five times the number of leukemias and lymphomas that would normally be expected to occur during an eight-year period in a population the size of Montecito's, and was an event that could be expected to happen by chance in only about two out of a thousand communities of that size. After receiving the verification, Dr. Chovil asked the Department of Health Services' Environmental Epidemiology and Toxicology Section to help investigate the cluster, and plans were drawn up to interview the parents of the afflicted youngsters and to conduct an environmental investigation that would include reviewing historical records for information about possible contamination of the area with pesticides or other chemicals, taking soil samples, testing drinking water, and measuring the electromagnetic fields at the local elementary school. The last factor was introduced into the study when Bronte Reynolds, the principal of the Montecito Union School, which is near the intersection of San Ysidro Road and Santa Rosa Lane, told state investigators that he and a group of parents were worried about electromagnetic fields because an electrical substation owned by the Southern California Edison Company was situated next to the school's kindergarten playground, and because an electric-transmission line crossed school property.

During the first week of August, shortly before state investigators were scheduled to interview the parents of the leukemia and lymphoma victims, the Santa Barbara *News-Press* ran a story about the cluster, by a staff writer named Melinda Burns. She reported that three of the afflicted children "live so close together"—presumably on or near Santa Rosa Lane—"that they can see each other's homes," and that four of the children had attended the Montecito Union School. Since the school has an enrollment of about four hundred students, and cancer occurs in only one in ten thousand children, the incidence of cancer among the student population of Montecito Union was at least a hundred times what might have been expected. Burns interviewed a number of people about the study that was in progress. Among them was Dr. Chovil, and he seemed ambivalent about it. "We've been trying to play it as low-key as possible," he said. "This is a tight little community, and we've been keeping in close touch with residents in the area." He also said, "There are more coincidences than you'd like to see," and added that he was "not a bit surprised that the citizens got concerned."

Dr. Lawrence Garfinkel, of the American Cancer Society, gave an assessment of the situation which sounded very much like the ones that the C.D.C. researchers had given Rose Post. "It's very, very rare to find a cause for a reported cluster," he said. "The conclusion that epidemiologists have to come to is that it's a chance phenomenon." Robert Schlag, a toxicologist with the California Department of Health Services, was even more pessimistic. "We'd like to find the cause of this," he said. "We don't think that we will." Schlag told Burns that by ruling out obvious environmental factors the state investigators would at least be able to assure the residents of Montecito that "there's no environmental hot spot here," so "they don't have to move out of town." He went on to say, however, that the cancer cluster among their children was "one of the sad facts of life," and that such a cluster "will happen again." Concerning the electromagnetic fields being given off by the substation and by the power line, Schlag said that very little was known about such radiation, and that the state was still in the process of obtaining the proper instruments to measure it.



On Sunday, September 24th—a time of the week when power demand is invariably lower than on weekdays, and when the strength of the magnetic fields given off by high-current wires is invariably reduced—staff members of the Environmental Epidemiology and Toxicology Section, who had never made electromagnetic-field measurements before, used borrowed equipment to measure the strength of the magnetic fields in a number of locations in the vicinity of the substation next to the Montecito Union School and a sixty-six-thousand-volt high-current feeder line that originates at the substation and passes forty feet in front of the school. (Curiously, no readings were taken inside the school.) Even on Sunday, however, a level of twelve milligauss was found under the power line opposite the substation, and one of four magnetic-field readings taken on the kindergarten patio was nearly two milligauss—a level just below that shown in three different epidemiological studies to be associated with twice the expected incidence of cancer among children.

The report of the state investigators, which was issued in draft form in December, under the title "Investigation of the Montecito Leukemia and Lymphoma Cluster," tried to put the best face on these measurements. "Exposure to electric and magnetic fields is an inevitable consequence of living in a society that uses electricity," it stated. "The earth has a DC [direct current] magnetic field of about 500 milligauss, and electric power lines and appliances generate AC EMF [alternating-current electromagnetic fields] of various magnitudes that decrease with distance from the source." With such language the authors of the report glossed over the fact that human evolution has occurred in the earth's steady-state, direct-current magnetic field, and ignored the fact that man-made sixty-hertz alternating-current magnetic fields will cause anything magnetic in their path, including the molecules of the human brain and body, to vibrate to and fro sixty times a second. The report went on to say that "we are all exposed to various degrees from ambient sources, household appliances, and from occupational sources," and to include a diagram of various sources of exposure which had been drawn up by EPRI.

The EPRI diagram indicated that magnetic fields close to household appliances are far stronger than those at the edge of a power-line right-of-way. It failed to point out, however, that the fields from almost all appliances fall off sharply within a few inches of their source, and that since people rarely stay as close as that to hair dryers, toasters, vacuum cleaners, and the like for eight hours a day, they cannot possibly be subjected to the same long-term chronic exposure as that of, say, a child attending a school situated within a few feet of a high-current feeder line. (Notable exceptions are electric blankets and electrically heated water beds.)

A page later, this paragraph appears:

> The Southern California Edison substation and electric lines around the school are features relatively unique to Montecito Union Elementary School. Measurements were taken around school grounds to see if the substation was responsible for EMF's higher than those measured in other places in the area and in the country and to inform members of the community who were calling the principal and the health department about this concern. Measured levels fall within the range of measurements taken in other studies. They indicate that the EMF environment around the school does not appear to be different from other parts of the country even though there is a substation nearby.

After advancing the proposition that substations and the high-current distribution wires leading from them—well known to electrical engineers as sources of powerful alternating-current magnetic fields because the wires leading from them are carrying all the current to be delivered to a given load area—do not contribute to the electromagnetic-field environment, the authors of the state report asserted that they had "found nothing that might have caused the cancers." They concluded by recommending that the California Tumor Registry "maintain the Montecito area under surveillance for cancer cases, and report yearly on trends in cancer occurrence in the area."

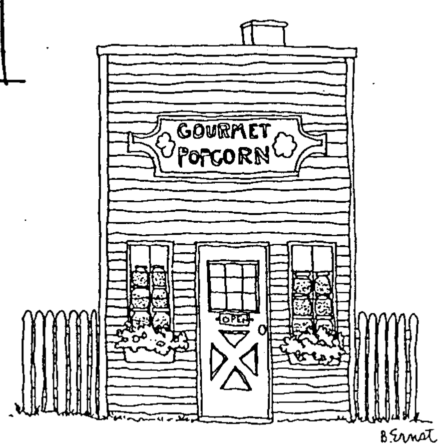
On December 14th, the day the findings of the state report were presented to more than a hundred Montecito residents in the school auditorium, *Montecito Life*—a weekly community newspaper—ran a front-page story, by a reporter named Laurie Koch Thrower, under the headline "RESEARCHERS CAN'T EXPLAIN MONTECITO'S CANCER CLUSTER." Dr. Chovil told Thrower that tests of Montecito's water showed it to be "squeaky clean," and that readings of a transformer in the schoolyard did not indicate that it was emitting any excess radiation. Richard Kreutzer, an epidemiologist with the Environmental Epidemiology and Toxicology Section, told Thrower that "nothing turned up in the investigation that explained the cases," and that "any combination of causes you can think of is possible." One possibility, of course, was that chronic exposure to sixty-hertz magnetic fields, which have been shown in experimental studies to be capable of hindering human T-lymphocyte cells from combatting cancer, could have promoted cancer in children attending the Montecito Union School by suppressing their immune systems.

Many Montecito residents were puzzled by the lack of answers in the state report. Some were distressed by the way the California authorities had measured the magnetic fields near the school. One reason for the distress was that several parents had bought gaussmeters and taken their own readings of the magnetic fields on weekdays, when their children were in school. Not surprisingly, these readings turned out to be considerably higher than the ones taken by the state investigators on a weekend. In view of this disparity, Bronte Reynolds, the school principal, said that until more was known he was in favor of shielding the power lines. (Unfortunately, that would not help, because there is almost no way to shield the magnetic fields given off by power lines.) The state investigators responded by saying that they would address the concerns that had been raised, and present additional findings in their final report.

During January and February of this year, Thrower continued to cover the story in detail for *Montecito Life*. On January 18th, she reported that Montecitans and their school representatives had been dissatisfied with the research conducted by county and state health officials, and had arranged for those officials and officials of Southern California Edison to remeasure the strength of the magnetic fields given off by the power lines near the school. John Britton, the area manager for Southern California Edison, told her that the company would coöperate fully in the new investigation. He pointed out, however, that state regulations mandating that new schools be situated at least two hundred feet from lines carrying a hundred thousand volts or more did not apply to power lines carrying less than that. Britton did not point out that a sixty-six-thousand-volt feeder line, such as the one passing within forty feet of the Montecito school, could at that distance give off magnetic fields exceeding those given off by high-voltage transmission lines at a distance of two hundred and fifty feet.

On February 8th—the day when funeral services were held for an eighteen-year-old leukemia victim who had attended the school—*Montecito Life* ran a front-page story by Thrower under the headline "CANCER STRIKES SEVENTH CHILD IN MONTECITO." The new case involved a non-Hodgkin's lymphoma that had been diagnosed a few weeks earlier in a fifteen-year-old girl who had been attending the Howard School, which is a block and a half from Montecito Union. County health officials told Thrower that they were not going to consider the case part of the cancer cluster under study, because they had found no evidence of a common denominator between it and the six original cancer cases. Dr. Chovil had another explanation. "We know we have too many cases," he said, but "if we haven't found it"—the cause—"among six, one more isn't going to help." He went on to say that so little was known about the effects of electromagnetic radiation upon health that when the results of the new measurements of the power-line fields at Montecito Union were made available he and his colleagues would not know what to do with them. "Even if we discovered all the children had been exposed to the same levels, it would not prove this was causing the cases," he said. Chovil then told Thrower that the seventh case of cancer had raised the hypothesis that "air travel could be a factor," because of the cosmic rays that air travellers are exposed to.

On March 1st, Chovil told Melinda Burns, of the *News-Press*, that the substation at the Montecito Union School was "completely irrelevant" to the ongoing study of the cancer cluster. A day later, Jack Sahl, a researcher for Southern California Edison, who was monitoring the magnetic-field measurements being made at the school, echoed Chovil's opinion. "Montecito looks like just a normal school in terms of electromagnetic fields," he said. "These fields have been here as long as Montecito has had electricity. We're confident they're not associated with the cancer cluster." After conceding that he could not guarantee that there was no danger from magnetic fields, Sahl said that more studies were needed to verify the findings of the studies that had already been conducted. Perhaps the most interesting revelation came from Chovil: he told Burns that one student at Montecito Union had been afflicted with testicular cancer but had not been included in the study, because the identified cluster did not include such cancers. This reasoning flew in the face of a number of epidemiological studies; for example, both Wertheimer and Savitz had found that deaths from cancer of all parts of the body were significantly elevated among children living near high-current wires, and Matanoski had found that cancer of all parts of the body was significantly elevated in telephone-company cable splicers.



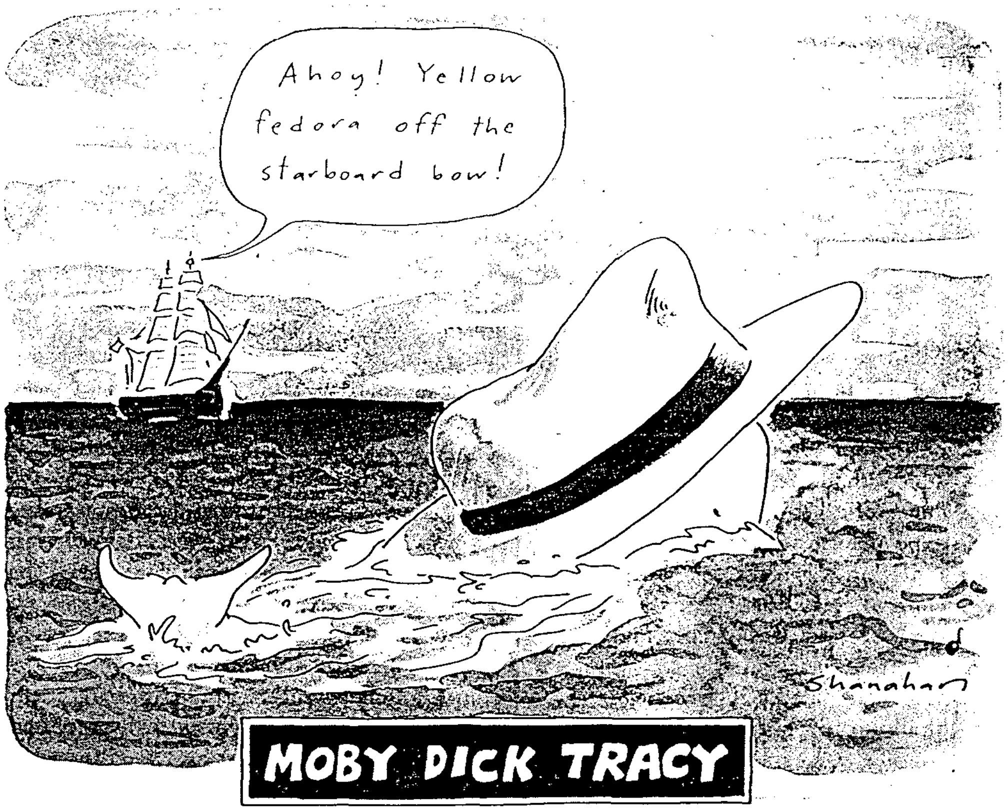
In an article that appeared in the *News-Press* on March 2nd, a staff writer named Pamela Harper reported that many parents were alarmed by reports that the substation and the high-current wires near the school might be producing dangerous magnetic fields, and that a mass exodus of students to private schools in the area was feared. Harper went on to note that Montecito had some of the most expensive homes in Santa Barbara County, and that "an underlying fear that some parents—as well as residents in the nearby neighborhood—have is that publicity about the [cancer cluster] will bring property values crashing down." And Barbara Koutnik, a real-estate agent and the mother of two children who were attending Montecito Union, told Harper that prospective buyers had recently taken several houses out of escrow, and she suspected that they might have used fear of cancer as a reason for terminating the deals.

By now, there were a considerable number of people in Montecito who wished to "keep a lid on the situation," as one member of the Montecito School Board put it, and who blamed the press for making disclosures about the cluster which could adversely affect the community. On March 8th, *Montecito Life* ran an editorial that addressed this issue head on. It began:

> To report or not to report, that is the question. At least it sometimes is in small communities, where editors are occasionally rebuked for covering events that might be perceived by some as adversely affecting the public welfare.
>
> During a recent gathering of parents at the Montecito Union School, it was suggested, from the audience, that media coverage of the possible relationship between electromagnetic radiation levels emitted by power transmission lines and the high

number of cancer cases in the Montecito Union School District was irresponsible. Panic potential was given as one reason. Unstated, but understood privately, is the effect this kind of news might have on property values. This attitude by no means reflects how most at that meeting felt. But it crops up frequently enough so that journalists must pause to consider why we relentlessly pursue the public's right to know.

The editorial concluded by declaring, "While we're not sure how Montecito residents might react to adverse information concerning the effects of power line radiation, and no case has been made at this time, our job is to provide the conduit for conveying information from reliable sources, even though we are ever mindful of the line from Shakespeare's King Henry IV that 'The first bringer of unwelcome news, hath but a losing office.' "



MOBY DICK TRACY

Meanwhile, on March 6th, Bronte Reynolds told a hundred parents who had gathered in the school auditorium that after looking at the results of the latest magnetic-field measurements he and a parents' task force would make recommendations to the school board for "immediate temporary measures" to restrict student exposure. Reynolds said that the measures might include roping off portions of the school, changing classroom seating, and calling for the rerouting of nearby power lines. Charles Cappel, a spokesman for an ad-hoc parents' committee that had called for the meeting, said that, according to Southern California Edison, burying the wires, so that the magnetic fields would cancel each other out, might also provide a solution to the problem. "We were certainly not willing to let our children be made guinea pigs in some experiment," he told Thrower. "We wanted something done now—we weren't sure what we wanted it to be—but we wanted something done, by God!" According to an account of the meeting that appeared in the *News-Press*, a Montecito resident who asked whether the authorities planned to measure the magnetic fields under high-current wires on nearby streets was told by Dr. Chovil that there were no such plans, "because at the moment EMF is not considered to be a cause of cancer." Chovil was supported in this contention by Dr. George Fisher, a physician in Montecito, who said that there was no reason to be concerned about the school, because no laboratory studies had produced cancer in animals by exposing them to magnetic fields. "It makes just as much sense to rope off your toaster, your electric blanket, your computer and your TV set," Fisher declared. "I think there's a little hysteria going on." He was evidently unaware of Savitz' findings, or that back in November—presumably as a result of the childhood-cancer studies and of other studies showing an association between electric-blanket use and miscarriages—*Consumer Reports* had advised children and pregnant women not to use electric blankets.

On March 15th, the parents' task force, in a meeting with the Montecito School Board, recommended that a determination be made whether the metal cyclone fence along the north side of the kindergarten playground was contributing to the electromagnetic field that had been measured there, and that if this was found to be the case the fence be replaced by one of wood. The task force also recommended that those portions of the kindergarten patio with magnetic fields of more than two milligauss be roped off; that benches and playground equipment on some terraces beneath the sixty-six-thousand-volt feeder line be moved farther away; that desks be removed from the southeast corner of a classroom that was near a high-voltage transformer in one of the school's parking lots; and that stripes marking ten-foot "restricted" zones be painted around the transformer and around a high-voltage circuit-breaker panel in the fire lane outside the main building.

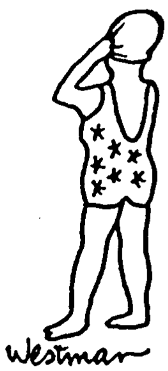
At the same meeting, the parents' task force released the preliminary results of magnetic-field measurements that had been made earlier in the month by Enertech, an engineering consulting firm in the Bay Area, and that had been paid for by Southern California Edison. The results showed levels of between four and six milligauss on the kindergarten patio and along its fence; a level of almost seven milligauss on the benches beneath the feeder line; a level of seventeen milligauss in the corner of a classroom on the southeast side of the school; and levels of between six hundred and a thousand milligauss next to the transformer in the parking lot. Obviously, these measurements were far higher than the ones taken on the Sunday in September by officials of the California Department of Health Services' Environmental Epidemiology and Toxicology Section.

At a meeting held at the school that

night and attended by about fifty parents, the school board voted unanimously to accept the task-force recommendations. "To me these measures are like buckling your seat belt," one of the board members said. "What's the harm?" This question was addressed by Dr. Fisher, who said that he was representing twelve other physicians with children at the school. According to an account of the meeting written by Melinda Burns, Fisher claimed that the school board had no business making a decision based on the opinion of laymen, and added that the scientific evidence of a health hazard from exposure to electromagnetic radiation was inconsistent and contradictory, that the magnitude of risk was small, and that the focus on the school was misguided. "We believe that significant emotional trauma will come to our children if we selectively isolate areas of the campus as potential cancer zones," he declared. Dr. Abraham I. Potolsky, a hematologist in Santa Barbara, disagreed. "It's ridiculous not to take these minimum measures to avoid these potential hazards," he said.

During the last week of May, the California Department of Health Services issued a second draft report, in which it tried once again to put the best possible face on the situation at the Montecito Union School. The report's authors declared that magnetic-field levels at Montecito Union were "not unusually high in most parts of the school," and that there was no evidence that they posed a health hazard. They went on to say that the levels near the power lines along the north side of the school, which had been found to include some distribution wires buried in an alley along the kindergarten patio, were in the five-to-thirty-milligauss range, and they described these fields as "similar to what one is exposed to when near a common electrical household appliance such as a TV or a radio." This, however, had little, if any, relevance to the situation at Montecito Union, for the simple reason that one would be exposed to five milligauss from a television or a radio only if one sat within a few inches of it, and to thirty milligauss only if one pressed one's face to certain locations on its side.

On June 1st, officials from the Department of Health Services met with members of the Montecito School Board and the parents' task force to discuss the state's report. At the meeting, Charles Cappel pointed out that a person can decide how close to get to household appliances, but that attendance at school constitutes involuntary long-term exposure. Dr. Raymond Neutra, the chief of the health department's special-epidemiological-studies program, declared that not enough was known about the effects of electromagnetic radiation to say if the levels measured at the school posed a health threat. According to Neutra, it would take at least two more years before enough data were collected to make such a judgment. Meanwhile, Southern California Edison informed school authorities that in the absence of conclusive evidence of a health hazard it would not underwrite the sixty thousand dollars necessary to unearth the wires near the kindergarten patio and move them farther away. On June 20th, the members of the Montecito School Board used similar reasoning in deciding not to underwrite the cost of moving either the underground wires or the sixty-six-thousand-volt overhead feeder line. They declared that not enough was known about the biological effects of electromagnetic radiation to warrant taking any permanent action. Six days earlier, the *News-Press* had reported something that Dr. Chovil had known since July of 1989, and that state health officials had known since December—that four cases of leukemia had developed in young children who attended the Montecito Union School in the late nineteen-fifties.



STRONG measures should, of course, be the order of the day in schools that are close to power substations and high-current wires. Unfortunately, there are many such schools —one reason being that in years past utilities have often sold company-owned land cheap to cities and towns for schools and other municipal buildings, in return for assistance in acquiring easements for new power lines and substations; another being that, because of aesthetic considerations, land is less desirable in the vicinity of power lines than elsewhere, and can thus be purchased cheaply. For the latter reason, no fewer than five elementary schools in the Fountain Valley School District, which serves both Fountain Valley (a city of fifty-five thousand, in Orange County, about thirty miles south of Los Angeles) and part of Huntington Beach (a city of a hundred and seventy thousand, just to the west of Fountain Valley), have been built on land next to an easement for a pair of two-hundred-and-twenty-thousand-volt lines and a high-current feeder line. These lines carry power for Orange County from Southern California's generating plant at Huntington Beach. As in the case of the Montecito Union School, high-current distribution wires have been buried in the ground beside many of these schools, and transformers have apparently been installed near some classrooms. As a result, magnetic-field strengths far exceeding those associated with the development of cancer in children and adults have been measured in areas immediately adjacent to several of these schools, including a level of twenty-five milligauss at the doorway of a boys' room at the Samuel E. Talbert Middle School; a level of fifteen milligauss at a kindergarten playground beside the Roch Courreges Elementary School; a level of nearly ten milligauss beside some outdoor lunch tables at the Harry C. Fulton Middle School; and a level of five milligauss in the kindergarten playground of the Tamura Elementary School. Because of resistance by officials of the Fountain Valley School District, no measurements have yet been taken inside any of these schools. The superintendent of the school district has said that the evidence of magnetic-field hazards is too inconclusive to warrant taking any action. Interestingly, in January of this year, school-district officials entered into a multimillion-dollar joint venture with a developer to build at least sixty homes on land occupied by the James O. Harper Elementary School, which was shut down five years ago, and is next to the same power-line right-of-way as the other schools.

Not surprisingly, serious magnetic-field hazards exist elsewhere in Fountain Valley. Levels as high as twenty-five milligauss can be measured at a public playground directly under the two-hundred-and-twenty-thousand-volt lines in the right-of-way; levels of fifteen milligauss can be measured near houses built alongside the high-current feeder line on the north side of the power-line corridor; and similar levels can be found in a number of neighborhoods traversed by other high-current distribution wires. Up to this point, no studies have been conducted of the health experience of children who have attended schools near the power-line right-of-way, or who live near the right-of-way or in the vicinity of other high-voltage or high-current lines. However, a preliminary survey gives some cause for concern. An eleven-year-old girl at the Fulton school, who previously attended Courreges, and lives near a high-voltage line, has been afflicted with ovarian cancer, and has undergone several operations—including a hysterectomy, and chemotherapy. A two-year-old girl who lived directly opposite the Courreges school, in a house next to the high-current feeder line in the right-of-way, died of leukemia. And a five-year-old boy living in a house close to a high-current feeder line on Magnolia Street—a main thoroughfare—suffered cancer of the eye, and lost the eye.

Farther south, in La Jolla—a wealthy community of thirty thousand inhabitants, which is on the Pacific Coast, about fifteen miles north of San Diego—concern expressed last February by the parents of an eight-year-old girl, who had developed precancerous lesions on her head, resulted in the San Diego Gas & Electric Company's measuring magnetic-field strengths at the four-hundred-and-seventy-pupil Bird Rock Elementary School, where the child is a student. The school is within a few feet of a pair of high-current distribution wires that run along La Jolla Hermosa Drive. In spite of the fact that a level of more than five milligauss was found in the school auditorium, and a level of nearly four milligauss at the kindergarten jungle gym—both of which are situated on the side of the school nearest the power lines—company officials assured the parents of children attending the school that the readings were "quite low," posed no hazard, and could be found throughout the community.

In April, Stellan Knöös, a physicist and engineer, two of whose children attend the Bird Rock school, measured magnetic fields there, using a state-of-the-art gaussmeter manufactured in Sweden. Knöös, who was accompanied by Douglas Adams, the safety coördinator for the San Diego Unified School District, not only corroborated the measurements that had been taken by San Diego Gas & Electric but also found magnetic-field levels of eight milligauss at the typical eye position of children using color-display monitors in the school's crowded computer room. (Recent measurements of some color-display monitors show that many of them routinely emit levels of over four milligauss at a distance of twelve inches from their screens, and up to fifteen milligauss at the same distance from their sides.)

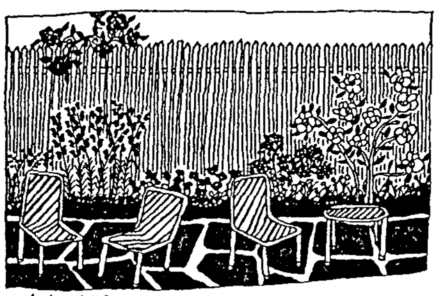
Early in May, Knöös, again accompanied by Adams, measured magnetic-field levels of between six and almost eighteen milligauss in three classrooms at the Brooklyn Elementary School, which is in the Golden Hill section of San Diego, just a few feet from a high-current feeder line that runs along Fern Street. In a report to the school district on May 17th, Knöös recommended that classrooms with magnetic-field levels between two and four milligauss be marked for limited use only; that classrooms with levels above six milligauss be closed immediately; and that a thorough analysis be made of the health records of the children who attend the school. Elsewhere in San Diego, the magnetic-field hazard is extensive, as it is in virtually every other city in the nation. Strong magnetic fields can be measured, for example, near hundreds of homes close to high-current feeder lines emanating from a substation at El Cajon Boulevard and Iowa Street, and very strong fields can be measured at the four-story Kearny Villa Medical Center, on Kearny Villa Road, in Kearny Mesa, which is situated a few feet from a high-voltage line that runs along Route 805 and feeds into the substation from the north.

The danger posed by substations and nearby high-current feeder lines appears to be particularly acute. Nancy Wertheimer, in her investigation of the association between alternating-current magnetic fields and childhood-cancer deaths, discovered that of the six children in her study population who had lived within five hundred feet of a power substation and within a hundred and thirty feet of a high-current feeder line coming from the substation, all were cancer victims—four of leukemia, one of a nervous-system tumor, and one of a sarcoma. Since her study population consisted of three hundred and forty-four children who had died of cancer and a matched control group of three hundred and forty-four living children, Wertheimer believed this to be a highly unusual finding. "Although these numbers are small, they are striking," she wrote in the March, 1979, issue of the *American Journal of Epidemiology*, and pointed out that "each cancer case had lived at the substation address within three years or less of his illness."

Wertheimer's finding seems all the more striking in view of the extraordinary incidence of cancer among the residents of Meadow Street, the residents of Dukeville Road, and the children attending the Montecito Union School. The cancer victims on Meadow Street and in the Montecito school were spending a good part of each day within a hundred feet or so of a power substation and within fifty feet or so of high-current wires leading from the substation, while most of the cancer victims in the Trading Ford-Dukeville area had either worked at the Buck Steam Plant or lived in the company village, both of which were adjacent to a large substation and to more than half a dozen high-voltage transmission lines that were surely giving off very strong electric and magnetic fields. In all three situations, people were afflicted with brain cancer and brain tumors or with leukemia and lymphoma at rates far greater than the expected incidence of these diseases in the general population.

Since many, and perhaps most, of the residents of Meadow Street and Dukeville were undoubtedly subjected daily to magnetic-field levels approximating those to which electricians, power-station operators, and power and telephone linemen are exposed, and since children attending the Montecito Union School were similarly exposed to magnetic-field levels approximately half as strong as those associated with a sevenfold increase of leukemia among telephone-company cable splicers, it seems appropriate to point out that during the past ten years nearly two dozen epidemiological studies have been conducted and published in the peer-reviewed medical literature here and elsewhere in the world, showing that electricians, power-station operators, power and telephone linemen, and other workers whose occupations expose them to electromagnetic fields develop and die of leukemia, lymphoma, brain cancer, and brain tumors at rates that are significantly higher than those observed in unexposed workers. The first of these studies was conducted by Dr. Samuel Milham, Jr., a physician and epidemiologist with the Washington State Department of Social and Health Services, in Olympia. Milham examined the data for four hundred and thirty-eight thousand deaths occurring among workingmen in Washington between 1950 and 1979, and he noticed that among men whose occupations required them to work in electric or magnetic fields the ratio of deaths caused by leukemia was higher than the proportionate mortality ratio in ten out of eleven occupations he investigated. Milham's findings, which were published as a letter in the *New England Journal of Medicine* in July of 1982, have since been supported by similar findings among electrical workers in Los Angeles, New Zealand, Canada, and southeastern England.

Even more striking has been the growing evidence of a link between such exposure and brain tumors. This link was recently examined in some detail by Louis Slesin, the editor and publisher of *Microwave News*, which is a newsletter that reports on non-ionizing radiation and is published six times a year in New York. In the March-April, 1990, issue of the newsletter, Slesin pointed out that, according to a study in the medical journal *The Lancet*, brain-cancer deaths had nearly tripled among older white men and women in the United States between 1968 and 1983, and he went on to list no fewer than twelve studies conducted, published, or reanalyzed between 1985 and 1989 that showed significantly increased rates of brain tumors among people exposed to electric and magnetic fields at home or at work. Among the studies were an investigation revealing that a higher than expected number of white male residents of Maryland who were employed as electricians, electrical and electronics engineers, and utility servicemen had died of brain tumors between 1969 and 1982; an analysis by Dr. Milham of data from his earlier survey showing that electricians in Washington State experienced a fifty-five-per-cent greater risk of dying of brain tumors than other workers; and a 1988 study of people who had died of brain cancer in East Texas between 1969 and 1978 which showed that the risk for electric-utility workers was thirteen times that of workers who were not exposed to electromagnetic fields. Also included was the recent finding by Genevieve Matanoski and her associates at Johns Hopkins that telephone-company cable splicers are afflicted with brain tumors at almost twice the rate of other workers; a 1989 study by Susan Preston-Martin and some colleagues at the University of Southern California School of Medicine, in Los Angeles, showing that men with high exposure to electric and magnetic fields were more likely than other workers to develop brain cancers, such as gliomas, particularly astrocytomas; an analysis of data from the earlier childhood-cancer study by David Savitz and his colleagues, which found that children living near high-current power lines are almost twice as likely to develop brain tumors as children living near low-current wires; and another finding by Savitz and an associate that electrical and electronic technicians develop brain tumors at three times the rate of workers who are not exposed to electromagnetic fields, while electric-power repairmen and installation workers develop such tumors at more than twice that rate. Particularly disturbing were the results of a study published in 1989 in the *International Journal of Epidemiology* by Christine Cole Johnson, the head of epidemiology at the Division of Biostatistics and Research Epidemiology of the Henry Ford Hospital, in Detroit, and by Margaret R. Spitz, an epidemiologist in the Department of Cancer Prevention of the University of Texas M. D. Anderson Cancer Center, in Houston. They found that children whose fathers were electricians ran three and a half times the risk of developing tumors of the central nervous system that other children ran; indeed, tumors of the brain stem had been diagnosed in no fewer than four of seven children of



electricians in their study population.

As for the ways that exposure to electric and magnetic fields might adversely affect the central nervous sys- and the brain, and either cause or ote cancer, there is a wealth of information on that subject, starting with a 1965 study conducted by Dr. Robert O. Becker, an orthopedic surgeon at the Veterans Administration Hospital in Syracuse, New York, and Howard Friedman, a psychologist at the hospital, which showed that exposure to strong pulsed magnetic fields considerably slowed the reaction times of human volunteers. In 1964, a Soviet investigator named Yuri Alexandrei Kholodov had reported that exposure to strong magnetic fields produced areas of cell death in the brains of rabbits. Shortly thereafter, other Soviet scientists reported that workers in high-voltage switchyards were experiencing fatigue, drowsiness, headaches, and other symptoms of central-nervous-system stress. During the nineteen-seventies, Dr. W. Ross Adey, a neurological scientist, who was then the director of the Space Biology Laboratory at the Brain Research Institute of the University of California at Los eles, conducted a series of experi- s demonstrating that weak electromagnetic fields oscillating at extra-low frequencies could significantly alter the chemistry of the cerebral tissue of chickens and of the brains of living cats.

During the early nineteen-eighties, Adey, who had become associate chief of staff for research and development at the Jerry L. Pettis Memorial Veterans' Hospital, in Loma Linda, California, conducted experiments with some colleagues which demonstrated that electromagnetic fields pulsed at the electrical-distribution-system frequency of sixty hertz could inhibit the ability of cultured T-lymphocyte cells from mice to kill cultured cancer cells—a result suggesting that these fields may be acting as cancer promoters by suppressing the immune system. Subsequently, an associate of Adey's used simulated sixty-hertz high-voltage power-line fields to produce the same result. Also worrisome are the results of a 1986 experiment in which Adey his colleagues found that a one- r exposure to a sixty-hertz electric field of between one-tenth of a millivolt and ten millivolts per centimetre produced a fivefold increase in the activity

"I'm a bachelor myself."

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of an enzyme known to be associated with the development of tumors.

Following the publication of these results in the journal *Carcinogenesis*, in October of 1987, Adey said that he and his colleagues could now theorize that "exposure to low-energy fields, such as those emanating from power lines, may provide a tumor-promoting stimulus." This was an ominous hypothesis, because an alternating-current electric field of one-tenth of a millivolt is present at all times in the tissue of a human being who is standing beneath a typical overhead high-voltage transmission line. It becomes additionally ominous in the light of a study conducted in 1987 by Reba Goodman, a geneticist and cell biologist at Columbia University's Medical Center, in New York, and Ann S. Henderson, a molecular biologist at Hunter College, who have demonstrated that weak, pulsed sixty-hertz electric and magnetic fields similar to those given off by power lines may trigger the development of cancer by altering RNA transcription—the way genetic instructions are carried out in organisms—to increase the production of proteins frequently found in tumor cells.

All this epidemiological and experimental evidence of the cancer-producing potential of power-line electric and magnetic fields is, of course, frighteningly relevant to the predicament of thousands upon thousands of people who, like the residents of Meadow Street, live so close to substations and high-current wires that they are continuously exposed within their own homes to electromagnetic fields of occupational levels. In addition, there is epidemiological and experimental evidence from Sweden and the Soviet Union to suggest that electromagnetic fields can cause fertility problems among men working in high-voltage substations and switchyards, and an increased rate of birth defects among their children—findings that certainly appear to be relevant to the experience of many of the residents of 48 Meadow over the past thirty-five years. For example, in 1983, Professor S. Nordström, of the Department of Public Health and Environmental Studies of the University of Umeå, in Sweden, and some colleagues reported in the medical journal *Bioelectromagnetics* that they had found a significant increase in congenital anomalies among the children of men who worked in high-voltage switchyards and were thus being constantly "electrically charged and then discharged," causing "cell disturbances, including chromosomal aberrations." Laboratory studies of lymphocytes from a sample of high-voltage substation workers in Sweden indicate that chromosome breaks and aberrant cells are significantly more common among these workers than among a control group of unexposed men. Other studies suggest that such effects may be caused by exposure to the electrical pulses (spark discharges) that are given off by transformers and other equipment in substations, rather than to the sixty-hertz electromagnetic fields. In this connection, it is interesting to note that a recent study conducted by researchers at McGill University's School of Occupational Health, in Montreal, shows that certain electric-utility workers (and so, quite probably, the residents of Meadow Street) have been exposed to ten times the ordinary background level of sixty-hertz electric and magnetic fields, and up to a hundred and seventy times the background level of the high-frequency transient electromagnetic fields that are common in the vicinity of substations and other facilities where switching operations are conducted. For this reason, Slesin points out that future epidemiological studies should take these transient fields into account, as well as the sixty-hertz electric and magnetic fields. Unfortunately, only one (the ongoing McGill study) of the two dozen investigations of residential and occupational exposure now being conducted around the world is doing so.

THE response of the electric-utility industry to this growing body of evidence scarcely seems designed to enlighten the public about the power-line hazard. Last year, the Edison Electric Institute, of Washington, D.C.—an association of electric companies—published a brochure stating that measurements of behavior and brain function in animals exposed to power-line electromagnetic fields showed "some small effects that may be the result of body rhythm changes," but that "the connection between these laboratory results and human health is not known." The credibility of this assertion was soon placed in doubt by news that a team of experimental psychologists had found that men subjected to strong electromagnetic fields exhibited motor responses ten per cent slower than those of their unexposed counterparts, and slower heartbeat rates and brain-wave patterns as well. The Virginia Power Company and the North Carolina Power Company recently published a newsletter offering the assurance that "there is always some electrical current in everyone's body and it is necessary for life," and that "electric and magnetic fields induce small additional amounts." In a pamphlet mailed to consumers in 1989, the Commonwealth Electric Company, of Massachusetts, acknowledged the existence of an epidemiological study showing that childhood-cancer victims are "more likely" (the study's actual finding is twice as likely) to have high-current power lines outside their homes than are children without cancer, but it added, "Just what the results of this study mean is not at all clear." The authors of a bulletin issued by the Southern California Edison Company—no doubt written before the most recent cancer cluster at the Montecito Union School came to light—pose the question of whether magnetic fields given off by power lines are harmful to human health, and supply an answer that contains an interesting euphemism for cancer. "There is no proven health hazard from electric and magnetic fields from electric utility facilities," they declare. "However, some studies *suggest* that there may be an association between either magnetic or electric fields and certain health risks."

As for the federal government, its response to growing evidence that the magnetic fields from power lines pose a public-health hazard has been cautious at best and irresponsible at worst. Thanks to budget cuts imposed by the Reagan Administration, a promising program of investigation into the biological effects of extra-low-frequency (ELF) electromagnetic fields, which had been under way for ten years at the Environmental Protection Agency's Health Effects Research Laboratory, at Research Triangle Park, in North Carolina, was shut down in 1986. Since that time, almost no funding has been made available by the E.P.A. for research in this area, and federal-government involvement has been limited to a modest research program financed by the Department of Energy, which, as can be seen from the gross mismanagement of the nuclear plants under its jurisdiction, has shown little interest in protecting the public health.

During the past year, the E.P.A., by its own admission, has been "swamped" with requests from the public for information about electromagnetic fields, and in May it released preliminary information about a draft report prepared by its Office of Health and Environmental Assessment, which belatedly acknowledges the existence of a possible link between cancer and low-level electromagnetic fields, such as those given off by power lines. At the time, William Farland, the director of the office, told the press that the evidence showed only a statistical and not a causal association between the development of cancer and exposure to electromagnetic fields. "We are only saying that we are seeing a link that may be significant," he declared.

What Farland did not tell the press in May was that his own staff had recommended in the initial draft report that ELF electromagnetic fields be classified as "probable human carcinogens," and that this classification had been deleted from the executive summary of the E.P.A. report after a meeting, on March 6th, between agency officials and the White House Office of Policy Development. The deleted paragraph containing the E.P.A.'s original conclusion reads:

> Concerning exposure to fields associated with 60 Hz electrical power distribution, the conclusion reached in this document is that such exposure is a "probable" carcinogen risk factor, corresponding to a "B1" degree of evidence that it is a risk factor. This conclusion is based on "limited" evidence of carcinogenicity [in] humans which is supported by laboratory research indicating that the carcinogenic response observed in humans has a biological basis, although the precise mechanisms [are] only vaguely understood.

The deletion of the classification, which would have mandated measures to protect the public health, was revealed in the May-June issue of *Microwave News* by Slesin, who had acquired a copy of the original E.P.A. report. Slesin noted that the March 6th meeting had been attended by Teresa Gorman, the associate director of policy development for environment, energy, and natural resources at the White House Office of Policy Development; Dr. James Wyngaarden, the associate director for life sciences at the White House Office of Science and Technology Policy; Richard Guimond, the director of the agency's Office of Radiation Programs; Farland; and a representative of William Reilly, the administrator of the E.P.A., as well as representatives of the Department of Energy, the Centers for Disease Control, and the National Cancer Institute. This roster was notable in that high-ranking members of at least two of the organizations in attendance had been involved in attempts to deny that ELF electromagnetic fields could pose a biological hazard. In 1989, Dr. Wyngaarden, who was then the director of the National Institutes of Health (N.I.H.), in Bethesda, Maryland, was persuaded by adverse publicity to initiate a review of the circumstances under which three scientists at the National Cancer Institute had testified, in a court trial in behalf of the New York Power Authority, that there was no scientific basis for concluding that exposure to electromagnetic fields from power lines could cause cancer, and had received payment from the Power Authority for their testimony which far exceeded N.I.H. regulations governing remuneration for outside work and activities. (The N.I.H. has refused to make public the review ordered by Wyngaarden, but it has been learned that at least one of the researchers involved faced restrictions on outside work.) In addition, investigators and epidemiologists at the Centers for Disease Control, who were called upon during the nineteen-eighties to study clusters of miscarriages and birth defects occurring among women who while they were pregnant had worked with video-display terminals, dismissed the possibility that there could be any connection between miscarriages and birth defects and exposure to the low-frequency electromagnetic fields given off by display monitors. What was of chief interest about the March 6th meeting, however, was the apparent involvement of the White House in countermanding the efforts of responsible government officials to define and take action regarding an important environmental-health issue, and in forc-

ing the E.P.A. to dilute its assessment of a major public-health hazard.

Farland has subsequently claimed that he ordered the description of ELF electromagnetic fields as a probable human carcinogen to be deleted from the E.P.A. report because of the absence of both a mechanism of interaction and an observed dose-response relationship. Even if this were true, however, it would not provide a rationale for sound public-health policy, any more than the fact that the mechanism by which asbestos fibres cause cancer remains unknown, or the fact that a precise dose-response relationship between asbestos and cancer has not been observed, or the fact that the dose-response relationship for any carcinogen to which there is repeated, cumulative exposure cannot be precisely quantified could justify delaying the implementation of measures to prevent exposure to asbestos and other cancer-producing agents.

Thanks to the E.P.A.'s retreat from its mandate to safeguard the public health against environmental hazards, such as the magnetic fields given off by power lines, it will be left to the public to cope with the problem on its own until public concern about power-line fields forces the Bush Administration to deal with the matter on its merits and not out of political considerations. Meanwhile, utilities all over the nation are hurrying to install new power lines and upgrade old ones before any regulations can be implemented to prevent them from doing so. In Washington State, Seattle City Light—a municipally owned utility that in 1988 was prevented by a neighborhood group called Citizens Against Overhead Power Lines, Inc., from constructing two two-hundred-and-thirty-thousand-volt overhead transmission lines close to homes along Route 509 in the Highline area of South Seattle—is proceeding with a plan to build a large substation in the area, next to the Kennedy High School, and to construct new twenty-six-thousand-volt overhead feeder lines in the neighborhood, which will give off strong magnetic fields. Through its attorneys, the citizens' group has put Seattle City Light on notice that it intends to hold the utility "legally responsible for any adverse health effects that may result from any new installations of electrical power lines and/or substations," and also for any devaluation of property resulting from such installations. In addition, the group has written to Mayor Norman Rice, informing him that it may seek a court-ordered injunction to stop Seattle City Light's proposed construction of the new high-current feeder lines in the Highline area.

As might be expected, significant devaluation of residential property situated close to substations, high-current wires, and high-voltage transmission lines has already occurred in various sections of the nation where the power-line health hazard has become known, and wholesale devaluation appears to be in the offing as information about the problem continues to be disseminated. Together with the health hazard itself, the devaluation is resulting in widespread concern and litigation. During the past six months, numerous lawsuits have been brought against utilities in states from Maine to California and from Washington to Florida, and hundreds, perhaps thousands, more are clearly in prospect. In many states, citizens' groups similar to Citizens Against Overhead Power Lines are being organized to fight the installation of new power lines and substations in residential areas, and to seek a rerouting and redesign of existing power lines whose magnetic-field emissions are posing a serious health hazard in neighborhoods, schools, and office buildings.

Though spokesmen for some utilities have irresponsibly attempted to suggest that if worst comes to worst people will just have to endure the risk of being subjected to the harmful effects of alternating-current magnetic fields or else forgo the advantages of electric power, there are many relatively inexpensive measures that can be taken now to mitigate the problem. A simple and often-used procedure is to pull high-current distribution wires close together with spreaders; that can decrease their magnetic-field emissions and reduce exposure, especially in cases where residences are very near the wires. Vertical instead of horizontal placement of high-current wires on utility poles can also significantly reduce magnetic-field emissions, provided the current loads in the two circuits are equal. The use of the Delta-connection system of distribution—a system in which primary wires are grounded only at substations and are never directly connected to secondary-wire grounds—can reduce net-current effects and thus magnetic-field emissions. Spun secondary wires—wires wrapped together—encourage the current entering a house to return the way it came, instead of jumping to the plumbing to which the electrical systems of most houses are grounded, and creating imbalanced currents and strong magnetic fields. And the use of concrete water mains and polyvinyl-chloride (PVC) water pipes can effectively interrupt the conductive path provided by metal plumbing, and thus furnish another method of keeping imbalanced currents from producing high levels of magnetic-field exposure.

As for substations and high-current wires that are already situated dangerously close to dwellings, they will have to be relocated or rerouted—or, if necessary, buried—in a fashion that will prevent hazardous magnetic-field emissions. Until such preventive measures are taken to protect the public, and until physicians and public-health officials begin acknowledging the power-line hazard and seriously investigating the cancer clusters associated with it, alternating-current magnetic fields given off by substations and high-current lines on Meadow Streets across America will continue to prove that they can result in brain cancer, leukemia, and other malignancies as a matter not of statistical chance but of biological course.

—PAUL BRODEUR

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THE RIVER AT WOLF

Coming East we left the animals
pelican beaver osprey muskrat
  and snake
their hair and skin and feathers
their eyes in the dark: red and green.
Your finger drawing my mouth.

Blessed are they who remember
that what they now have they once
  longed for.

A day a year ago last summer
God filled me with himself, like gold,
  inside,
deeper inside than marrow.

This close to God this close to you:
walking into the river at Wolf with
the amimals. The snake's
green skin, lit from inside. Our second
  life.

—JEAN VALENTINE