

Florida State University Journal of Land Use and Environmental Law

Volume 13
Number 2 *Spring 1998*

Article 2

April 2018

EMF at Home: The National Research Council Report on the Health Effects of Electric and Magnetic Fields

Patsy W. Thomley
Cumberland School of Law of Sanford University

Follow this and additional works at: <https://ir.law.fsu.edu/jluel>



Part of the [Energy and Utilities Law Commons](#), and the [Environmental Law Commons](#)

Recommended Citation

Thomley, Patsy W. (2018) "EMF at Home: The National Research Council Report on the Health Effects of Electric and Magnetic Fields," *Florida State University Journal of Land Use and Environmental Law*: Vol. 13 : No. 2 , Article 2.
Available at: <https://ir.law.fsu.edu/jluel/vol13/iss2/2>

This Article is brought to you for free and open access by Scholarship Repository. It has been accepted for inclusion in Florida State University Journal of Land Use and Environmental Law by an authorized editor of Scholarship Repository. For more information, please contact bkaplan@law.fsu.edu.

EMF at Home: The National Research Council Report on the Health Effects of Electric and Magnetic Fields

Cover Page Footnote

The author thanks Dr. David A. Conner, P.E., Chairman and Professor of the Electrical and Computer Engineering Department at the University of Alabama at Birmingham, and James D. Gorham, Jr., Assistant to the Vice President and EMF Issues Manager, Alabama Power Co.

EMF AT HOME: THE NATIONAL RESEARCH COUNCIL REPORT ON THE HEALTH EFFECTS OF ELECTRIC AND MAGNETIC FIELDS

PATSY W. THOMLEY*

Table of Contents

| | |
|--|-----|
| I. Introduction | 309 |
| II. Some Effects of the Public Perception of Harm | 311 |
| A. Land Evaluation..... | 312 |
| B. Power Line Siting and Land Use | 315 |
| C. Personal Injury Tort Litigation..... | 319 |
| III. What are Electric and Magnetic Fields?..... | 320 |
| A. Power Delivery Systems | 321 |
| B. Frequency and the Electromagnetic Spectrum | 322 |
| C. Exposure to Electric and Magnetic Fields | 325 |
| IV. The National Research Council Committee Report | 331 |
| A. Cellular and Molecular Effects..... | 333 |
| B. Animal and Tissue Effects | 338 |
| C. Epidemiology | 346 |
| D. Cancer Epidemiology and Residential Exposures | 349 |
| E. Risk Assessment..... | 354 |
| F. Research Needs and Research Agenda..... | 357 |
| V. Conclusion | 358 |
| VI. Appendix | 361 |

I. INTRODUCTION

The quality of life of a country's citizens is most significantly indicated by the country's energy per capita consumption, which is directly proportional to a country's gross national product.¹ The United States is one of the leading consumers of energy with electrical energy making up thirty-six percent of all energy consumption.² Therefore, electrical energy contributes greatly to the quality of life of the citizens of the United States.

* Professor of Law, Cumberland School of Law of Samford University; J.D., 1980, Cumberland School of Law of Samford University. The author thanks Dr. David A. Conner, P.E., Chairman and Professor of the Electrical and Computer Engineering Department at the University of Alabama at Birmingham, and James D. Gorham, Jr., Assitant to the Vice President and EMF Issues Manager, Alabama Power Co.

1. See Imre Gyuk, Office of Conservation & Renewable Energy, United States Dep't of Energy, *An Overview and the Scientific Evidence to Date, Address at the Transmission & Distribution EMF Conference 3* (Mar. 1993) (illustrating the proportionality of energy per capita consumption to gross national product) (transcript on file with author).

2. See *id.*

Electrical energy provides benefits and conveniences that society now deems necessities. These benefits and conveniences range from the ability to read a book or newspaper after dark on a sultry summer evening, while being cooled by an electrically powered air conditioner to the ability to have a life-threatening tumor diagnosed by magnetic resonance imaging (MRI). Without question, electrical energy is one of the "good" resources contributing to modern life and one on which society now depends. Certainly from the time Benjamin Franklin discovered electricity, the public has been aware of the danger of death or injury upon contact with electrical power. In the seventies, concern arose about the possible ill effects caused by invisible emanations from electrical wires and appliances, consisting of electric and magnetic fields, generally referred to as "electromagnetic fields" or "EMF."³

Electric and magnetic fields exist wherever electricity is present. Some scientists, especially epidemiologists, suggest that electric and magnetic fields may cause adverse health effects such as brain cancer, childhood leukemia, testicular cancer, birth defects, and miscarriages.⁴ Other scientists disagree with the conclusion that electric and magnetic fields can cause adverse health effects.⁵ The press has emphasized the suggestions of harm to health in recent years, causing a public fear of electromagnetic fields.⁶ The perception that EMF can cause cancer or otherwise harm health has in some cases affected property values,⁷ influenced some governmental bodies to adopt land use rules and regulations affecting power line siting,⁸

3. See NATIONAL RESEARCH COUNCIL, POSSIBLE HEALTH EFFECTS OF EXPOSURE TO RESIDENTIAL ELECTRIC AND MAGNETIC FIELDS 13, 23 (1997) [hereinafter NRC REPORT]. The acronym, "EMF," has become a household word because of the publicity concerning the speculation that electric power lines and appliances may cause adverse health effects. Electric and magnetic fields are related; however, they are different in character. See *infra* Part III. Because the National Research Council Committee's report uses the term electromagnetic field (EMF) only when the electric and the magnetic fields are coupled (e.g., high-frequency fields), the terms "electromagnetic field" and "EMF" will not be used in a general way in the remainder of this article. Where these terms are used in the article, they will be used in connection with the popular or public perception.

4. See NATIONAL RESEARCH COUNCIL, *supra* note 3, at 44-54. Nancy Wertheimer and Edward Leeper are among the epidemiologists reporting an association between electric and magnetic fields and cancer.

5. See *San Diego Gas & Elec. Co. v. Superior Ct.*, 920 P.2d 669 (Cal. 1996) (involving an amicus brief filed by fourteen scientists in which they argued that there is no scientific basis that electromagnetic fields harm human health).

6. See, e.g., PAUL BRODEUR, CURRENTS OF DEATH: POWER LINES, COMPUTER TERMINALS, AND THE ATTEMPT TO COVER UP THEIR THREAT TO YOUR HEALTH (1989) (noting that a staff writer at THE NEW YORKER magazine published in book form a three-part series of articles on cancer hazards associated with electric and magnetic fields).

7. See *infra* notes 21-51 and accompanying text.

8. See *infra* notes 52-77 and accompanying text.

caused landowners to protest power line siting,⁹ and spawned personal injury tort litigation.¹⁰

In response to public perception and concern, the United States Congress passed the Energy Policy Act of 1992,¹¹ which established an electric and magnetic fields research and public information dissemination program. In addition to dissemination of information, this program determines whether the electric and magnetic fields produced by using electrical energy affect human health and conducting research to mitigate any potential adverse health effects.¹² The legislation provided that the United States Department of Energy (DOE) would be the agency responsible for electric and magnetic field research and directed the Secretary of Energy to arrange for the National Research Council of the National Academy of Sciences¹³ to review and evaluate the research on possible health effects of electric and magnetic fields.¹⁴ In late 1996,¹⁵ the National Research Council reported the conclusion "that the current body of evidence does not show that exposure to these fields presents a human-health hazard."¹⁶

Part II of this article presents the effect that the controversy surrounding electric and magnetic fields has had on public perception along with some of the concomitant effects on property evaluation, land use, and tort litigation. Part III explains electric and magnetic fields. Part IV summarizes the National Research Council Committee's report of its conclusions after prolonged study of the available acceptable research¹⁷ and the Conclusion, Part V, speculates on the likely effect of the National Research Council Committee's report on public perception.

II. SOME EFFECTS OF THE PUBLIC PERCEPTION OF HARM

When reports of suspected harmful health effects caused by exposure to electric and magnetic fields began to reach the public, the public's concern and fear impacted at least three areas of law. In

9. *See id.*

10. *See infra* notes 78-85 and accompanying text.

11. The Energy Policy Act of 1992, Pub. L. No. 102-486, 102 Stat. 2776 (1992) (codified at 42 U.S.C. §13478 (1994)).

12. *See* 42 U.S.C. §13478(a)(1)-(3) (describing the purpose of the program).

13. *See infra* notes 180-83 and accompanying text.

14. *See* 42 U.S.C. §13478(g)(2) (delegating research duties to the DOE).

15. On October 31, 1996, after almost 3 years of study, the Committee on the Possible Effects of Electromagnetic Fields on Biologic Systems released its report, which was widely reported by the news media.

16. NRC REPORT, *supra* note 3, at 2.

17. *See id.* at 17 (noting how the NRC Committee applied standards of acceptability for the research it would recognize).

the area of land valuations, public concern provided a reason for the devaluation of property located near power lines.¹⁸ In the area of land use, public concern influenced some governmental bodies to adopt land use rules and regulations affecting power line siting and caused neighboring landowners to protest power line siting.¹⁹ In the area of litigation, concern about the health effect of EMF radiation generated some tort litigation.²⁰

A. Land Evaluation

Issues concerning the effect of power lines located on or near an owner's property arise when an electric utility attempts to acquire property rights in the land on which it intends to place a power line.²¹ A utility may negotiate with the landowner to purchase the property right, either in fee simple or as an easement.²² If the landowner refuses to negotiate or a price cannot be agreed upon, the utility can exercise the power of eminent domain in a condemnation action.²³

The exercise of the right of eminent domain requires that just compensation be given for the property taken.²⁴ The determination of just compensation for the condemned property usually involves computing damages in the amount of compensation for the land actually taken and severance damages, which are those damages caused by a reduction in the value of the remaining property when the condemned property is severed.²⁵ The measure of damages for the property actually condemned is the fair market value of that property.²⁶ Since severance damages are based on the reduction in

18. See *infra* notes 21-51 and accompanying text.

19. See *infra* notes 52-77 and accompanying text.

20. See *infra* notes 78-85 and accompanying text.

21. See Sherry Young, *Regulatory and Judicial Responses to the Possibility of Biological Hazards from Electromagnetic Fields Generated by Power Lines*, 36 VILL. L. REV. 129, 153 (1991). Young's article provides a good discussion of utilities, their relationship to regulatory bodies, and their right to condemn property.

22. See *id.*

23. See *id.* at 153 (citing *Johnson v. Consolidated Gas, Elec. Light & Power Co.*, 50 A.2d 918 Md. (1947) and *Montana Power Co. v. Bokma*, 457 P.2d 769, 772 Mont. (1969) as examples of cases holding that a utility has the right of eminent domain).

24. See U.S. CONST. amend. V. The Fifth Amendment of the United States Constitution provides "nor shall private property be taken for public use without just compensation." States have similar just compensation provisions. See ALA. CONST. art. I, §23.

25. See Young, *supra* note 21, at 158.

26. See *id.* (noting the lack of flexibility in estimates of fair market value of the condemned property).

market value caused by the severance, evidence of factors effecting that reduction is relevant and admissible.²⁷

When fear of harm caused by exposure to electric and magnetic fields emanating from power lines became widespread, landowners, in an effort to increase severance damages,²⁸ began to introduce evidence in condemnation cases relating to EMF and the fear of exposure to EMF.²⁹ Courts required expert testimony regarding biological effects of electric and magnetic fields,³⁰ and expert or non-expert evidence of the public fear. Evidence of personal fear was inadmissible.³¹ One court excluded evidence of harmful effects of

27. See *Selective Resources v. Superior Ct.*, 700 P.2d 849, 850, 852 (Ariz. Ct. App. 1984) (ruling in a condemnation action that testimony of expert witnesses concerning the biological effects of exposure to electromagnetic fields was highly relevant to the issue of severance damages).

28. See *Young*, *supra* note 21, at 158-59.

29. See *Goadby v. Philadelphia Elec. Co.*, 639 F.2d 117, 122 (3d Cir. 1981) (complaining landowner claimed that electromagnetic field encroached on his land in an area wider than the right of way); *San Diego Gas & Elec. Co. v. Daley*, 253 Cal Rptr. 144, 150, 152-53 (1988) (admitting evidence of fear of danger from electromagnetic projections; not admitting evidence that no health hazard exists because fear was affecting the value of the retained land); *San Diego Gas & Elec. Co. v. 3250 Corp.*, 252 Cal. Rptr. 853, 859 (1988) (complaining landowner offered evidence at trial of public fear of electromagnetic fields, no error for court to refuse instruction that harmful effects of fields were a hidden defect); *Linnebur v. Public Svc. Co.*, 716 P.2d 1120, 1121-22 (Colo. 1986) (holding that condemnation action for transmission line easement where landowner appealed exclusion of two expert witnesses' testimony that line created a health hazard was not ripe for appeal); *Florida Power & Light Co. v. Jennings*, 518 So. 2d 895, 896, 898 (Fla. 1987) (holding that landowner's evidence of the effect of public fear of electromagnetic fields was admissible even though no proof fear was reasonable); *Florida Power & Light Co. v. Roberts*, 490 So. 2d 969, 971 (Fla. 5th DCA 1986) (allowing severance damages based on testimony about electromagnetic fields since research has shown a link between transmission lines and cancer in people living near the lines); *Dixie Textile Waste Co. v. Oglethorpe Power Corp.*, 447 S.E.2d 328, 330 (Ga. Ct. App. 1994) (excluding landowner's expert testimony regarding public fear of electromagnetic fields as hearsay); *Iowa Power & Light Co. v. Stortenbecker*, 334 N.W.2d 326, 331 (Iowa Ct. App. 1983) (ruling that expert testimony using words "leukemia" and "multiple sclerosis" to illustrate effects of electromagnetic fields from proposed transmission lines more prejudicial than probative as evidence for jury's determination of effect of public fear on market value of remaining land); *Ryan v. Kansas Power & Light Co.*, 815 P.2d 528, 534-35 (Kan. 1991) (holding evidence of public fear, but not personal fear, of health effects of power lines admissible because purpose of evidence is to show factors affecting property value and damages); *Meinhardt v. Kansas Power & Light Co.*, 661 P.2d 820, 822 (Kan. Ct. App. 1983) (excluding testimony of expert appraisers concerning the basis of public fear, court did not abuse its discretion in excluding biomedical engineer's testimony on the hazardous biological effects of power line, nor in concluding his evidence was not germane to market value issue); *Duerson v. Kentucky Power Coop.*, 843 S.W.2d 340, 343 (Ky. Ct. App. 1992) (holding that EMF emissions from transmission lines were not included in the statutory list of contaminants); *Zappavigna v. State*, 588 N.Y.S.2d 585, 586, (N.Y. App. Div. 1992); *Criscuola v. Power Auth.*, 592 N.Y.S.2d 79, 81 (N.Y. App. Div. 1992) (claiming severance damages award as a result of "cancerphobia," or a public perception that exposure to EMF poses a health risk).

30. See, e.g., *Banks v. Georgia Power Co.*, 469 S.E.2d 218, 222 (Ga. Ct. App. 1996) (excluding testimony regarding EMF because not expert).

31. See, e.g., *Ryan v. Kansas Power & Light Co.*, 815 P.2d 528, 535 (Kan. 1991) (admitting non-expert testimony about fear of lines as not prejudicial nor an abuse of discretion).

power lines because the landowner's proposed experts "could not testify within the reasonable degree of probability necessary to express an opinion concerning the actual physical effects of electromagnetic field exposure on humans."³² Other courts have excluded expert testimony regarding public fear of power lines because the witness failed to quantify any damage to the fair market value of the remaining property,³³ or to show how to calculate with reasonable certainty the effect of the public fear on the market value of the remaining property.³⁴ Another court found that issues concerning alleged health hazards created by the construction and operation of electric power transmission lines necessitated an action's dismissal because such issues should have been determined by the regulatory agency.³⁵

An important case involving a jury's decision after hearing evidence on the fear of electromagnetic fields and the effect of EMF on property that had been condemned for the construction of high-voltage transmission lines is *Houston Lighting & Power Co. v. Klein Independent School District*.³⁶ Following the utility's condemnation of a strip of land owned by the school district, the school district was awarded \$78,604 by the Public Utilities Commission (PUC).³⁷ The school district then filed objections with the trial court.³⁸ The utility deposited \$78,604 with the court, took possession of the strip of land, and constructed the transmission lines, which were energized in 1984.³⁹ The school district's pleadings alleged that the callous decision to locate the line on the school property, disregarding the safety and health of the school children, made the condemnation void.⁴⁰

At trial, several experts testified for the school district. An engineering professor testified that the children in the intermediate school located 300 feet from the transmission line were being exposed to magnetic fields between six and ten milligauss.⁴¹ An

32. *Linnebur*, 716 P.2d at 1121-22.

33. See *Chappell v. Virginia Elec. & Power Co.*, 458 S.E.2d 282, 284 (Va. 1995).

34. See *Dixie Textile Waste Co. v. Oglethorpe Power Co.*, 447 S.E.2d 328, 330 (Ga. Ct. App. 1994).

35. See *Stannard v. Axelrod*, 419 N.Y.S.2d 1012, 1016 (N.Y. Sup. Ct. 1979) (dismissing action seeking to compel Department of Health and Environmental Conservation to abate nuisance caused by creation of health hazards by installation of transmission line because PSC had jurisdiction).

36. 739 S.W.2d 508 (Tex. Ct. App. 1987).

37. See *id.* at 511.

38. See *id.*

39. See *id.*

40. See *id.*

41. See *id.* at 516. For a discussion of gauss unit of measuring magnetic field intensity, see *infra* notes 145-50 and accompanying text.

epidemiologist testified about the studies she and other epidemiologists conducted that showed correlation between cancer and power lines.⁴² She concluded that the children in the schools were at increased risk of cancer because of the electromagnetic fields.⁴³ An oncologist testified similarly.⁴⁴ A pharmacology department chairman testified that because the electromagnetic fields were not obstructed by buildings or anything else, the children would be exposed to them daily.⁴⁵ Testifying for the utility was an expert who critiqued the school district's expert studies.⁴⁶

The jury awarded the school district \$104,275 actual damages and \$25 million punitive damages, finding that the utility had abused its discretion in condemning the line and that it erected the line in reckless disregard of the school district's use of its property.⁴⁷ The lower court permanently enjoined the utility from using the transmission lines and ordered possession of the property restored to the school district.⁴⁸

The appellate court ultimately modified the trial court judgment, deleting the award of punitive damages, and affirming the actual damages.⁴⁹ At the time of the appellate decision, the utility had already received permission from the PUC to relocate the transmission lines in order to avoid the school district property.⁵⁰

The *Klein Independent School District* case thus demonstrates a jury's response to evidence that electromagnetic fields emitted from power lines may be dangerous to public health and that a utility's condemnation of property for power lines may be overturned. The dangers to public health caused by power lines have also increasingly become an issue in power line siting litigation.⁵¹

B. Power Line Siting and Land Use

Perceived health hazards associated with electric and magnetic fields emitted from power lines, and the public fear of power lines caused thereby, have frequently been issues in power line siting and

42. For a discussion of the studies, see *infra* notes 300-45 and accompanying text.

43. See *Klein*, 739 S.W.2d at 516.

44. See *id.*

45. See *id.* at 517.

46. See *id.*

47. See *id.* at 511.

48. See *id.*

49. See *id.* at 521. The appellate court did not explain the basis for an award of actual damages.

50. See *id.*

51. See Pam Black, *Rising Tension over High-Tension Lines*, BUS. WK., Oct. 30, 1989, at 158 (estimating that power companies have been parties to more than 100 suits where potential health hazards from power lines were an issue).

land use cases.⁵² The siting of power lines is regulated by state agencies, which may be designated the "Public Service Commission" (PSC), the "Public Utility Commission" (PUC), or some similar designation. These regulatory agencies investigate the need for new power lines and study the effects on the public of locating or siting those lines.⁵³ Public hearings constitute a part of a regulatory agency's investigation, and at these hearings property owners, municipalities, and other entities affected by the siting of proposed lines may raise their concerns.⁵⁴

Among the issues considered by a regulatory agency in an evidentiary hearing are the effects of electromagnetic fields on health and safety.⁵⁵ Though science has not confirmed the adverse health effects of electromagnetic fields, in an attempt to control the risks of exposure to electromagnetic fields the regulatory agencies have tried to regulate the level of exposure by adopting simple field strength

52. See *Woida v. United States*, 446 F. Supp. 1377, 1387 (D. Minn. 1987) (declining to require utility to analyze health and safety effects of EMF in its environmental impact statement); *Douglas County Bd. Comm'rs v. Public Util. Comm'n*, 866 P.2d 919, 922 (Colo. 1994) (challenging PUC conclusion that line upgrade did not cause potential adverse health effects mandating denial of application); *Couch v. Delmarva Power & Light Co.*, 593 A.2d 554, 555-56 (Del. Ch. 1991) (denying injunction against utility where owners of farm land claimed proposed lines would create electromagnetic fields that might be linked to cancer and birth defects); *Florida Power Corp. v. State Siting Bd.*, 513 So. 2d 1341, 1343 (Fla. 1st DCA 1987) (holding that Board erred because it denied certification of proposed transmission line corridor until it could determine whether utility had complied by yet-to-be-adopted rules specifying proposed line width necessary to protect against electric and magnetic fields); *Stannard v. Axelrod*, 419 N.Y.S.2d 1013, 1016 (N.Y. Sup. Ct. 1979) (holding that issues regarding public health aspects of non-ionizing electromagnetic radiation from proposed high voltage transmission line should have been determined in PSC proceeding); *Chester Township v. Power Siting Comm'n*, 361 N.E.2d 436, 440-41 (Ohio 1977) (upholding commission's decision to base ruling on engineers' testimony that electromagnetic fields surrounding proposed lines would not be detrimental to public); *Fretz v. Pennsylvania Pub. Util. Comm'n*, 666 A.2d 372, 375-76 (Pa. Commw. Ct. 1995) (finding that utility's proposed upgrade of line using taller structures and reversed phasing would reduce electromagnetic fields at edge of right of way by more than seventy percent); *Barensfeld v. Pennsylvania Pub. Util. Comm'n*, 624 A.2d 809, 811 (Pa. Commw. Ct. 1993) (denying Citizens Opposed to Unsafe Power the right to intervene in PUC siting and transaction proceedings or to have proceedings consolidated for several reasons, including the effect of EMF on the public). See also *State of Wisconsin v. Weinberger*, 745 F.2d 412, 420 (7th Cir. 1984) (seeking injunction of extremely low frequency (ELF) submarine communications project where court held that post-1977 evidence of effects of ELF on health was not required to be included in EIS because it did not present a different picture from the one in 1977).

53. See Young, *supra* note 21, at 169-78. A PUC balances the public's interest in being able to access a reliable source of electric power against the harm the facilities required to provide that source may cause to the public. See *id.*

54. See *id.*

55. See *Goadby v. Philadelphia Elec. Co.*, 639 F.2d at 119 (finding "[b]oth the ground level electric field and the magnetic flux density of the line, using the most extreme theoretical conditions, are well below the danger levels . . . [T]he proposed line . . . will present no danger to the public's health or safety.").

safety standards.⁵⁶ Some state regulatory agencies have adopted a strategy of "prudent avoidance" as a means of risk management.⁵⁷ A strategy of prudent avoidance means taking steps that would prevent the public from being exposed to electromagnetic fields, but taking only those steps involving modest costs.⁵⁸ Some possibilities for prudent avoidance include attempting to route new transmission lines so that they avoid people; widening transmission line rights-of-way; developing designs for distribution systems, including new grounding procedures, which minimize associated fields; developing new approaches to house wiring that minimize associated fields; and redesigning appliances to minimize or eliminate fields.⁵⁹

In addition to the cases involving regulatory agencies and proposed power line sitings or proposed upgrades of existing lines, at least one case involved a pre-existing line and the public perception of health hazards caused by the line. In *Borenkind v. Consolidated Edison Co.*,⁶⁰ plaintiffs, who were vendors of residential property located near the power line, sued the utility seeking consequential damages because of the alleged decrease in value caused by the public's perception of a health risk associated with living near the line.⁶¹ However, the court dismissed the complaint.⁶²

Electric and magnetic fields and the fear of health hazards associated with power lines have also been issues in cases involving zoning ordinances, zoning changes, and land use ordinances regulating power lines.⁶³ The town of East Greenwich, Rhode Island, is a party in two such cases: *East Greenwich v. O'Neill*⁶⁴ and *East Greenwich v. Narragansett Electric Co.*⁶⁵ Because the citizens of East Greenwich

56. See OFFICE OF TECHNOLOGY ASSESSMENT, U.S. CONGRESS, OTA-BP-E-53, BIOLOGICAL EFFECTS OF POWER FREQUENCY ELECTRIC AND MAGNETIC FIELDS—BACKGROUND PAPER 76 (May 1989) [hereinafter OTA BACKGROUND PAPER]. THE OTA BACKGROUND PAPER is an earlier report on the possible health effects of electric and magnetic fields by the Congress of the United States Office of Technology Assessment (OTA), an office whose function is to help Congress keep abreast of technological changes.

57. See *Douglas County Bd. of Comm'rs v. Public Util. Comm'n*, 829 P.2d 1303, 1306 (Colo. 1992) (challenging PUC conclusion that cost of burial of proposed lines as a means of prudent avoidance outweighed the benefits of burial).

58. See OTA BACKGROUND PAPER, *supra* note 56, at 78-79 (citing M.G. Morgan et al., *Controlling Exposure to Transmission Line Electromagnetic Fields: A Regulatory Approach that is Compatible with the Available Science*, PUBLIC UTILITIES FORTNIGHTLY (Mar. 17, 1988)).

59. See *id.* at 79.

60. 626 N.Y.S.2d 414 (N.Y. Sup. Ct. 1995).

61. See *id.*

62. See *id.* at 415-16.

63. See generally Sager A. Williams, Jr., Comment, *Limiting Local Zoning Regulation of Electric Utilities: A Balanced Approach in the Public Interest*, 23 U. BALT. L. REV. 565 (1994) (discussing zoning laws applied to the electric power industry because of EMF).

64. 617 A.2d 104 (R.I. 1992).

65. 651 A.2d 725 (R.I. 1994).

expressed concern about the possible harmful effects of electromagnetic fields emanating from power lines, the town adopted an ordinance creating a three-year moratorium on the construction of transmission lines exceeding sixty kilovolts.⁶⁶ The ordinance prevented the utility from constructing its proposed transmission line through the town and the utility appealed to the state Public Utilities Commission (PUC), which scheduled a hearing to follow the determination of the outcome of the town's suit challenging the PUC's jurisdiction in the matter.⁶⁷ The appellate court invalidated the ordinance and held that the PUC had jurisdiction of the matter.⁶⁸

The *Narragansett Electric Co.* case resulted from the town's suit to quash a PUC order invalidating amendments to the town's comprehensive plan.⁶⁹ Implementing its concern about the possible harmful effects of electromagnetic fields emanating from high-voltage power lines, the town council approved five amendments to its comprehensive plan.⁷⁰ On appeal, the court affirmed the PUC's invalidation of the amendments because they invaded the "field of public utilities regulation, which the General Assembly had expressly preempted from town and city intrusion."⁷¹

Other land use related cases raising electromagnetic field issues⁷² include those where landowners challenged a zoning change that would allow construction of a power substation because of the risk of health hazards⁷³ and where a town challenged the regulatory

66. See *O'Neill*, 617 A.2d at 106. The ordinance was known as the "High Voltage Line Moratorium Act" and stated that the purpose of the Act was to allow time for those entities studying the effects of exposure to electromagnetic fields to determine whether they present a health risk. See *id.* at n.1.

67. See *id.* at 107.

68. See *id.* at 114.

69. See 651 A.2d at 725.

70. See *id.* at 727-30. The amendments provided that the siting and construction of power lines and power generating facilities be done in an effort to reduce EMF exposure, that future substations be designed with the same objective, and that the town adopt a policy to regulate siting of lines to reduce EMF exposure to the lowest possible level.

71. *Id.* at 729.

72. See, e.g., *Nynex Mobile Communications Co. v. Hazlet Township Zoning Bd. Of Adjustment*, 648 A.2d 724 (N.J. Super. Ct. App. Div. 1994). In this case, the town had denied a zoning variance to permit a cellular telephone facility on top of a nonconforming-use water tower. See *id.* The town's experts said that EMF was "definitely detrimental," though the level of cause and effect was *unknown*. See *id.* at 728. The court, in reversing the denial of the variance, said that "the so-called health and safety issues are nothing but rank speculation" and "unsubstantiated fears which cannot form the basis for a denial of an otherwise viable application." *Id.* at 732. For a discussion of EMF with respect to cellular telephone facilities, see Dean J. Donatelli, Note, *Locating Cellular Telephone Facilities: How Should Communities Answer When Cellular Telephone Companies Call?*, 27 RUTGERS L.J. 447 (1996).

73. See *MacNamara v. County Council of Sussex County*, 738 F. Supp. 134, 137-38, 141-42 (D. Del. 1990) (dismissing claim because property owners concerned about EMF had no property interest with respect to the rezoning that was protected by due process).

agency's decision to grant a utility an exemption from the town's zoning restriction.⁷⁴ Interestingly, in one case, the party petitioning the PUC to invalidate the town's rezoning of its lot from heavy industrial to residential was the utility, the party that usually tries to refute the existence of health hazards associated with electromagnetic fields.⁷⁵ At the PUC hearing, the utility argued that the rezoning would adversely affect its utility operations.⁷⁶ If the utility were to construct power lines on its re-zoned lot and connect them to a substation on its adjoining property, the utility "could be potentially liable for the putative harmful effects of the electromagnetic fields (EMF) from such lines on residents on those lots."⁷⁷

C. Personal Injury Tort Litigation

Liability for the putative effects of electric and magnetic fields emanating from power lines and facilities has been alleged in tort litigation.⁷⁸ However, because of the failure of science to definitively link causation of cancer and other alleged personal injuries to electric and magnetic fields, there has been no recovery based on the allegations and few reported cases.⁷⁹ When the reports of an association between cancer and the electric and magnetic fields around power lines and electricity became known to the public, the suggestion was that electromagnetic field litigation would be the next asbestos.⁸⁰ One source predicts that litigation over health problems allegedly caused by electromagnetic fields will continue despite the National Research Council Committee's report finding no conclusive

74. See *Town of Framingham v. Department of Public Util.*, 244 N.E.2d 281 (Mass. 1968).

75. See *Newport Elec. Corp. v. Town of Portsmouth*, 650 A.2d 489, 493 (R.I. 1994) (complaining utility company supported its objection to the re-zoning to residential of its lots located next to its property zoned industrial and on which it may construct a future power line by testimony that it had "concerns and objections relative to EMF and these overhead power lines.").

76. See *id.*

77. *Id.* at 493.

78. See John Weiss, *The Power Line Controversy: Legal Responses to Potential Electromagnetic Field Health Hazards*, 15 COLUM. J. ENVTL. L. 359, 363 (1990).

79. See *id.*

80. See Andrews Continuing Education Institute, *Electromagnetic Field Litigation: The Next Asbestos?* (1993) (transcript on file with author). This seminar was presented "for attorneys, insurers and other professionals interested in the latest legal strategies, and state-of-the-art scientific data concerning magnetic fields" and "[f]eatu[re]d cellular telephone, power line and radar gun litigation discussions, a mock EMF trial and much more!" *Id.* at 1. In May 1993 Andrews Publications began publishing the ELECTROMAGNETIC FIELD LITIG. REP., a monthly journal reporting on cases involving personal injury, property devaluation, fear of cancer, admissible science and other issues in the electromagnetic field litigation area of law.

evidence linking electric and magnetic field radiation exposure with cancer and other diseases.⁸¹

Health issues related to electromagnetic field exposure have produced litigation in which liability was claimed against utilities for purportedly causing non-Hodgkin's lymphoma,⁸² emotional distress,⁸³ and chronic myelogenous leukemia.⁸⁴ However, no definitive scientific proof exists linking the alleged injuries and electromagnetic fields and in none of these personal injury cases did plaintiffs recover.⁸⁵ Since electric and magnetic fields have caused litigation and controversy, a discussion of these fields is helpful.

III. WHAT ARE ELECTRIC AND MAGNETIC FIELDS?⁸⁶

General science courses teach that elementary particles of matter such as electrons and protons carry an electric charge, with protons carrying a positive charge and electrons carrying a negative charge. Like charges repel one another and opposite charges attract one another. When an object has the same number of electrons as it does protons, as usually happens, the effect of the charges cancel out and the object has no overall charge. But when an object acquires an excess of positive or negative charges, the object becomes charged.⁸⁷

81. See Mark A. Hoffman, *Study Debunks EMF Risks: Report Sees No Link to Illness*, BUSINESS INSURANCE (Nov. 4, 1994), 1996 WL 12786305. For a survey of health and other claims related to EMF, see generally ELECTROMAGNETIC FIELD LITIG. REP. (reporting cases involving electromagnetic litigation).

82. See *Jordan v. Georgia Power Co.*, 466 S.E.2d 601, 603 (Ga. App. 1995) (claiming that as a result of EMF property was unsafe and Nancy Jordan developed non-Hodgkin's lymphoma).

83. See *San Diego Gas & Elec. Co. v. Superior Ct.*, 920 P.2d 669, 679-80, 694 (Cal. 1996) (alleging five personal injury causes of action including "medical monitoring," intentional and negligent infliction of emotional distress, strict product liability, and negligent product liability).

84. See *Florida Power & Light Co. v. Glazer*, 671 So. 2d 211, 213 (Fla. 3d DCA 1996) (alleging contraction of chronic myelogenous leukemia (CML) because of continuous exposure to magnetic fields emanating from utility's transformer and distribution lines).

85. See *In re Brewer*, 18 ELECTROMAGNETIC FIELD LITIG. REP. 10 (Apr. 1995). In this workman's compensation case, the Washington Department of labor & Industries first awarded benefits to an aluminum smelters plant worker based on his claim that his terminal non-Hodgkin's lymphoma was caused by exposure to high levels of EMF and then reversed that award of benefits because the condition did not result from a defined industrial injury and was not an occupational disease.

86. The following explanation of electric and magnetic fields and their effects is gleaned from the National Research Council Committee's report. See NRC REPORT, *supra* note 3. This explanation is in no way intended to be comprehensive; rather, the intent is to provide sufficient simplified explanations and definitions of terminology necessary to communicate the results of studies and the bases of the National Research Council Committee's report. The scientific underpinnings of the electric and magnetic fields and their effects on human health are technical and complex.

87. A commonly experienced example of this phenomenon is when a sock clings to a shirt after both items have been in a drier rubbing together. The rubbing together causes the clothes to pick up or lose electrons from one another producing the familiar "static electricity." See *id.*

If a charged object is capable of exerting a force on other charges brought into a region around the charged object, then the force is called the "electric field" of the charged object.⁸⁸ A "magnetic field" is a mathematical means of representing the magnetic force that a wire carrying a current of electricity exerts on any charged particle that is nearby.⁸⁹

These two types of fields, electric and magnetic, are present wherever electric power is present. These fields result from the electric charges that electric power generating stations pump through power lines and ultimately to the consumer of power. In general terms, the electric field originates from the amount of the electric charge pumped, and the magnetic field originates from the motion of that charge.⁹⁰ Electric and magnetic fields are ubiquitous in modern society, being found wherever there are power transmission or distribution lines and wherever there is an electrical appliance.⁹¹ A brief description of a power delivery system follows.

A. Power Delivery Systems

Power delivery systems begin with the generation of power, which is measured by "voltage." Voltage is a measure of electric potential energy that makes electric charges flow through a circuit.⁹² The power is generated at about 20,000 volts (twenty kilovolts or twenty kV), but because power is more efficiently transferred over long distances at a higher voltage, large transformers increase or "step-up" this voltage to a level measuring from 65 to 765 kilovolts for transmission over high voltage transmission lines.⁹³ The high voltage transmission lines deliver the power to substations, where it is transferred through step-down transformers to lower-voltage distribution lines in which the voltage measures from five to twenty-five kilovolts.⁹⁴ The power then is transferred through a distribution step-down transformer (the large "cans" hanging on the power poles in neighborhoods and along streets) to the customer.⁹⁵ The power in

88. See OTA BACKGROUND PAPER, *supra* note 56, at 7.

89. See *id.* at 8.

90. See *id.* at 1.

91. See *id.* at 4. Hair dryers, electric razors, electric curlers, bedside radios, blenders, vacuum cleaners, televisions, microwave ovens, and personal computers are routinely used in modern society. These items are now considered necessities of modern life, rather than mere conveniences. Electric and magnetic fields also arise from many natural sources and are present in all living organisms. See *id.*

92. See OTA BACKGROUND PAPER, *supra* note 56, at 4.

93. See *id.* at 5 (Fig. 2-1).

94. See *id.*

95. See *id.* at 4.

homes is measured at 115/230 volts.⁹⁶ Just as electrical potential energy causing electric charges to flow through a circuit is called "voltage" and is measured in units called "volts," this flow of charges is called "current" and is measured in units called "amperes" (amps), describing the rate at which the electrical charges flow in a power line or wire.⁹⁷ The 115/230 volt wiring in houses is designed to carry currents of up to thirty amps.⁹⁸

Over 370,000 miles of transmission line and over two million miles of distribution line exist in the United States today.⁹⁹ One would have to look long and hard to find dwellings in the United States that are not wired for electricity. Therefore, because of the universal exposure of people to sources of electric power and electric devices, the primary area of investigation for the National Research Council (NRC) Committee was the low-frequency electric and magnetic fields associated with electric power and electric devices.¹⁰⁰

B. Frequency and the Electromagnetic Spectrum

Electric power is either alternating current (AC) or direct current (DC).¹⁰¹ Batteries produce direct current; power used in homes and workplaces is alternating current.¹⁰² Power line fields alternate from positive voltage to negative voltage.¹⁰³ The number of times per second that the variation occurs is called the "frequency" of the current.¹⁰⁴ One cycle per second is measured as one Hertz (Hz), an internationally accepted unit of frequency.¹⁰⁵ For example, a power field that alternates sixty times per second is said to have a frequency of sixty Hz.¹⁰⁶ The frequency of electric power produced in the United States is sixty Hz, while countries in Europe and other places generally produce power at a frequency of fifty Hz.¹⁰⁷

96. *See id.*

97. *See id.*

98. *See id.*

99. *See id.* (citing D. Minner, *The Top 100 Utilities 1986 Operating Performance*, ELECTRIC LIGHT AND POWER (August 1987); Energy Information Administration, U.S. Department of Energy, *Statistics of Privately-Owned Electric Utilities, 1981 Annual Technical Report* 130 E/ELA-0044(81) (1983)).

100. *See* NRC REPORT, *supra* note 3, at 11.

101. *See* OTA BACKGROUND PAPER, *supra* note 56, at 1.

102. *See id.*

103. *See* NRC REPORT, *supra* note 3, at 11 n.1.

104. *See id.*

105. *See id.*

106. *See id.*

107. *See id.* at 12 n.4.

Associated with the characteristic of frequency of electromagnetic energy is the characteristic of "wavelength."¹⁰⁸ The relationship between frequency and wavelength is that higher frequencies have shorter wavelengths.¹⁰⁹ Frequency and wavelength of electromagnetic energy are related to the electromagnetic spectrum because the spectrum is a classification of electromagnetic energy by frequency and wavelength ranging from extremely low frequencies (ELF) with longer wavelengths to very high frequencies with shorter wavelengths.¹¹⁰ The frequencies are commonly expressed as powers of ten; for example, a frequency of 10^9 is one gigahertz (Ghz) and is 1,000,000,000 Hz.¹¹¹ The range of the electromagnetic spectrum¹¹² frequencies is from zero to 10^{22} ¹¹³ The extremely low frequencies or extra-low frequencies (ELF)¹¹⁴ include the fifty to sixty Hertz power associated with electric current in homes.¹¹⁵ In increasing frequencies, the spectrum includes radio waves at 10^6 to 10^{10} Hz, microwaves at 10^{10} to 10^{12} Hz, infrared radiation at 10^{12} to 10^{14} Hz, visible light at 10^{14} Hz, ultraviolet radiation at 10^{15} Hz, and at greater than 10^{17} Hz, X-rays and gamma rays, which have very high frequencies and very short wavelengths.¹¹⁶

The electromagnetic spectrum ranges from "non-ionizing" radiation at the low end of the spectrum to "ionizing" radiation at the high end.¹¹⁷ Energy is ionizing if it is capable of causing an atom or a molecule to gain or lose one or more electrons, thus producing charged particles when it interacts with the atoms or molecules.¹¹⁸ Gamma rays, X-rays, and some types of ultraviolet lights are ionizing radiation.¹¹⁹

Ionizing radiation has been long-studied and known to damage biological systems¹²⁰ because it is able to break chemical bonds,

108. *See id.* at 24. Waveform, the change in amplitude and phase with time, is another characteristic of AC electric or magnetic fields. *See id.* The waveform of 50-60 Hz AC fields encountered in the environment is the sinusoidal field, those most often used in biological experiments. *See id.* Sinusoidal fields can contain distortions causing "harmonics," which are multiples of the fundamental frequency, such as 120 Hz, 180 Hz, 240 Hz, etc. *See id.*

109. *See id.* at 12.

110. *See id.*

111. *See id.* at 11 n.2.

112. *See* Appendix.

113. *See* NRC REPORT, *supra* note 3.

114. *See id.* at 12 n.3, 24 (noting the frequencies that are generally designated "ELF" are range from 3 Hz to 3000 Hz (3 kHz)).

115. *See id.* at 12.

116. *See id.*

117. *See id.*

118. *See id.*

119. *See id.*

120. *See id.*

thereby adversely affecting health.¹²¹ Lower on the spectrum than the ionizing radiation bands are bands of high frequency non-ionizing radiation that do not break chemical bonds. These include visible light, microwaves, and radio and television waves.¹²² Microwaves do have the capacity to cause water molecules to vibrate, which produces heat; therefore, microwaves can also adversely affect human health because of the capacity to heat human tissue.¹²³

As the lowest bands on the spectrum, ELF energy is non-ionizing and is not able to break chemical bonds, nor can it vibrate water molecules or heat human tissue.¹²⁴ The manner in which ELF energy interacts with biological systems is "speculative;"¹²⁵ however, ELF effects have been reported to "include effects on cell metabolism and growth, gene expression, hormones, learning and behavior, and promotion of tumors."¹²⁶ Scientists have debated the validity of the above effects, leading to the National Research Council Committee's study and report discussing the possible health effects of exposure to electric and magnetic fields.¹²⁷

121. See Tom Watson and Curtis S. Renner, *The Scientific and Legal Bases for Litigating EMF Property Cases*, in CURRENT CONDEMNATION LAW: TAKINGS, COMPENSATION & BENEFITS 126, 128 (Alan T. Ackerman ed., 1994). The concern about possible health effects of exposure to EMF originated during World War II when men were exposed to high-frequency radar systems and video screens. Subsequently, claims of adverse health effects arose in connection with police radar guns, cellular phones, microwave ovens and other high-frequency sources. See NRC REPORT, *supra* note 3, at 10. Radar guns and cellular telephones are beyond the very high frequency range on the Electromagnetic Spectrum and thus are not examples of the extra low frequency residential electric and magnetic fields. See *Blesy et al. v. Kustom Signals*, 18 ELECTROMAGNETIC FIELD LITIG. REP. 13 (concerning radar guns); *Ward v. Motorola*, 18 ELECTROMAGNETIC FIELD LITIG. REP. 8 (concerning cellular telephones).

122. See NRC REPORT, *supra* note 3, at 12.

123. See Watson & Renner, *supra* note 121, at 129.

124. See *id.*

125. NRC REPORT, *supra* note 3, at 12.

126. *Id.* at 13.

127. See OTA BACKGROUND PAPER, *supra* note 56, at 6. Electric and magnetic fields are either propagating or non-propagating. See *id.* Propagating fields travel long distances from their source; non-propagating fields are confined to the vicinity of their source. See *id.* "A wavelength is the distance that a propagating field travels during one oscillatory cycle." *Id.* The intensity of a confined field decreases more rapidly with distance from the source of the field than does the intensity of a propagating field, so propagating fields dominate at distances far from the source as compared to the distance traveled by one 60 Hz wavelength, which covers several thousand kilometers. See *id.* The power frequency fields that people are exposed to are the non-propagating type because the 60 Hz wavelength is on the lower end of the electromagnetic spectrum. See *id.* The exposure to people is greatest because of the proximity of power lines and electric appliances. The term "radiation" refers to propagating fields and not to the confined, non-propagating type, but because low frequency EMF or ELF are non-propagating, to use the term "ELF radiation" is technically inappropriate. See *id.*

C. Exposure to Electric and Magnetic Fields

Humans are affected by electric and magnetic fields, which are generated from both external and internal sources. Until about 125 years ago, external human exposure was limited to those fields emanating naturally from atmospheric electricity and geomagnetism.¹²⁸ Since the discovery of electricity and its ever-increasing use to power all the modern conveniences, the electric and magnetic fields to which humans are exposed have greatly multiplied.¹²⁹ Internal sources also exist because humans and all other organisms have within them "endogenous electric fields and currents that play a role in the complex mechanisms of physiological control such as neural and neuromuscular activity, tissue growth and repair, glandular secretion, and cell membrane function."¹³⁰ Given the role that electric and magnetic fields play internally in the biology of humans, a natural inquiry concerns the effect that the external electric and magnetic fields have on that biology.

Studies have shown that electric and magnetic fields, by the processes of induction, can affect humans by producing currents in the body¹³¹ as well as charges on the surface of the body.¹³² When a person's body is exposed to an electrical field, induced fields within the body are extremely weak because the conductivity of the body tissue weakens the electrical field.¹³³ However, the same is not true for magnetic fields. The conductivity of the body tissue does not affect the magnetic fields, so magnetic fields pass through the body

128. See ASHER R. SHEPPARD & MERRILL EISENBUD, *BIOLOGICAL EFFECTS OF ELECTRIC AND MAGNETIC FIELDS OF EXTREMELY LOW FREQUENCY 1-1* (1977).

129. See *id.*

130. *Id.* at 2-7, 2-8. Electric or magnetic fields are involved in the following normal biological functions: normal brain rhythms as observed by electroencephalogram and magnetoencephalogram patterns; the activity of the nervous system; bone growth, and the regeneration of new bone growth after injury; and natural sensitivity to very weak electric and magnetic fields in fish, birds, and bacteria. See *id.*

131. See NRC REPORT, *supra* note 3, at 22. Interestingly, nerve cells have electric activity within them and cause current densities on the surface of the body. A human would have to be exposed to a 60 Hz field of 1 G to produce an equivalent current density within the body. Typical residential fields are about 1 mG, and thus cause induced current densities that are 1,000 times less than those induced by nerve cell activity.

132. See OTA BACKGROUND PAPER, *supra* note 56, at 16 (citing Kaune & Phillips, *Dosimetry for Extremely Low-Frequency Electric Fields*, in *BIOLOGICAL EFFECTS OF AND DOSIMETRY OF STATIC AND ELF ELECTROMAGNETIC FIELDS* (M. Grandolfo & S. Michaelson eds., 1985)). When the free electric charges, contained in the ion-rich blood and lymph fluids in the human body, move in response to charges on and currents in nearby power lines and appliances, the currents in the body have been produced by electric or magnetic induction. See *id.* Body shape, posture, orientation, size of charges and currents in the source, distance from source, and presence of shields all affect the surface charge and body currents. See *id.*

133. See NRC REPORT, *supra* note 3, at 13.

inducing electric currents within the body.¹³⁴ Nor do most common building materials weaken magnetic fields, which can pass through thin sheets of metal; however, iron and other magnetic materials that serve as paths of conduction of magnetic fields can sometimes be used as shields from magnetic fields exposure.¹³⁵ Because most materials have enough conductivity to sufficiently weaken electric fields, most materials can easily shield people from exposure to electric fields.¹³⁶

The electric power used in homes and workplaces produces both electric and magnetic fields because when electric charges move to create a current, magnetic fields are created.¹³⁷ Even if an electric appliance plugged into an electrical outlet is turned off, it might have an electric field present. If the appliance is turned on and operating, a magnetic field will also be present.¹³⁸ When the two fields, which are quite different in character, are "coupled" in this manner, they are referred to in the NRC Report as "electromagnetic fields" (EMF).¹³⁹ However, because coupling at the low frequencies of fifty and sixty Hz is extremely weak, considering the electric and magnetic fields as independent and not substantially linked is more appropriate. For this reason the NRC Report reserves the use of the term "electromagnetic field" for high frequency fields where the electric and magnetic fields are substantially linked.¹⁴⁰

The fields to which people are exposed can be measured. The intensity of an electric field is measured in units of volts per meter (V/m).¹⁴¹ Since a thousand volts equals a kilovolt, a thousand volts per meter is a kilovolt per meter (kV/m).¹⁴² The intensity of an electric field decreases rapidly as distance from the source increases.¹⁴³ Several different units are used to measure strength and intensity of a magnetic field. For instance, the ampere per meter (A/m) properly

134. *See id.*

135. *See id.*

136. *See id.*

137. *See id.* at 12. Physicist James Clerk Maxwell described the relationship between magnetic fields and electric fields in the nineteenth century. He showed that changing magnetic fields produce electrical fields and that alternating currents of electricity produce magnetic fields. *See* OTA BACKGROUND PAPER, *supra* note 56, at 16.

138. *See* NRC REPORT, *supra* note 3, at 12.

139. *See id.* at 13. The term "electromagnetic field" or "EMF" is used to generally describe electric and magnetic fields together.

140. *See id.*

141. *See* OTA BACKGROUND PAPER, *supra* note 56, at 7.

142. *See id.* at 7.

143. *See id.* at 8.

measures magnetic field intensity and corresponds to the V/m for electric fields.¹⁴⁴

Magnetic flux density is a related quantity indicating magnetic field strength and comprises the number of field lines (lines representing graphically either an electric or magnetic field) that cross a unit of surface area.¹⁴⁵ The unit measuring magnetic flux density is the gauss (G), with 10,000 gauss making a unit called a "tesla."¹⁴⁶ The magnetic field intensity measured in A/m is eighty times as great as the measurement of the magnetic flux density in gauss, though both the gauss and the tesla are considered large units.¹⁴⁷ When measurements of magnetic fields are reported, they are usually in thousandths of a gauss or milligauss (1mG = 0.001 G). For example, the magnetic fields produced underneath the commonly observed neighborhood distribution power lines generally measure around five mG, though densely populated areas may produce fields measuring as high as fifty mG.¹⁴⁸ The strength of magnetic fields produced by electric appliances varies from very few milligauss to several hundred milligauss.¹⁴⁹ The intensity of the magnetic field decreases rapidly as the distance from the source increases.¹⁵⁰

Though electric fields and magnetic fields at the power line frequency of sixty Hz can each be measured or calculated in most any environment,¹⁵¹ the determination of human exposure is more difficult.¹⁵² Some of the difficulties include the many varieties of electric and magnetic field environments that the average person encounters in a day, the lack of knowledge of the specific characteristic of electric and magnetic fields that interact with biological systems, and whether a specific characteristic does indeed interact with the biological system.¹⁵³

144. *See id.*

145. *See id.*

146. *See id.*

147. *See id.*

148. *See id.*

149. *See* NRC REPORT, *supra* note 3, at 16.

150. *See id.*

151. *See id.* at 26-27 (citing ANSI/IEEE, PROCEDURES FOR MEASUREMENT OF POWER FREQUENCY ELECTRIC AND MAGNETIC FIELDS FROM AC POWER LINES. 644 (1987)). Measurement procedures are described in detail by the cited study.

152. *See id.* at 25-26.

153. *See id.* at 25. Electric and magnetic fields have many complex characteristics such as strength, harmonics (integral multiples of a fundamental frequency), transients (short duration signals containing a range of frequencies and appearing at irregular time intervals), temporal and spatial changes. *See id.* Strength of the 60 Hz magnetic field has been the characteristic tacitly assumed in the majority of studies to be directly related to exposure. *See id.* The strength is measured as the average root-mean-square (rms, a time averaged measurement).

Other problems of measurement and calculation are caused by the perturbation of electric fields by conducting objects.¹⁵⁴ If people and animals are in a measured field, their presence affects the field. Consequently, a significant difference occurs in the measurement of a field without a person present and the measurement of a field with a person present.¹⁵⁵ The measured field of an ELF magnetic field, being unaffected by the presence of humans and animals, represents the actual exposure field.¹⁵⁶

Given all the above-mentioned problems, typical exposures to electric and magnetic fields have been investigated. Devices to measure the electric and magnetic fields have been designed to determine the average root mean square (rms) field strength, which is either magnetic flux density for magnetic fields or electric field strength, for a specific time period.¹⁵⁷ The usual minimum time period that the instruments average is about one second.¹⁵⁸

The electric equipment used in the workplace and the home is responsible for exposure to electric fields in those environments. However, electric fields have not been satisfactorily categorized because of the ease of shielding sixty Hz electric fields. When attempts to measure personal exposure to electric fields have been made, the measurements have depended greatly on several factors, including where the exposure meter was worn, the orientation of the meter, and the presence of any conductors near the exposure.¹⁵⁹ One study found the range of the mean personal exposure to sixty Hz electric fields in home or office to be from five to ten V/m.¹⁶⁰

While workplace and home electric fields have not been well characterized, power line electric fields have. Ground-level electric fields under a line depend on the line voltage and may be as high as ten kV/m. A field of ten kV/m is strong enough to shock a person touching a vehicle parked under the high-voltage line and can also cause a fluorescent tube to glow when held under the line. The

154. *See id.*

155. *See id.* at 25 (citing W.T. Kaune and M.L. Gillis, *General Properties of the Interaction Between Animals and ELF Electric Fields*, 2 BIOELECTROMAGNETICS 1-11 (1981)).

156. *See id.* at 25.

157. *See id.*

158. *See id.* at 26-27. The devices can be set to record many samples of a magnetic field over a long period of time, for example, a sample every 10 seconds for 24 hours. *See id.* The electric and magnetic field measuring devices frequently are calibrated against the calculated field because, when properly performed, calculations of the fields are more accurate than measurements.

159. *See* NRC REPORT, *supra* note 3, at 27.

160. *See id.* (citing Electric Power Research Institute, Palo Alto, Cal., PROJECT RP 2966-1, THE EMDEX PROJECT: TECHNOLOGY TRANSFER AND OCCUPATIONAL MEASUREMENTS, EN-7048-V1, -V2, and -V3 (1990)) [hereinafter EMDEX PROJECT].

study mentioned above showed that electrical substation, distribution line, and transmission line workers experience a mean personal exposure ranging from fifty to 5,000 V/m.¹⁶¹

Exposure to residential magnetic fields is most commonly caused by electric appliances in the home, the grounding system (usually the water pipes), and nearby low voltage distribution power lines.¹⁶² The internal wiring usually is not a significant source of magnetic field exposure unless a problem with the wiring exists.¹⁶³ Nor are high voltage transmission lines at a distance of more than one hundred meters from the residence considered a significant source of exposure.¹⁶⁴ However, transmission lines can be a source of magnetic fields if the home is near the line, especially during the time of peak power usage.¹⁶⁵ In addition, substations, while usually not an important source of magnetic fields, do provide a greater possibility of exposure to residences near those facilities because power lines converge at the substations and may be closer to the ground as they approach the substation.¹⁶⁶

The neighborhood power lines are usually lower voltage distribution lines, not the transmission lines discussed above. As mentioned earlier, the distribution lines produce magnetic fields that are usually about five mG with densely populated areas sometimes measuring up to fifty mG.¹⁶⁷ Burying distribution lines does not necessarily decrease the magnetic field associated with the lines unless the lines are buried in a single metal pipe.¹⁶⁸ The other method of burying the lines is called direct burial, a method that can produce ground-level magnetic fields equal to overhead lines.¹⁶⁹

Typical exposures to magnetic fields in the home and in the workplace have been studied.¹⁷⁰ While electric appliances cause the

161. *See id.* at 27-28.

162. *See id.* at 28.

163. *See id.*

164. *See id.* (citing OFFICE OF RADIATION AND INDOOR AIR, U.S. ENVTL. PROTECTION AGENCY, EPA/402/R-92/008, EMF IN YOUR ENVIRONMENT: MAGNETIC FIELD MEASUREMENTS OF EVERYDAY ELECTRICAL DEVICES (1992)) [hereinafter EMF ENV'T]. For a 115 kV transmission line, an average representative magnetic field 91.4 m away was 0.2 mG; for a 230 kV line, the average field was 0.8 mG; and for 500 kV line, the average field was 1.4 mG.

165. *See* NRC REPORT, *supra* note 3, at 32. At peak usage the average figures given in note 118 could double.

166. *See id.* Of course, magnetic fields are strongly present within the substation itself.

167. *See id.*

168. *See id.*

169. *See id.* at 32-33. Burial in underground pipes decreases the typical field to less than one mG because the close spacing of the wires and the metal pipe decreases the field. However, with direct burial, though the wires are closer, thus decreasing the field, the wires are closer to the surface of the ground than overhead wires, thus increasing the field. *See id.*

170. For example, the NRC Committee cited and included in its report tables from: EMF ENV'T, *supra* note 164; EMDEX PROJECT, *supra* note 160.

strongest magnetic fields in homes, grounding systems, power lines, or a combination of the two, produce fields referred to as "background magnetic fields" in the center of rooms away from most appliances.¹⁷¹ One study of 992 homes showed that only five percent of the homes had average background magnetic fields greater than 2.9 mG.¹⁷²

The strong magnetic fields produced in homes by electric appliances usually decrease rapidly with distance from the appliance. For example, one study reporting the range of magnetic field strengths of common household appliances showed that the magnetic fields of microwave ovens range from 100 to 300 mG at a distance of six inches and from one to 200 mG at a distance of one foot.¹⁷³ The study used measurements of rms fields that were averaged over one second or more for spot measurements and up to twenty-four hours for long-term and personal exposure measurements.¹⁷⁴ Another study showed that ninety-five percent of all of the 485 microwave ovens measured emitted magnetic fields less than seventeen mG at fifty-six centimeters (twenty-two and one-half inches).¹⁷⁵ Differences in design of appliances of the same type can cause different magnetic fields to be produced. Electric blankets have been a cause for concern about exposure to magnetic fields because when blankets are in use they are very close to internal organs, which lie about five centimeters from the surface of the blanket. When magnetic fields associated with conventional electric blankets are measured at that distance, the field strengths average about twenty-two mG.¹⁷⁶

When personal exposure is measured, the fact that a person moves around the house or workplace means that the measurement is a combination of exposures to electric appliances, power lines, and grounding systems.¹⁷⁷ The office environment magnetic field measurements are similar to those for the home, however, personal exposure measurements are somewhat higher. This is probably caused

171. See NRC REPORT, *supra* note 3.

172. See *id.* at 28-29 (citing Geomet Technologies, Inc., PROJECT RP2966-04, ASSESSMENT OF CHILDREN'S LONG-TERM EXPOSURE TO MAGNETIC FIELDS (THE GEOMET STUDY), Rep. TR-101406 (1993) [HEREINAFTER GEOMET STUDY]. At the 95th percentile the kitchens averaged 3.5 mG. Interpretation of the study assumes that a person's activity pattern is uniformly distributed in the living space.

173. See NRC REPORT, *supra* note 3, at 29-30 (citing EMF ENV'T, *supra* note 164).

174. See *id.*

175. See *id.* at 31 (citing GEOMET STUDY, *supra* note 172).

176. See *id.* at 30. For positive-temperature-coefficient blankets the fields average about one mG.

177. See *id.* at 31. When measurements are taken at fixed positions in the rooms, they are consistently lower than personal exposure measurements.

by the more constant use of electric equipment and the proximity to that equipment at the workplace.¹⁷⁸

The foregoing discussion of measuring exposure has been based on direct measurement by instruments of the electric and magnetic fields. Epidemiological studies use indirect methods of measuring magnetic fields and will be considered in the following section discussing the National Research Council Committee Report.¹⁷⁹

IV. THE NATIONAL RESEARCH COUNCIL COMMITTEE REPORT

The National Research Council is an agency of the National Academy of Sciences (NAS), granted a charter by Congress in 1863 with the mandate to advise the federal government on scientific and technical matters.¹⁸⁰ Under the charter of the NAS, the National Academy of Engineering was established in 1964 to share responsibility for advising the federal government.¹⁸¹ In 1916 the NAS organized the National Research Council (NRC) for the purpose of associating the science and technology community with the Academy's purposes.¹⁸² Since its establishment, the NRC has become the chief operating agency of both the NAS and the National Academy of Engineering. The NRC provides services to the government, the public, and the scientific and engineering communities.¹⁸³

When the United States Department of Energy (DOE) requested that the NAS review the scientific evidence of potential health risk from exposure to the electric and magnetic fields generated by electric devices, the Committee on Possible Effects of Electromagnetic Fields on Biologic Systems (NRC Committee) was convened.¹⁸⁴ The charge to the NRC Committee from the DOE included: reviewing and evaluating the existing scientific information on the potential effects of exposure to electric and magnetic fields on cancer incidence, reproduction and development, and learning and behavior; critically examining epidemiological and laboratory data relating to those topics and assess potential health effects; focusing on electric- and magnetic-field frequencies and exposure modalities found in residential settings; and producing a report that contains a review of pertinent information on the effects of electric and magnetic fields;

178. *See id.* at 33.

179. *See id.* at 118-19.

180. *See id.* at xix.

181. *See id.*

182. *See id.*

183. *See id.*

184. *See id.* at 9-10. The Board on Radiation Effects Research of the NRC's Commission on Life Sciences convened the Committee to perform the review and report its finding.

identification of research areas in which data are needed to better understand any potential health hazard; and recommendations for research in those areas and strategies for implementing research that would enhance understanding.¹⁸⁵ If data of appropriate quality is available, the NRC Committee should include a health risk assessment of power-frequency electric-field and magnetic-field exposures.¹⁸⁶

As the charge reflects, the NRC Committee was to evaluate three categories of health hazards: carcinogenic effects, neurobehavioral effects, and reproductive effects.¹⁸⁷ After almost three years of study, the NRC Committee released its Report.

The NRC Report consists of an Executive Summary, an Introduction, and chapters on Exposure and Physical Interactions, Cellular and Molecular Effects, Animal and Tissue Effects, Epidemiology, Risk Assessment, and Research Needs and Agenda. Appended to the Report are tables summarizing various studies discussed in the Report and a discussion on "wire codes," or wiring configurations, used in some epidemiological studies instead of direct measurement

185. See *id.* at 10. The Committee on the Possible Effects of Electromagnetic Fields on Biologic Systems consisted of the following people:

CHARLES F. STEVENS (*Chair*), Howard Hughes Medical Institute, Salk Institute, La Jolla, Calif.

DAVID A. SAVITZ (*Vice Chair*), Department of Epidemiology, University of North Carolina, Chapel Hill, N.C.

LARRY A. ANDERSON, Pacific Northwest National Laboratory, Richland, Wash.

DANIEL A. DRISCOLL, Department of Public Service, State of New York, Albany, N.Y.

FRED H. GAGE, Laboratory of Genetics, Salk Institute, San Diego, Calif.

RICHARD L. GARWIN, IBM Research Division, Yorktown Heights, N.Y.

LYNN W. JELINSKI, Center for Advanced Technology-Biotechnology, Cornell University, Ithaca N.Y.

BRUCE J. KELMAN, Golder Associates, Inc., Redmond, Wash.

RICHARD A. LUBEN, Division of Biomedical Sciences, University of California, Riverside, Calif.

RUSSELL J. REITER, Department of Cellular and Structural Biology, University of Texas Health Sciences Center, San Antonio, Tex.

PAUL SLOVIC, Decision Research, Eugene, Oreg.

JAN A. J. STOLWIJK, Department of Epidemiology and Public Health, Yale University School of Medicine, New Haven, Conn.

MARIA A. STUCHLY, Department of Electrical and Computer Engineering, University of Victoria, B.C., Canada.

DANIEL WARTENBERG, UMDNJ-Robert Wood Johnson, Medical School, Piscataway, N.J.

JOHN S. WAUGH, Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Mass.

JERRY R. WILLIAMS, The Johns Hopkins Oncology Center, Baltimore, Md.

186. See *id.*

187. See NRC REPORT, *supra* note 3, at 17. Cancer is an especially dreaded disease. One can easily understand why a potential risk of cancer caused by exposure to electric and magnetic fields is of particular concern, and the fact that childhood leukemia has been associated with ELF only increases that concern.

of exposure.¹⁸⁸ The Executive Summary, Introduction, and the Exposure and Physical Interaction chapter are reflected in the materials above. The other chapters are discussed below.

A. Cellular and Molecular Effects

The NRC Report discussed the published scientific studies of the effects on cells and molecules "in vitro" (in glass) of exposure to power frequency electric and magnetic fields.¹⁸⁹ Concluding that residential strength magnetic field exposures do not produce significant in vitro effects,¹⁹⁰ the NRC Report also specifically discussed effects on genotoxicity, signal-transduction pathways, intracellular calcium concentrations, and general patterns of gene expression.¹⁹¹

1. Heritable Changes in Cells Exposed In Vitro

Scientists often study the ill effects that certain environmental agents have on genes, or genotoxicity, by using cultured cells. Genotoxicity can be indicated by direct heritable changes such as mutation or chromosomal aberrations, or indications of heritable changes such as DNA damage or repair.¹⁹² After reviewing twenty-nine published articles reporting effects of exposure to residential power, twenty-four of which used frequency of sinusoidal form, the NRC Committee concluded that power frequency electric and magnetic fields are not directly a genotoxic agent.¹⁹³

188. *See id.*

189. *See id.* at 53-54. The NRC Committee cautioned that a problem exists in interpreting the responses of cells in culture in terms of the manner in which cells in a living body (in vivo) would respond. Similar exposures and appropriate surrogates are required. Confidence in results from power frequency field exposure is gained by experiments that produce responses similar to those responses produced by known carcinogens, neurotoxins, or developmental toxins.

190. *See id.* at 52-53. The NRC Committee was impressed by the number and quality of studies reporting negative results. The few studies reporting positive results used no superior methods or cell systems as would warrant the NRC Committee concluding other than that residential magnetic field strengths (0.1 to 10 G) have no significant effects on cultured cell systems.

191. *See id.* at 53.

192. *See id.* at 56. Other indicated heritable changes include non-heritable chromosomal aberrations and sister chromatid exchanges (SCE).

193. Twenty-two of the 24 sinusoidal field exposure studies reported negative results. *See id.* (citing J.E. McCann, et al., *A Critical Review of the Genotoxic Potential of Electric and Magnetic Fields*, 297 MUTAT. RES. 61 (1993) (reviewing many of the studies in Table A3-1 in Appendix A of the NRC Report and concluding that no convincing evidence exists that power frequency fields induce direct genotoxic effects)); J.C. Murphy et al., *Power Frequency Electric and Magnetic Fields: A Review of Genetic Toxicology*, 296 MUTAT. RES. 221 (1993) (studying under the auspices of the International Commission for Protection Against Environmental Mutagens and Carcinogens and concluding no genotoxic effect by the preponderance of the data, but noting need for further study)). Two studies from the same laboratory reported positive genotoxicity results. *See id.* (citing G. D'Ambrosio et al., *Chromosomal Aberrations Induced by Extremely Low Frequency Electric Fields*, 4 J.

2. Transient Changes to Cells Exposed In Vitro

Whereas the NRC Committee found no direct heritable changes, that is, no genotoxicity, in cells exposed in vitro to electric and magnetic fields, it did discuss the evidence that magnetic fields can induce transient changes in cell expression in three categories: signal transduction pathway changes, gene expression changes, and intracellular calcium level changes.¹⁹⁴

a. Signal Transduction Changes

Signal transduction processes, in which molecular systems inside the cell and at the cell membrane receive signals from the environment and from other cells, provide a mechanism by which cell functions may be influenced by electric and magnetic fields.¹⁹⁵ Metabolic activities, gene expression, cell proliferation, and other intracellular processes are regulated by the signals received, therefore, if the electric and magnetic fields affect or change the path of the communication of signals (signal transduction changes), the function of the cell might be changed.¹⁹⁶ Signal transduction changes are a common result in experiments and such changes alone do not

BIOELECTROMAGNETICS 279 (1985); D'Ambrosio et al., *Chromosomal Aberrations in Bovine Lymphocytes Exposed to 50-Hz Electric Currents*, 7 J. BIOELECTROMAGNETICS 239 (1988-1989)). Studies using fields other than sinusoidal 50-60 Hz fields, such as high-frequency EMF, static fields, or pulsed (intermittently applied) fields, were also included in Table A3-1. See *id.* Genotoxic effects were reported where fields were pulsed or intermittent and the exposure levels were much higher than those commonly experienced in residences and workplaces. See *id.* at 56-57 (citing I. Nordenson et al., *Chromosomal Aberrations in Human Amniotic Cells After Intermittent Exposure to Fifty Hertz Magnetic Fields*, 15 BIOELECTROMAGNETICS 293 (1994); A.M. Khalil & W. Qassem, *Cytogenic Effects of Pulsing Electromagnetic Field on Human Lymphocytes In Vitro: Chromosome Aberrations, Sister-Chromatid Exchanges and Cell Kinetics*, 247 MUTAT. RES. 141 (1991)). Positive genotoxic effects in the form of excess SCE in human lymphocytes when exposed to 50-Hz sinusoidal magnetic fields and an agent used in the treatment of ovarian cancer were reported, though the authors of the study questioned the results. See *id.* at 57 (citing M. Rosenthal & G. Obe, *Effects of 50-Hertz Electromagnetic Fields on Proliferation and on Chromosomal Alterations in Human Peripheral Lymphocytes Untreated or Pretreated with Chemical Mutagens*, 210 MUTAT. RES. 329 (1989)). A study using pulse-modulated microwaves alone and following or preceding X-rays reported transformed foci in certain cells. See *id.* (citing E.K. Balcer-Kubiczek & G.H. Harrison, *Neoplastic Transformation of C3H/10T1/2 Cells Following Exposure to 120-Hz Modulated 2.45-GHz Microwaves and Phorbol Tumor Promoter*, 126 RADIAT. RES. 65 (1991)). These studies and others involving high-frequency EMF and tumor promoters prompted the NRC Committee to mention the possibility of the need for further study in this area, but, because of the great majority of negative effects for 50-60 Hz field exposure, the NRC Committee concluded that power frequency fields are not a direct genotoxic agent.

194. See NRC REPORT, *supra* note 3, at 58. Heritable changes and transient changes are the two categories of changes observed in cultured cells exposed to electric and magnetic fields and are relevant to carcinogenic, neurobehavioral, and reproductive effects of concern in attempts to evaluate potential hazards associated with fields. Because developmental toxins need act only a short time during gestation, developmental effects are most susceptible to transient changes caused by electric and magnetic field exposure.

195. See *id.* at 58.

196. See *id.* at 6.

indicate an adverse effect.¹⁹⁷ Studies indicate that changes in membrane-transduction pathways are caused by low frequency electric and magnetic fields.¹⁹⁸ However, most of the studies have not been independently replicated, a requirement given great weight in reaching conclusions about the result of studies and experiments.¹⁹⁹

One study that has been independently replicated by at least two laboratories²⁰⁰ observed that magnetic field exposure produces changes in ornithine decarboxylase (ODC) activity, an enzyme involved as a cell membrane signal transduction pathway.²⁰¹ The significance of this observation is that ODC activity is associated with mitogen activity and the various activities of tumor-promoting agents during carcinogenesis. The observation led to the hypothesis that low strength electric fields acting on the cell membrane, while not causing cancer, might be a copromoter and act with another tumor-promoting agent to cause more growth of an existing cancer than the agent acting alone.²⁰²

197. *See id.*

198. *See id.* at 58 (citing W.R. Adey, *ELF Magnetic Fields and Promotion of Cancer Experimental Studies & Collective Properties of Cell Membranes*, in INTERACTION MECHANISMS OF LOW-LEVEL ELECTROMAGNETIC FIELDS IN LIVING SYSTEMS at 23-46, 47-77 (B. Norden & C. Ramel eds., 1992); R. Cardossi et al., *Lymphocytes and Low-Frequency Electromagnetic Fields*, 6 FASEB J. 2667 (1992); S.F. Cleary, *A Review of In Vitro Studies: Low-Frequency Electromagnetic Fields*, 54 J. AM. IND. HYG. ASSOC. 178 (1993); R.P. Liburdy, *ELF Fields and the Immune System: Signal Transduction, Calcium metabolism, and Mitogenesis in Lymphocytes with Relevance to Carcinogenesis*, in INTERACTION MECHANISMS OF LOW-LEVEL ELECTROMAGNETIC FIELDS IN LIVING SYSTEMS at 217 (B. Norden & C. Ramel eds., 1992); R.A. Luben, *Effects of Low-Energy Electromagnetic Fields (Pulsed and DC) on Membrane Signal Transduction Processes in Biological Systems*, 61 HEALTH PHYS. 15 (1991); R.A. Luben, *Effects of Low-Energy Electromagnetic Fields (EMF) on Signal Transduction by G Protein-Linked Receptors*, in ELECTRICITY AND MAGNETISM IN BIOLOGY AND MEDICINE at 57 (M. Blank ed., 1993); T.S. Tenforde, *Biological Interactions of Extremely-Low-Frequency Electric and Magnetic Fields*, 25 BIOELECTROCHEMISTRY AND BIOENERGETICS 1 (1991); T.S. Tenforde, *Biological Interactions and Potential Health Effects of Extremely-Low-Frequency Magnetic Fields from Power Lines and Other Common Sources*, 13 ANNU. REV. PUBLIC HEALTH 173 (1992); J. Walleczek, *Electromagnetic Field Effects on Cells of the Immune System: The Role of Calcium Signaling*, 6 FASEB J. 3177 (1992)).

199. *See* NRC REPORT, *supra* note 3, at 16. The NRC Committee explains:

At the end of the risk-assessment process, the body of evidence is weighed together to reach an overall assessment of a possible hazard. If the results from several areas of research (e.g., epidemiologic [sic] studies, tests in cell systems, or whole animal studies) are consistent and have been replicated and if a biologically plausible mechanism of action for the effect is evident, the evidence for the effect is given great weight. In contrast, a body of evidence that includes inconsistent and conflicting results, no replication of results, and effects that are often at the threshold of detection might be given little weight in reaching a conclusion.

Id.

200. *See id.* at 62.

201. *See id.* at 53, 61-62 (citing C.V. Byus et al., *The Effects of Low-Energy 60-Hz Environmental Electromagnetic Fields Upon the Growth-Related Enzyme Ornithine Decarboxylase*, 8 CARCINOGENESIS 1385 (1987) (reporting that human lymphoma cells, mouse myeloma cells, and rat hepatoma cells showed increase in ODC activity when exposed to 60 Hz electric field)).

202. *See id.* at 61-62. The hypothesis is discussed further *infra* at notes 205-11 and accompanying text.

Among the unreplicated studies examining the effects of magnetic fields on signal transduction pathways is a study suggesting a possible correlation between magnetic field exposure and the growth of cancer cells.²⁰³ The cancer cells exposed to a twelve mG sinusoidal magnetic field at sixty Hz were human estrogen-responsive breast cancer cells, which grow rapidly in the presence of normal concentrations of estrogen, a female sex hormone.²⁰⁴ The study confirmed that the growth rate decreases in the presence of normal concentrations of melatonin, a hormone produced by the pineal gland, but that exposure to the sixty Hz magnetic field at twelve mG prevented the melatonin's effect of decreasing the cancer cell growth rate.²⁰⁵ No significant effect was observed when the strength of the magnetic field was lowered to two mG, leading to the suggestion that a threshold for effect might exist between two and twenty mG.²⁰⁶

The NRC Committee noted that if other laboratories replicated the above effects, an exception to the observation that cells in tissue culture are not significantly affected by residential strength magnetic fields would exist.²⁰⁷ Stressing the need for independent replication of most of the studies in the area of signal transduction, the NRC Committee concluded that while evidence exists that fields of strengths greater than residential strength fields²⁰⁸ probably do have an effect on signal-transduction-related pathways in cells, essentially no evidence exists for such effects at residential field strengths.²⁰⁹

b. Gene Expression Changes

Whether exposure to residential strength electric and magnetic fields might change DNA²¹⁰ structure or function has been studied. Most studies show that such a change is unlikely, however, a 1991 study²¹¹ reported results showing an increase in transcription

203. See *id.* at 62-63 (citing R.P. Liburdy et al., *ELF Magnetic Fields, Breast Cancer, and Melatonin: 60-Hz Fields Block Melatonin's Oncostatic Action on ER-Positive Breast Cancer Cell Proliferation*, 14 J. PINEAL RES. 89 (1993)).

204. See *id.*

205. See *id.*

206. See *id.* at 63.

207. See *id.*

208. See *id.* Magnetic fields at one G and above and electric fields at 10 kV/m and above likely have some effect.

209. See *id.*

210. DNA is the molecular basis of heredity. When genetic information is transferred to a messenger RNA molecule from the DNA molecule, the process is called "transcription." See 18 THE OXFORD ENGLISH DICTIONARY 393 (2d ed. 1989).

211. See NRC REPORT, *supra* note 3, at 63 (citing R. Goodman & A. Shirley-Henderson, *Transcription and Translation in Cells Exposed to Extremely Low Frequency Electromagnetic Fields*, 25 BIOELECTROCHEMISTRY AND BIOENERGETICS 335 (1991) (reporting an increase in transcription in selected chromosome loci of salivary gland cells)).

activity after brief exposures to fields at higher than residential strengths.²¹² Other studies showing changes in gene expression followed,²¹³ but like the 1991 study, they were highly criticized because of a lack of method precision and a lack of consistent controls, both external and internal.²¹⁴ The criticisms led two groups to attempt replication studies using improved experimental techniques and elaborate precautions.²¹⁵ Despite those efforts, the groups failed to replicate the gene expression effects that had been previously reported.²¹⁶ The NRC Committee concluded, "[e]vidence for electric- and magnetic-field effects on gene expression at residential field strengths is completely lacking."²¹⁷

c. Calcium Changes

Calcium, as an inorganic ion that serves as a biochemical event messenger, is important in biological processes such as bone formation, muscle contraction, and synaptic transmission.²¹⁸ The concentration of calcium inside a cell regulates enzyme catalysts, thus serving as a second messenger in neural function.²¹⁹ Because calcium is so important in biological processes, any external agent causing calcium ions to flow into or out of the cell could have a significant effect on biological function.²²⁰

During the past two decades many studies have sought the effect that power frequency electric and magnetic fields have on calcium. The NRC Report summarized only such studies that had appeared in peer-reviewed journals from 1990 to October 15, 1994 in Table A3-2 in Appendix A.²²¹ The NRC Committee notes that, though most of the studies show some sort of positive association between calcium concentration changes and exposure to electric and magnetic fields,

212. *See id.*

213. *See id.* at 64-65 (citing J.L. Phillips et al., *Magnetic Field Induced Changes in Specific Gene Transcription*, 1132 *BIOCHEMISTRY AND BIOPHYSICS ACTA* 140 (1992) (showing transient changes in transcription rates)).

214. *See id.* at 65.

215. *See id.* at 65-66 (citing J.D. Saffer & S.J. Thurston, *Short Exposures to 60 Hz Magnetic Fields Do Not Alter MYC Expression in HL60 or Daudi Cells*, 144 *RADIAT. RES.* 18 (1995); A. Lacy-Hulbert et al., *No Effect of 60-Hz Electromagnetic Fields on MYC or Beta-actin in Human Leukemic Cells*, 144 *RADIAT. RES.* 9 (1995)).

216. *See id.*

217. *Id.* at 65.

218. *See id.* at 66.

219. *See id.*

220. *See id.* at 66-67.

221. *See id.* at 67. The NRC Report did not discuss earlier studies except for those on the effects of electric and magnetic fields on calcium efflux from chick brains.

problems exist relating to explaining the results,²²² difficulty in observing the effects,²²³ and inadequate replication.²²⁴ Only three of the Table A3-2 studies have been replicated by independent laboratories, published in peer-reviewed journals, and have identified explicitly the exposure strengths used.²²⁵ Having met those exacting requirements, the three studies, involving experiments showing an increase in calcium transport when thymic lymphocytes were exposed to pulsed magnetic fields having flux densities that were about 10,000 times greater than the average environmental flux densities, can be given more weight.²²⁶

The NRC Committee cautioned that results observed when the field strengths are higher than residential and workplace field strengths cannot be extrapolated to the lower field strengths since it is not known whether the mechanisms inducing the high field strength effects are the same as those at the lower strengths.²²⁷ Therefore, based on its analysis of the in vitro experiments, the NRC Committee concluded that fifty to sixty Hz magnetic field exposures induce changes in cultured cells only when the field strengths are 1000 to 100,000 times that experienced at residential levels.²²⁸

B. Animal and Tissue Effects

Focusing on three areas of principal interest (carcinogenesis, reproduction and development, and neurobehavioral and neuroendocrine responses), the NRC Committee evaluated the published literature on the exposure of animals and tissues to power frequency electric and magnetic fields.²²⁹ In considering this literature, the NRC Committee's criteria for the reported experiments included the following: the literature must be peer-reviewed; results must be exposure related; and results must be statistically significant; with

222. *See id.* at 72. Many studies from the past twenty years show some positive association between changes in calcium concentrations and field exposure, but often depend on concepts designated as "frequency windows," "temperature windows," or "power-density windows" to explain the association.

223. *See id.* Often statistical significance is achieved only after data is pooled.

224. *See id.* In some of the experiments, the exact experimental protocols were not followed. In others, the investigators were not able to replicate the experiments.

225. *See id.* at 72 (citing R.P. Liburdy, *Calcium Signaling in Lymphocytes and ELF Field: Evidence for an Electric Field Metric and a Site of Interaction Involving the Calcium Ion Channel*, 301 FEBS LETT. 53 (1992); J. Walleczek & T.F. Budinger, *Pulsed Magnetic Field Effects on Calcium Signaling in Lymphocytes: Dependence on Cell Status and Field Intensity*, 314 FEBS LETT. 351 (1992); M.G. Yost & R.P. Liburdy, *Time-Varying and Static Magnetic Fields Act in Combination to Alter Calcium Signal Transduction in the Lymphocyte*, 296 FEBS LETT. 117 (1992)).

226. *See id.*

227. *See id.* at 53.

228. *See id.*

229. *See id.* at 73.

the greatest weight being given to blinded studies²³⁰ that were confirmed in peer-reviewed literature.²³¹

The NRC Committee concluded that no convincing evidence exists that adverse health effects such as cancer, harm to reproduction and development, or behavior distortion are caused by exposure to power frequency electric and magnetic fields.²³² However, the NRC Committee did report evidence of a positive health effect associated with the healing of bones when the broken bones were exposed to higher-than-residential field strengths.²³³

Before summarizing more specifically the NRC Committee's conclusions in the areas mentioned above, a background discussion of the use of animals in studies evaluating risk to humans is appropriate. Animal studies, which are important in evaluating risk to humans from suspected toxic agents, are based on two principles: that the effects produced in the laboratory on animals apply to humans; and that exposing animals to the toxic agent in high doses is a valid method to discover possible hazards to humans.²³⁴

Other important assumptions in animal studies concern the "dose-response" relationship, a relationship forming the basis for toxicology that allows scientists to predict adverse health effects because of the expected predictable interactions between organisms and the toxic agent.²³⁵ The assumptions regarding dose-response relationships include the following: the agent administered caused the response;²³⁶ a relationship exists between the measurement of the dose and the response;²³⁷ and means are available to measure and

230. See *id.* at 156. A study is conducted blindly when the researchers are without knowledge as to whether the subject is a case or a control. The knowledge that a home was occupied by a case child or a control child could have introduced bias in the study.

231. See *id.* at 74.

232. See *id.* at 73-74. Though evidence does exist that neuroendocrine changes result from exposure to residential strength fields, these changes have not been shown to produce adverse health effects.

233. See *id.* at 74.

234. See *id.* at 75-76 (citing C.D. Klaasen & D.L. Eaton, *Principles of Toxicology*, in CASARATT AND DOUL'S TOXICOLOGY: THE BASIC SCIENCE OF POISONS 12 (M.O. Amdur et al. eds., 4th ed. 1991)).

235. See NRC REPORT, *supra* note 3, at 74-75. There are two types of dose-response relationships: individual dose-response relationship, describing the responses of an individual to different doses of an agent; and population dose-response relationship, describing the distribution of responses of a population of individuals to different doses.

236. See *id.* at 75. The NRC Committee urged caution in using the term "dose-response" relationship where an epidemiological study finds an association between a disease and one or more variables because such use is always "suspect until the variable is shown to be a representative factor of the putative causative agent." *Id.*

237. See *id.* Actually measuring the dose that reached the site where an effect is detected is the most accurate way to determine dose-response data. This is usually not done because of the cost, but rather, measurement of exposure is substituted for true dose measurement. In

express toxicity precisely.²³⁸ The foregoing assumptions are presumed to hold true for ELF fields if they indeed are found to be toxic agents.²³⁹

1. *Carcinogenic and Mutagenic Effects*

After presenting its conclusion that no convincing evidence exists that exposure to power frequency electric and magnetic fields causes cancer in animals,²⁴⁰ the NRC Committee discussed the few peer-reviewed laboratory animal studies examining the issue of magnetic fields and cancer, summarized in the Report at Appendix A, Table A4-1.²⁴¹

The experiments on animals examining the carcinogenic effects of exposure to power frequency electric or magnetic fields are either complete carcinogen studies, tumor-initiation studies, or tumor-promotion studies.²⁴² If an electric or magnetic field's potential to cause cancer development is being tested, then the field is being tested for its potential to be a complete carcinogen.²⁴³ Such a study would need one and a half to two years of exposure of rats or mice to the field.²⁴⁴ This would allow the animals to be observed for most of their life-spans, during which time exposure to confounding agents²⁴⁵ must be minimized, and would require a large number of animals because several dosage groups should be included. The number of animals and the length of time involved cause complete carcinogenicity studies to be expensive; therefore, few such studies have been completed. Of three studies, which were studies of control groups exposed to magnetic fields without being exposed to a chemical initiator, and which were criticized by the NRC Committee for having inadequate group sizes, one found an increase in tumors while two found no increase in tumors.²⁴⁶

considering adverse health effects in individual dose-response relationships, the usual characteristic is the greater the dose of a toxin, the greater the response.

238. *See id.*

239. *See id.*

240. *See id.* at 73.

241. *See id.* at 79. The epidemiological studies reporting an association between estimated exposures to fields and cancer generated research interest in a possible connection between magnetic fields and cancer. The epidemiological studies are discussed at *infra* notes 298-346 and accompanying text.

242. *See id.* at 79-80.

243. *See id.* at 79.

244. *See id.* at 80.

245. *See id.* at 122-23. Confounding agents are agents "causing a mixing of effects between the exposure of interest and extraneous risk factors" and "is not a product of the design or conduct of the study, but results from a natural association among risk factors." *Id.*

246. *See id.* at 79-81 (citing D.Sh. Beniashvili & M.Z. Menabde, *Low-Frequency Electromagnetic Radiation Enhances the Induction of Rat Mammary Tumors by Nitrosomethyl Urea*, 61 *CANCER*

Along with the complete carcinogen approach to studying carcinogenicity, another approach is to assume that the suspected carcinogenic agent acts as either a cancer initiator or a cancer promoter. Because carcinogenesis is considered a multi-step process, studies of two phases of the process, initiation and promotion, may be performed.²⁴⁷ Initiation is a genotoxic event where a carcinogen affects the DNA directly.²⁴⁸ Promotion is responsible for initiated cells changing to cancerous cells.²⁴⁹ Initiation and promotion studies use less time, fewer animals, and are less expensive than complete carcinogenesis studies.²⁵⁰ However, because the energies involved in power frequency electric and magnetic fields are too weak to break chemical bonds, and because the in vitro studies provide no evidence of DNA damage from exposure to residential strength fields, no tumor-initiation studies have been reported and few animal studies of tumor promotion have been completed.²⁵¹

A few recent studies have investigated promotion of mammary tumors by exposure to magnetic fields.²⁵² In these studies a chemical initiated the tumors, then the tumors were exposed to the magnetic field.²⁵³ Though the studies have yet to be replicated and their results are inconsistent,²⁵⁴ they seem to suggest a positive

LETT.75 (1991) (reporting a mammary tumor-promotion study in rats finding an increase in mammary gland tumors in rats exposed to magnetic fields at 200 mG for 3 hours a day); B.M. Svedenstal & B. Holmberg, *Lymphoma Development Among Mice Exposed to X-rays and Pulsed Magnetic Fields*, 64 INT. J. RADIAT. BIOL. 119 (1993) (reporting a lymphoma study in mice finding no increase in tumors with long-term exposure to magnetic fields); A. Rannug et al., *A Study on Skin Tumor Formation in Mice with 50-Hz Magnetic Field Exposure*, 14 CARCINOGENESIS 573 (1993) (reporting a mouse skin-tumor promotion study finding no increase in tumors with long-term exposure)).

247. See *id.* at 80.

248. See *id.*

249. See *id.* If one were examining an electric or magnetic field to see if it were an initiator, one high-dose exposure would be followed by repeated doses of a known promoter. To examine to see if a field were a promoter, animals would be exposed to a known initiator and then exposed to electric or magnetic fields for a long period of time.

250. See *id.*

251. See *id.* at 81.

252. See *id.* at 81-82 (citing M. Mevissen et al., *Effects of Magnetic Fields on Mammary Tumor Development Induced by 7,12-dimethylbenz[*a*]anthracene in Rats*, 14 BIOELECTROMAGNETICS 131 (1993) (reporting that the number of tumors per animal increased in the animals exposed to the magnetic field, but a repeat of the experiment found no difference in the number of tumors); D.Sh. Beniashvili & M.Z. Menabde, *Low-Frequency Electromagnetic Radiation Enhances the Induction of Rat Mammary Tumors by Nitrosomethyl Urea*, 61 CANCER LETT. 75 (1991) (reporting a mammary tumor-promotion study in rats finding an increase in mammary gland tumors in rats exposed to magnetic fields at 200 mG for 3 hours a day); W. Löscher et al., *Tumor Promotion in a Breast Cancer Model by Exposure to a Weak Alternating Magnetic Field*, 71 CANCER LETT. 75 (1993) (reporting a significant increase in mammary tumor induction)).

253. See *id.*

254. See NRC REPORT, *supra* note 3, at 116. Although biological responses have been shown, the question of whether exposure to electric and magnetic fields causes cancer remains unanswered given the inconsistent results and unreplicated studies.

relationship between breast cancer in animals treated with a carcinogen and exposure to magnetic fields of about one Gauss.²⁵⁵

2. Reproductive and Developmental Effects

The NRC Committee next discussed the biological effects of residential strength electric and magnetic fields on reproduction and development. The NRC Committee considered the following types of studies: effects of electric fields on non-mammals such as fish²⁵⁶ and chicken;²⁵⁷ effects of electric fields on mammals such as mice,²⁵⁸ rats,²⁵⁹ swine,²⁶⁰ and cattle;²⁶¹ effects of magnetic fields on non-mammals such as chicken,²⁶² and effects of magnetic fields on mammals such as mice²⁶³ and rats.²⁶⁴ Based on the studies, which are summarized in Appendix A, Table A4-2, the NRC Committee concluded

255. See *id.* at 73.

256. See *id.* at 82 (citing I.L. Cameron, K.E. Hunter, & W.D. Winters, *Retardation of Embryogenesis by Extremely-Low-Frequency 60-Hz Electromagnetic Fields*, 17 *PHYSIOL. CHEM. PHYS. MED. NMR* 135 (1985) (reporting developmental delays that did not result in abnormal development or decrease in survival)).

257. See *id.* at 83 (citing C.F. Blackman et al., *Influence of Electromagnetic Fields on the Efflux of Calcium Ions from Brain Tissue In Vitro: A Three-Model Analysis Consistent with the Frequency Response up to 510 Hz*, 9 *BIOELECTROMAGNETICS* 215 (1988) (finding that calcium efflux from brain tissue of chicks exposed to 60-Hz fields affected); C.F. Blackman et al., *Effect of Ambient Levels of Power-Line-Frequency Electric Fields on a Developing Vertebrate*, 9 *BIOELECTROMAGNETICS* 129 (1988) (finding calcium efflux affected in exposed brain tissue)).

258. See *id.* (citing C.I. Kowalczyk & R.D. Saunders, *Dominant Lethal Studies in Male Mice after Exposure to a 50-Hz Electric Field*, 11 *BIOELECTROMAGNETICS* 129 (1990) (reporting inability to detect exposure-related mutations in male mice exposed to 60-Hz electric fields)).

259. See *id.* at 84 (citing D.N. Rommereim et al., *Reproduction, Growth, and Development of Rats During Chronic Exposure to Multiple Field Strength of 60-Hz Electric Fields*, 14 *FUNDAM. APPL. TOXICOL.* 608 (1990) (finding no exposure-related reproductive effects at any of three field strengths: 10, 65, or 130 kV/m)).

260. See *id.* at 86 (citing M.R. Sikov et al., *Developmental Studies of Hanford Miniature Swine Exposed to 60-Hz Electric Fields*, 8 *BIOELECTROMAGNETICS* 229 (1987) (finding inconsistent results in that the first generation showed no differences, the second generation showed malformations, and the third generation showed no significant adverse effects; however, disease outbreak complicated interpretation of the results)). Note that in three follow-up studies on rats, no exposure-related effects were detected. See *supra* note 217.

261. See NRC REPORT, *supra* note 3, at 87 (citing G. Algiers & J. Hultgren, *Effects of Long-Term Exposure to a 400-kV 50-Hz Transmission Line on Estrous and Fertility in Cows*, 5 *PREV. VET. MED.* 21 (1987) (detecting no changes)).

262. See *id.* at 87 (citing A. Martin, *Development of Chicken Embryos Following Exposure to 60-Hz Magnetic Fields with Differing Waveforms*, 13 *BIOELECTROMAGNETICS* 223 (1992) (detecting no effects)).

263. See *id.* at 88 (citing M.J. Wiley et al., *The Effects of Continuous Exposure to 20 k-Hz Sawtooth Magnetic Fields on the Litters of CD-1 Mice*, 46 *TERATOLOGY* 391 (1992) (detecting no effects in mice; study was designed to be relevant to video-display terminals)).

264. See *id.* at 89 (citing H. Huuskonen et al., *Effects of Low-Frequency Magnetic Fields on Fetal Development in Rats*, 14 *BIOELECTROMAGNETICS* 205 (1993) (finding no increase in malformation or resorption rates with increases in minor skeletal anomalies and in mean number of implants and living fetuses in 50 Hz)).

that ELF electric or magnetic fields have not been shown to affect reproduction and development in animals, especially mammals.²⁶⁵

3. Neurobehavioral and Neuroendocrine Effects

The third area of concern to the NRC Committee is whether exposure to ELF electric and magnetic fields cause neurobehavioral effects or neuroendocrine effects. These effects were considered separately in the NRC Report.

a. Neurobehavioral Effects

The studies of neurobehavioral effects caused by exposure of animals to ELF electric and magnetic fields that meet the NRC Committee's requirements of publication in peer-reviewed journals and descriptions of methods adequate for replication are summarized in Appendix A, Tables A4-3 through A4-6.²⁶⁶ Of those studies, only repeatable and reliable reports were discussed by the NRC Committee.²⁶⁷ The NRC Committee considered the effect on animal detection of electric fields²⁶⁸ and magnetic fields,²⁶⁹ and whether animals would exhibit aversion to those fields.²⁷⁰ The review of these studies produced two conclusions: although animals can detect and respond to electric fields, the behavioral response is not one of aversion nor are the effects adverse neurobehavioral ones; and little evidence exists of neurobehavioral response in animals to magnetic fields and neither aversive nor adverse behavioral effects have been shown.²⁷¹

265. See *id.* at 73.

266. See NRC REPORT, *supra* note 3.

267. See *id.* at 90.

268. See *id.* at 90-91 (citing R. J. Weigel et al., *Stimulation of Cutaneous Mechanoreceptors by 60-Hz Electric Fields*, 8 BIOELECTROMAGNETICS 337 (1987) (finding that cat detected electric field; hair removal caused decrease in response; and oil application on skin caused a further decrease)).

269. See *id.* at 91-93 (finding no evidence of detection of magnetic fields except at very high field strengths).

270. See *id.* at 90 (citing S. Stern & V.G. Laties, *Comparison of 60-Hz Electric Fields and Incandescent Light as Aversive Stimuli Controlling the Behavior of Rats*, 10 BIOELECTROMAGNETICS 99 (1989) (finding that electric field produced no aversive effect); R.H. Lovely et al., *Rats Are Not Aversive When Exposed to 60-Hz Magnetic Fields at 3.03 mT*, 13 BIOELECTROMAGNETICS 351 (1992) (finding that magnetic field produced no aversive effect)).

271. See *id.* at 93. The NRC Committee noted that behavioral, chemical, and electrophysiological effects of long-term and short-term exposure to 60-Hz magnetic fields have been shown in the area of decrease in stable performance in dealing with reinforced behavior and decrease in induced-seizure duration. The NRC Committee speculated that these effects hypothetically could be associated with a decrease in opiate activity since some reports show that 60-Hz magnetic fields inhibit endogenous opiate activity. See *id.* at 93.

b. Neuroendocrine²⁷² Effects

Neuroendocrines consist of various glands in the body that produce hormones which influence nerve activity.²⁷³ Most of the reported studies of the relationship between exposure to electric and magnetic fields and neuroendocrine effects have concerned pineal melatonin production and are summarized in Appendix A, Table A4-7 through Table A4-11.²⁷⁴ Melatonin is a hormone in humans, and possibly all animals, produced mainly by the pineal gland.²⁷⁵ The pineal gland, an end-organ of the visual system, has nerves whose activity is determined by light perception at the retina.²⁷⁶ More melatonin is present during the night than during the day because more is produced in darkness than in light.²⁷⁷ Melatonin is associated with circadian or biological rhythms of organisms.²⁷⁸

Visible light, as well as some ultraviolet wavelengths and some infrared wavelengths, have been shown to alter pineal melatonin production.²⁷⁹ Residential strength electric and magnetic fields are of extremely low frequency, have long wavelengths, and are below the visible light range.²⁸⁰ Studies considering the effects of electric fields on melatonin production in animals report suppression of melatonin concentrations,²⁸¹ as do studies considering the effects of magnetic fields²⁸² and studies considering the effects of combined

272. See 10 THE OXFORD ENGLISH DICTIONARY 348 (2d ed. 1989).

273. See NRC REPORT, *supra* note 3, at 95, 103. For example, the pineal gland produces melatonin and stress hormones such as pituitary adrenocorticotropin ("ACTH"), corticosterone, cortisol, norepinephrine, and epinephrine are released from the adrenal medulla.

274. See *id.* at 95.

275. See *id.*

276. See *id.* at 95 (Fig. 4-1).

277. See *id.*

278. See *id.*

279. See *id.* at 95 (citing R.J. Reiter, *Action Spectra, Dose-Response Relationships, and Temporal Aspects of Light's Effects on the Pineal Gland*, 453 ANN. N.Y. ACAD. SCI. 215 (1985) (reporting that synthesis of melatonin controlled by exposure to electromagnetic wavelengths in visible light region); G.C. Brainard et al., *Mechanisms in the Eye that Mediate the Biological and Therapeutic Effects of Light* 29 & R.J. Reiter, *The Mammalian Pineal Glands as an End Organ of the Visual System* 145, in LIGHT AND BIOLOGICAL RHYTHMS IN MAN (L. Wetterberg ed., 1993) (reporting ultraviolet and infrared wavelengths alter pineal melatonin production)).

280. See *id.* at 96.

281. See *id.* at 96-99 (citing B.W. Wilson et al., *Chronic Exposure to 60-Hz Electric Fields: Effects on Pineal Function in the Rat*, 2 BIOELECTROMAGNETICS 371 (1981) (reporting a reduction in nighttime pineal melatonin in rats)). The NRC Committee noted that though early studies of the effect of electric fields were "somewhat convincing," the current evidence that electric fields significantly impair pineal gland melatonin production is not convincing.

282. See *id.* at 99-101 (citing S.M. Yellon, *Acute 60 Hz Magnetic Field Exposure Effects on the Melatonin Rhythm in the Pineal Gland and Circulation of the Adult Djungarian Hamster*, 16(3) J PINEAL. RES. 136 (1994) (reporting two out of three experiments on hamsters showed reduced and delayed pineal and blood melatonin; in one, no effect was shown)).

electric and magnetic fields.²⁸³ Humans have been found to have melatonin rhythms that are similar to those in other mammals.²⁸⁴ However, two reports showed no significant change in blood melatonin concentrations when adult males were exposed to the electric and magnetic fields of magnetic resonance imaging (MRI).²⁸⁵

Understanding how ELF fields affect melatonin production in humans is important because suppression of melatonin levels may be related to the higher cancer incidence reported by some epidemiological studies. The NRC Committee presents two theories that describe a link between the alleged increase in cancer and ELF field exposure:

[R]educed melatonin concentrations lead to an increased secretion of prolactin and gonadal steroids. That increase causes proliferation of cell division in breast or prostate tissue and stimulates growth of initiated cancer cells [M]elatonin suppression reduced the total antioxidative potential of the organism, thereby increasing the likelihood of damage by a carcinogen to the DNA of any cell. DNA damage can increase the risk of cancer particularly if electric- and magnetic-field exposure also increases the half-life production of free radicals.²⁸⁶

Though epidemiological reports have prompted the above possible explanations, no convincing evidence exists that human melatonin concentrations are affected in the same way animal melatonin concentrations are when exposed to ELF fields.²⁸⁷

c. Bone Healing and Stimulated Cell Growth

Experiments considering the effects on bone tissue exposed to electric and magnetic fields have been conducted in vivo on animals²⁸⁸ and humans.²⁸⁹ In vitro studies of those effects have also

283. See *id.* at 101-02 (citing W. Rogers et al., *Rapid Onset/Offset, Variably Scheduled 60-Hz Electric and Magnetic Field Exposure Reduces Nocturnal Serum Melatonin Concentration in Non-human Primates*, 3 BIOELECTROMAGNETICS SUPPL. 119 (1995) (reporting baboons showed nighttime depressed melatonin)).

284. See *id.* at 102.

285. See *id.* (citing F.S. Prato et al., *Effects of Exposure to Magnetic Resonance Imaging on Nocturnal Serum Melatonin and Other Hormone Levels in Adult Males: Preliminary Findings*, 7 J. BIOELECTROMAGNETICS 169 (1988-89); J.S. Schiffman et al., *Effect of MR Imaging on the Normal Human Pineal Body: Measurement of Plasma Melatonin Levels*, 4 J. MAGN. RESON. IMAGING 7 (1994)).

286. *Id.* at 107.

287. See *id.* at 74.

288. See *id.* at 110 (citing C.T. Brighton et al., *Evaluation of the Use of Constant Direct Current in the Treatment of Non-union 213*, in ELECTRICAL PROPERTIES OF BONE AND CARTILAGE: EXPERIMENTAL EFFECTS AND CLINICAL APPLICATIONS (C.T. Brighton et al. eds., 1979) (reporting implanted DC electrodes can heal nonunion fractures and congenital bone defects)).

been performed.²⁹⁰ The studies show that normal functions of the bone and the healing processes in bone are influenced by exposure to electric and magnetic fields. Bone fracture healing in response to this exposure has been well documented,²⁹¹ but the mechanism by which this healing occurs is not clearly established.²⁹²

Bone in living organisms is known to possess an electric component,²⁹³ and several hormones are known to regulate activities of the bone cells that synthesize and calcify bone matrix (osteoblasts) and the cells that reabsorb bone mineral and matrix (osteoclasts).²⁹⁴ Bone growth has long been hypothesized to be influenced by endogenously generated electric fields; consequently, externally generated electric fields applied to bone fractures or defects have been hypothesized to be therapeutic.²⁹⁵ Upon a review of the experiments testing the hypotheses, the NRC Committee concluded that convincing evidence exists of an association between bone-healing in animals and exposures to pulsed magnetic fields with strengths greater than five Gauss.²⁹⁶ This field strength is much higher than that ordinarily encountered in residential environments.²⁹⁷

C. Epidemiology

Few of the laboratory experiments considering the effects of electric and magnetic field exposure on animals were studies of humans.²⁹⁸ Humans, however, are the subjects of all epidemiological studies because epidemiology is "the study of patterns of health and

289. See NRC REPORT, *supra* note 3, at 110 (citing Z.B. Friedenbergs et al., *Healing of Nonunion of the Medial Malleolus by Means of Direct Current*, 11 J. TRAUMA 883 (1971) (reporting a case involving one human)).

290. See *id.* at 108, 113 (citing R.A. Luben et al., *Inhibition of Parathyroid hormone actions on Bone Cells in Culture by Induced Low Energy Electromagnetic Fields*, 79 PROC. NATL. ACAD. SCI. USA 4180 (1982) (demonstrating that the osteoblast was desensitized when bone cells were exposed in vitro to pulsed electric and magnetic fields)).

291. See *id.* at 106.

292. See *id.* at 112.

293. See *id.* at 109. However no magnetic component has been reported.

294. See *id.* at 108.

295. See *id.* at 109 (citing C.T. Brighton & W.P. McCluskey, *Cellular Response and Mechanisms of Action of Electrically Induced Osteogenesis*, 4 BONE AND MINERAL RESEARCH 213 (W.A. Peck ed., 1986)).

296. See *id.* at 74. For magnetic fields below one gauss and electric fields lower than one mA/cm², evidence of effects on bone is scarce.

297. See *id.* at 108. The effects on bone have been associated with magnetic fields of strengths from one to 150 G and for a current density from one to 100 mA/cm² (current density is proportional to electric fields).

298. See NRC REPORT, *supra* note 3, at 245, 254. Table A4-5: Magnetic-Field Exposure and Neurobehavioral Effects, summarizes one study of humans conducted by Tucker and Schmitt in 1978. Table A4-11: Effects of Different Types of Electric- and Magnetic-Field Exposure on Melatonin Metabolism in Humans, summarizes three studies: Prato et al., 1988-89; Schiffman et al., 1994; and Wilson et al., 1990.

disease in human populations to understand causes and identify methods of prevention."²⁹⁹ Since 1979 when Nancy Wertheimer and Edward Leeper first reported an association between childhood leukemia and electric power distribution line configurations,³⁰⁰ the question most frequently asked by the public and one that has caused the greatest concern relative to electric and magnetic fields is: "Do they cause cancer?" DOE's charge to the NRC Committee included the mandate to review and evaluate existing evidence on the effect of exposure to residential ELF on the incidence of cancer.³⁰¹ Consequently, the NRC Committee reviewed and evaluated more than fifteen years of epidemiological research providing data on cancer in its Report.³⁰²

Determining whether exposure to electric and magnetic fields causes cancer based on the results of epidemiological studies is a problem because epidemiological research involves studies of observations to which statistical methods are applied, but which lack the ability to assign exposure in a random manner. As the NRC Committee Report explains:

Without randomly assigning the potential causes of interest (e.g., magnetic-field exposure) and observing the resulting health event (e.g., a change in cancer incidence), a mistaken inference that a given exposure causes a specific disease can result from a number of potential errors or misinterpretations. Conversely, even when a true causal relationship is present, it will not always be discerned easily. Ultimately, causal inference is enhanced when a number of non-causal explanations have been carefully postulated, tested, and refuted.³⁰³

In fact, the NRC Committee labels the question of when a causal inference has been established as "unanswerable" and substitutes a more practical inquiry of when does evidence of a causal association exist that is sufficient to take some specific action because it *presumes*

299. *Id.* at 118.

300. See Nancy Wertheimer & Edward Leeper, *Electrical Wiring Configurations and Childhood Cancer*, 109 AM. J. EPIDEMIOLOGY 273 (1979).

301. See NRC REPORT, *supra* note 3, at 117.

302. See *id.* The NRC Committee also considered the two areas of concern other than cancer: potential health effects of exposure to electric and magnetic fields related to reproduction and development, see *id.* at 181-85, and potential health effects related to neurobehavioral responses, see *id.* at 185-90. The NRC Committee concluded that "[t]here is no convincing evidence of an association between exposure to power-frequency electric and magnetic fields and reproductive or developmental effects" nor "of an adverse neurobehavioral effect in association with exposure to residential electric and magnetic fields." *Id.* at 199.

303. *Id.* at 119 (citing SMOKING AND HEALTH, PUB. NO. 1103, REPORT OF THE ADVISORY COMMITTEE TO THE SURGEON GENERAL OF THE U.S. (1964)).

a causal relationship.³⁰⁴ Other factors in the problem of determining causality are the potential sources of error in epidemiological studies, including random error,³⁰⁵ information bias or misclassification,³⁰⁶ selection bias,³⁰⁷ and confounding and effect modification.³⁰⁸

When epidemiological studies report an association between exposure and disease, as indicated above, a judgment must be made that sufficient evidence exists to justify the acceptance of a causal association. Several criteria have been suggested that bear on the question of causality and also relate to whether errors described above have affected the study. The criteria are:

Strength of association: If a given exposure and disease are strongly associated (i.e., a large relative risk), then unrecognized confounders are less likely to be responsible for the association;

Consistency: If the association is observed in different populations under different circumstances, it is more likely to be a causal relationship and not a product of some methodologic artifact in the study;

Specificity: A cause should lead to a single effect rather than multiple effects; if multiple diseases are associated with a suspected agent, the associations are more likely to be spurious;

Temporality: The exposure must logically precede the disease in time if the association is causal;

Biologic gradient: A dose-response gradient, in which risk of disease rises with increasing exposure level, is generally more likely

304. See NRC REPORT, *supra* note 3, at 119 (emphasis added).

305. See *id.* at 119-20. Statistical processes produce variable results in a given study.

306. See *id.* at 121. Disease misclassification results from false negatives (disease present but not identified) and false positives (disease not present but identified as being present). Exposure misclassification occurs in many ways, such as when trying to classify exposure based on job titles. Misinformation of any type can distort the association between exposure and disease.

307. See *id.* at 122 (noting error in selecting the groups to be compared as one selection bias).

308. See *id.* at 122-23. An extraneous risk factor mixed with the exposure being studied can produce confounding results. For example, if the use of electric blankets by children is being studied and if children using electric blankets are those more likely to be in ill health and thus more likely to have more X-rays, and if exposure to X-rays caused an increased risk for leukemia and X-ray exposures were not accounted for in the study, then use of electric blankets would be blamed for increased risk of leukemia rather than the X-rays that were actually responsible for the increased risk. When an association between an exposure and a disease is affected by a third variable, effect modification occurs. For example, if parents' tobacco smoking initiates leukemia, but magnetic fields promoted the leukemia in its late stages, the relationship between magnetic fields and leukemia would be stronger among children whose parents smoked than among children of nonsmoking parents. The parental smoking is said to act as an effect modifier of the magnetic field exposure.

to indicate causality than some other pattern of association between exposure and disease;

Plausibility: Plausibility refers to whether the association is supported by scientific studies or information from disciplines other than epidemiology;

Coherence: A causal interpretation should not be in conflict with current knowledge about the natural history of the disease. This criterion is virtually the same as plausibility;

Experimental evidence: When possible, experimental evidence in the form of randomized trials with prescribed exposures is highly desirable;

Analogy: If other known and accepted causal agents have been found that are similar to the one under evaluation in their manner of action on the biologic system, then the one under evaluation is more likely to be causal.³⁰⁹

Because the relationship between childhood cancer, especially leukemia, and residential exposure to ELF electric and magnetic fields is the major public concern, the NRC Committee concentrated on those epidemiological studies.³¹⁰

D. Cancer Epidemiology and Residential Exposures

Epidemiological studies have persistently reported an association between the incidence of childhood leukemia and "wire codes," a hypothetical estimate of electric and magnetic field exposure.³¹¹ Wire codes are external wire configurations that are used to classify houses according to the amount of magnetic flux density expected to be inside the house.³¹² Wire codes are used as substitutes to estimate the size of the magnetic field rather than actually measuring magnetic flux density inside the house.³¹³ Because the studies are of homes over a period of years retrospectively, actually measuring the magnetic fields inside the homes is too difficult, too expensive, and too time consuming.³¹⁴ Wire codes of various classifications,³¹⁵

309. *Id.* at 124-25 (citing Bradford A. Hill, *The Environment and Disease: Association or Causation?*, 58 PROC. R. SOC. MED. 295 (1961)). These criteria were accompanied by caveats regarding their interpretation including one against using a checklist approach in relying on the criteria.

310. *See* NRC REPORT, *supra* note 3, at 127.

311. *See id.* at 2.

312. *See id.*

313. *See id.*

314. *See id.*

315. *See id.* at 287-89. Class 1 wiring includes high-voltage transmission lines, six or more wire distribution lines, or a thick wire single three-phase distribution circuit. Class 1 wiring within 50 feet of the home is further classified as Very High Current Configuration (VHCC)

consisting of outdoor factors such as the distance of the home from the power line and the size of the wire near the home, were first used by Wertheimer and Leeper³¹⁶ in their study of childhood cancer occurring in Denver, Colorado between 1950 and 1973. The results of that study, which showed an association between electric power distribution lines and childhood cancers, were published in 1979.³¹⁷ The 1979 Wertheimer and Leeper study was of 344 cases (children with a Colorado birth certificate who lived in the area most of their lives and who also died of cancer under the age of nineteen between 1950 and 1973) in 491 homes compared to 344 controls (children whose birth certificate was placed next in the birth certificate files unless the next birth certificate was that of a sibling of a case child) in 472 homes.³¹⁸ The homes were classified according to two wire codes, High Current Configuration (HCC) and Low Current Configuration (LCC).³¹⁹ The results of the study showed that children in HCC homes had a 1.6 to 2.2 times higher incidence of cancer than did the controls.³²⁰ One study has shown that the expected number of cases of childhood leukemia in children up to the age of fourteen is about ten in 100,000.³²¹ The results in the 1979 Wertheimer and Leeper study mean that the risk to children exposed to HCC wiring configurations is about doubled, or twenty in 100,000. The study accounted for the possible confounders of socioeconomic class, family pattern, and traffic congestion near the homes, but not other

and as Ordinary High Current Configuration (OHCC) if the home is from 50 to 130 feet from the line. Class 2 wiring is a thin wire single circuit three phase distribution line and is classified as VHCC if within 25 feet of the home, OHCC if from 25 to 50 feet, and Ordinary Low Current Configuration (OLCC) if from 50 to 130 feet. Class 3 wiring configurations consist of first-span wires (secondary wires that are connected to the transformer on one end), and serve three or more homes. If within 50 feet of the home, it is classed as OHCC; if between 50 and 130 feet, then it is classed as OLCC. Class 4 wiring consists of second-span secondary wires serving 3 or more homes or first-span secondary wires serving one or two homes. If the homes are within 130 feet of the Class 4 wires, they are OLCC. Class 5 wiring are not attached directly to the transformer (end-pole configurations). They are secondary wiring, serve only one or two homes, and are classed as Very Low Current Configuration (VLCC). *See id.*

316. *See WERTHEIMER & LEEPER, supra* note 300, at 289. In this first Wertheimer and Leeper study, only two categories of wire codes were used: High Current Configuration (HCC) and Low Current Configuration (LCC). The division into the further classes described *supra* at note 315 occurred later in the 1982 Wertheimer and Leeper study. *See NRC REPORT, supra* note 3, at 263.

317. *See OTA BACKGROUND PAPER, supra* note 56, at 58.

318. *See id.* at 58; *NRC REPORT, supra* note 3, at 255.

319. *See OTA BACKGROUND PAPER, supra* note 56, at 58. Wertheimer and Leeper estimated the home's magnetic field from the wire code classification scheme developed from a series of measurements of magnetic fields.

320. *See id.*

321. *See id.* (citing R.S. Greenberg & J.L. Shuster, *Epidemiology of Cancer in Children*, 7 *EPIDEMIOLOGIC REVIEWS* 22 (1985)).

possible confounders or bias-causing factors.³²² Consequently, the study has been widely criticized,³²³ among other reasons, for its use of wire codes to measure exposure, for its consideration of cancer deaths only and not all diagnosed cancers, and for failing to conduct the study "blind."³²⁴

Since the 1979 Wertheimer and Leeper study, other researchers have examined the possible association between residential exposure to electric and magnetic fields and the incidence of cancer.³²⁵ The NRC Report organized the results of these studies into tables in Appendix A thus: Table A5-1 summarizes the structures of the studies; Table A5-2 summarizes the methods of control selection in case-control studies; Table A5-3 summarizes exposure assessment approaches; Table A5-4 focuses on childhood leukemia; Table A5-5 focuses on childhood brain tumors; Table A5-6 focuses on childhood lymphoma; Table A5-7 focuses on other childhood cancers; Table A5-8 focuses on childhood cancers in the aggregate; Table A5-9 focuses on cohort studies of residential exposure and cancer including all ages; Table A5-10 focuses on adult leukemia; and Table A5-11 focuses on adult cancers generally.³²⁶ The NRC Committee noted its recognition that increasingly sophisticated study designs have replicated the association between location near power lines and childhood leukemia and its determination to concentrate on studies concerning exposure to magnetic fields and the occurrence of childhood leukemia.³²⁷

The NRC Committee reviewed the studies of the association between exposure to magnetic fields and the incidence of childhood

322. See *id.*

323. See *id.* (citing P. COLE, FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION, AN EPIDEMIOLOGIC PERSPECTIVE ON ELECTROMAGNETIC FIELDS AND CANCER (1987); D.A. Savitz & E.E. Calle, *Leukemia and Occupational Exposure to Electromagnetic Fields: Review of Epidemiologic Studies*, 29 J. OCCUP. MED. 47 (1987)).

324. Blind studies are defined at *supra* note 230.

325. See J.P. Fulton et al., *Electrical Wiring Configurations and Childhood Leukemia in Rhode Island*, 111 AM. J. EPIDEMIOL. 292 (1980) (assessing the exposure by wire codes); A. Myers et al., Cartwright, *Childhood Cancer and Overhead Power Lines: A Case-Control Study*, 62 BR. J. CANCER 1008 (1990) (reporting a study in Yorkshire, England, that assessed exposure by distance from overhead lines and calculated fields); L. Tomenius, *50-Hz Electromagnetic Environment and the Incidence of Childhood Tumors in Stockholm County*, 7 BIOELECTROMAGNETICS 191 (1986) (reporting a study in Stockholm County, Sweden, that assessed exposure using wire codes and spot field measurements); D. A. Savitz et al., *Case-Control Study of Childhood Cancer and Exposure to 60-Hz Magnetic Fields*, 128 AM. J. EPIDEMIOL. 21 (1988) (reporting a study of childhood cancer from 1976-1983 in Denver, Colorado, designed to be similar to the 1979 Wertheimer and Leeper study but without the weaknesses of that study, and which used wire codes and spot field measurements to assess exposure). See also OTA BACKGROUND PAPER, *supra* note 56, at 59; NRC REPORT, *supra* note 3, at 255-56.

326. See NRC REPORT, *supra* note 3, at 126.

327. See *id.* at 127.

leukemia by undertaking a "meta-analysis," which is "a statistical method used to provide a single risk estimate that summarizes the results of a set of similar studies."³²⁸ Of the twelve studies focusing on childhood leukemia, results have been conflicting with some reporting an association between childhood leukemia and residential exposure and some reporting no association.³²⁹ The reaction of scientists examining the evidence has also been conflicting; the disagreements concerning quality, bias, accuracy, and uncertainties have resulted in varying interpretations. Some find evidence of an overall association,³³⁰ others consider the positive results to be caused by bias, either systematic or random with no proper adjustment made for multiple comparisons, with most concluding that no consistent pattern of association has been shown by the results.³³¹ The NRC Committee's goal in using the meta-analysis included the following:

- (1) to examine quantitatively the consistency of the existing epidemiologic studies; (2) to analyze the influence of any single study on the combined effect measures; and (3) to estimate the sample size or number of studies needed to balance the combined results of previous studies. In short, the purpose of this meta-analysis is to consider the possible role of bias due to random error as an explanation for the observed results in a set of such studies.³³²

After examining the data in the studies focusing on the relationship between residential exposure to magnetic fields and childhood leukemia using a variety of analyses, the NRC Committee concluded that a statistical explanation based on random fluctuations did not support the positive trend in the risk associations.³³³ Nor was it clear whether the associations were really due to the exposure to magnetic fields or some other factor.³³⁴

328. *Id.* at 128-29. Applying this method, which is usually applied to clinical trial data where the specific populations examined are the major differences among the studies, to epidemiological studies is controversial because the differences to which it is applied are the characteristics of the study designs.

329. *See id.* at Appendix A, Table A5-1.

330. *See id.* at 129 (citing A. Ahlbom et al., *Electromagnetic Fields and Childhood Cancer*, 342(8882) LANCET 1295 (1993)).

331. *See id.* at 129 (citing COMMITTEE IN INTERAGENCY RADIATION RESEARCH AND POLICY COORDINATION, OAK RIDGE ASSOCIATED UNIVERSITIES, PUB. NO. 92/F8, HEALTH EFFECTS OF LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS (1992); H.G. PEACH ET AL., THE VICTORIAN GOVERNMENT, MELBOURNE AUSTRALIA, REPORT OF THE PANEL ON ELECTROMAGNETIC FIELDS AND HEALTH (1992); NATIONAL RADIOLOGICAL PROTECTION BOARD, 3 ELECTROMAGNETIC FIELDS AND THE RISK OF CANCER 1 (Chilton, Didcot, U.K.) (1992)).

332. *Id.* at 129.

333. *See id.*

334. *See id.*

The magnitude of the possible risk was also uncertain, however, the overall conclusion was that the studies do show an association of childhood leukemia with wire codes, proximity to source, and magnetic fields calculated from power consumption records.³³⁵ The NRC Committee remained puzzled by the inconsistent results of the various studies and also by the lack of a positive association when the exposure was assessed by spot measurements.³³⁶

The only exposure assessment strategy of the epidemiological studies analyzed that failed to show an association with childhood leukemia was that of spot measurements of magnetic field strength.³³⁷ Another contradiction was the failure of the data to indicate a consistent dose-response relationship.³³⁸ The NRC Committee noted two possible explanations for the spot measurement contradiction if the associations shown by the other exposure assessment strategies were reliable. One explanation is that the other ways to measure exposure might somehow indicate the true risk factor, which might not be related to magnetic field strength.³³⁹ The other explanation is that measurement methods might better represent some element of magnetic field strength that is related to the cause of leukemia.³⁴⁰ The inconsistent dose-response relationship pattern might be caused by an imperfect correlation with the true risk factor.³⁴¹ The NRC Committee suggested that future studies should try to understand these inconsistencies and stressed that "strong and consistent" data suggests "a relatively weak increased risk of leukemia for children living in close proximity to power lines."³⁴²

The NRC Committee summarized its analysis of the research linking electrical wires near homes to childhood cancer as falling "short of providing definitive evidence that an association exists, and even if an association were proved, the causal agent has not been identified."³⁴³ They also recognized suggestions of bias caused by

335. *See id.* at 143.

336. *See id.* at 144.

337. *See id.*

338. *See id.*

339. *See id.* at 145-46. The NRC Committee noted that investigation of several possible risk factors failed to explain the association.

340. *See id.* at 146. For example, the measurements might better represent average strength of the fields, peak strength, variability of the field, or time longer than some specific threshold value.

341. *See id.*

342. *Id.*

343. *Id.* at 158. It is important to remember that epidemiological studies showing an association between wiring near residences and childhood leukemia or other cancer is not the same as showing that such wiring *causes* the cancer.

control selection or too small a number of subjects in some studies.³⁴⁴ The NRC Committee based its overall conclusion of no association between exposure to magnetic fields and childhood cancer (which seems to be in conflict with its recognition of a link between wire codes and childhood leukemia), on the fact that those epidemiological studies estimating exposure to magnetic fields by measuring present-day average magnetic fields found no association between exposure and childhood leukemia and on the weak association between measured residential magnetic fields and wire code ratings.³⁴⁵

A further conclusion of the NRC Committee was that associations between magnetic fields and adult cancers, pregnancy outcome, and neurobehavioral disorders were not supported by epidemiological studies.³⁴⁶ After examining the epidemiological studies, the studies of animal and tissue effects, and those of cellular and molecular effects, the NRC Committee assessed the risk to human health from exposure to electric and magnetic fields.

E. Risk Assessment

The NRC Committee used a method called "risk assessment" to evaluate the risk to human health from exposure to residential electric and magnetic fields. When some hazard is thought to exist because of results observed in a study, for example, rats developing more cancerous tumors when fed a large amount of saccharin, the risk assessor attempts to estimate the risk to human health by extrapolation. Risk assessment is based on the principle that health

344. See *id.* at 175-76 (citing J.D. Jackson, *Are the Stray 60-Hz Electromagnetic Fields Associated with the Distribution and Use of Electric Power a Significant Cause of Cancer?*, 89 PROC. NATL. ACAD. SCI. USA 3508 (1992); COMMITTEE IN INTERAGENCY RADIATION RESEARCH AND POLICY COORDINATION, OAK RIDGE ASSOCIATED UNIVERSITIES, PUB. NO. 92/F8, HEALTH EFFECTS OF LOW FREQUENCY ELECTRIC AND MAGNETIC FIELDS (1992)). Studies have suggested that the fact that the consumption of residential electricity increased to the extent that per capita consumption is twenty times the rate it was fifty years ago while deaths from cancers, excluding respiratory cancer, did not increase but rather declined during that period, implies that magnetic fields could not cause cancer. The persuasiveness of this argument is affected by the knowledge that improvements in treatment and diagnosis of cancer make it difficult to infer anything about the relationship between electricity consumption and the decrease in deaths. Since the childhood leukemia incidence has remained stable while residential electricity consumption has doubled, increased consumption of electricity has not caused an increase in leukemia. However, what we do not know is the how electricity consumption relates to magnetic field exposure. Does an increase in consumption mean an increase in the exposure to magnetic fields? This relationship needs to be tested, but many difficulties are involved, such as how to measure the changes in exposure occurring during the years under consideration.

345. See NRC REPORT, *supra* note 3, at 3. Wire code ratings have been shown to correlate with factors such as age of home, housing density, and traffic density, though none of these have been identified as a likely cause of childhood leukemia.

346. See *id.*

effect data obtained from studying a small number of subjects that have been exposed to a high concentration of a suspected hazardous agent can by extrapolation predict the health effects in a large number of subjects that have been exposed to a lesser concentration of that agent.³⁴⁷ In the example above, the estimate might be that some specific number of persons ingesting a specific quantity of saccharin will develop cancer.³⁴⁸

The four stages of risk assessment are hazard identification,³⁴⁹ dose-response assessment,³⁵⁰ exposure assessment,³⁵¹ and risk characterization.³⁵² Risk characterization is quantitative in that it results in an estimate of the number or proportion (for example, one in one million) of the population that might be adversely affected.³⁵³ The assessor "weighs" the evidence at each stage of the process, with well-designed studies being given more weight than studies with weaknesses in some areas.³⁵⁴ At the conclusion of the assessment process, all evidence is weighed together to produce an overall conclusion about risk assessment.³⁵⁵ If all four stages of a risk assessment are used ending in a quantitative risk estimate, the risk assessment is a complete one.³⁵⁶ If only some of the stages are used, the assessment is said to be a partial one.³⁵⁷ Whether the assessment is complete or partial depends upon the available data and the purpose of the risk assessment.³⁵⁸

The NRC Committee did not perform a complete assessment of the risks of exposure to residential power frequency electric and

347. *See id.* at 192.

348. *See id.* at 191. If the hazard identified is that of cigarette smoking being related to cancer, a quantitative estimate of the risk might be that one out of every seven "pack-a-day" smokers will contract lung cancer.

349. *See id.* at 192-93 (citing NATIONAL RESEARCH COUNCIL, RISK ASSESSMENT IN THE FEDERAL GOVERNMENT: MANAGING THE PROCESS (1983)). The goal of this stage is to predict all possible adverse health effects from an agent.

350. *See id.* at 193. This stage determines the amount of exposure to a hazardous agent that is harmful to public health. This is accomplished by applying a mathematical equation to the data to describe the relationship of increased risk of disease to amount of the agent.

351. *See id.* (estimating the amount of the hazardous agent that a typical person is likely to experience).

352. *See id.* (estimating the overall risk to human health).

353. *See id.* at 15, 193.

354. *See id.* at 15-16.

355. *See id.* Evidence might be given little weight if it includes inconsistent and conflicting results, weak effects, and non-replicated results. Conversely, consistent, replicated studies are given great weight, especially if a "biologically plausible" explanation for the supposed relationship exists.

356. *See id.* at 15.

357. *See id.*

358. *See id.*

magnetic fields because of uncertain data.³⁵⁹ The NRC Committee did use the framework of risk assessment to perform a limited assessment because it recognized the public concern over the possible risks of exposure to residential electric and magnetic fields.³⁶⁰

Within the risk assessment framework and concentrating primarily on the risk of childhood cancer, the NRC Committee reviewed its previous conclusions. Under "Hazard Identification," the conclusions included the following: "no consistent or convincing evidence exists of effects" of typical residential electric- and magnetic-field exposure on cultured cells implying a human health effect at that exposure level,³⁶¹ "no consistent or convincing evidence" exists of that typical exposure on whole animals implying a human health effect, though neurobehavioral and neuroendocrine changes not considered evidence of adverse health effects on humans have occurred in response to much higher exposure levels,³⁶² and "a moderately consistent, statistically significant association between wire codes, . . . and childhood leukemia" exists.³⁶³ Under "Dose-Response Assessment," the NRC Committee concluded that the data did not furnish evidence of a dose-response relationship convincing enough for development of a mathematical model.³⁶⁴

Under "Exposure Assessment," the NRC Committee acknowledged the universal and unavoidable daily exposure of the population to electric and magnetic fields.³⁶⁵ This universal exposure would mandate the consideration of how even a very small proven adverse effect would affect public health.³⁶⁶ Under "Risk Characterization," the NRC Committee concluded that "the effects of exposure to electric and magnetic fields on biologic systems are either negative or so uncertain that making such an estimate would be

359. *See id.* at 194. Some NRC Committee members thought risk assessment should not even be undertaken because they considered the data so inconclusive. Other members were concerned about misinterpretations of the quantitative prediction of risk.

360. *See id.* One of the NRC Committee's purposes was to present observations concerning the risk of exposure that would help people decide on actions that might need to be taken or help the government decide if policies need to be established.

361. *Id.* at 194-95.

362. *Id.* at 195.

363. *Id.*

364. *See id.* at 196. A finding of a dose-response relationship is a strong indicator of a real rather than an artificial result of an experiment. The important finding of no dose-response relationship helps explain the NRC Committee's overall assessment.

365. *See id.*

366. *See id.* Note again that wire codes, the surrogate for magnetic field exposure used in studies showing an association with childhood leukemia, have not been confirmed as an appropriate indirect measurement of magnetic fields. When studies have used fields that are measured directly no association has been established.

injudicious and misleading."³⁶⁷ Furthermore, the relationship that is assumed to exist between electric and magnetic field exposure and adverse health effects has not been explained in a biologically plausible manner.³⁶⁸

Finally under "Overall Conclusions of Risk Assessment," the NRC Committee concluded that the evidence examined by it did not demonstrate that ELF electric and magnetic field exposure constitutes a human health hazard.³⁶⁹ Only the epidemiological studies of humans suggest adverse health effects with the results of those studies indicating relatively small risks as compared to other harmful exposures studied by epidemiologists.³⁷⁰ However, uncertainty about the validity of using wire codes as a surrogate for magnetic exposure, as well as other unresolved questions about epidemiological and laboratory findings, suggest a need for further research.³⁷¹

F. Research Needs and Research Agenda

The NRC Committee proposed areas of research needed to resolve the remaining uncertainties. The epidemiological studies' findings of an association between exposure to electric and magnetic fields and cancer, especially childhood leukemia, are the primary reason the public became concerned about the possible adverse health effects. Thus, epidemiological studies using wire codes should be conducted in a manner designed to eliminate control-selection bias and imprecision.³⁷² Possible confounders relating to wire codes and other risk factors for childhood cancer should be tested. In addition, more knowledge about sources of magnetic fields is needed, especially how outside wires relate to magnetic fields inside the homes and whether wire codes are representing some other source of exposure. The NRC Committee recommended improved studies of measured residential magnetic fields and sources of magnetic fields other than power lines.³⁷³

367. *Id.* at 197.

368. *See id.* If electric and magnetic fields had been shown to damage DNA, then a biologically plausible explanation would exist because cancer is associated with damaged DNA.

369. *See id.* at 197-99. The major health hazard considered was that of cancer. While the studies do not prove that residential electric and magnetic fields are carcinogenic, neither have they proved that the fields are not carcinogenic at some dose level, in combination with some other biologic agent, or for some sensitive populations of humans. The NRC Committee also concluded that no convincing evidence of health hazards exists in the areas of reproduction or development and neurobehavior.

370. *See id.* at 199 (providing a relative risk of 1.5 as an example).

371. *See id.* at 197-200.

372. *See id.*

373. *See id.* at 203-04.

In addition to proposing epidemiological research, the NRC Committee recommended additional laboratory research. While recommending improved engineering techniques for measuring exposure, the NRC Committee stressed the need for a plausible biological explanation to account for an association between exposure to electric and magnetic fields and adverse health effects.³⁷⁴ Among the possible productive areas of research for laboratories suggested were studies of bone-healing, studies of *in vitro* dose-response, and studies of the role that magnetic fields play as a promoter of initiated cancers or when combined with chemical carcinogens.³⁷⁵

Finally, the NRC Committee recognized that its work and all the other work supported by the Energy Policy Act of 1992 is not expected to answer all questions relating to the possible health effects of ELF electric and magnetic field exposure. The five-year program ended in 1997. Beyond that time, continued research is important.³⁷⁶

V. CONCLUSION

The long-awaited National Research Council Report on the possible health effects of exposure to the electric and magnetic fields which people encounter daily in their homes and places of work concludes that the current evidence does not show that such exposure presents a health hazard. The report also stresses the importance of continued research in this area of possible health effects. The law has been affected by public alarm at the possibility of electric and magnetic fields causing dreaded illnesses such as cancer, and in the devaluation of property in condemnation cases; power line siting controversies; and the causation of ill health effects as the basis of tort litigation. The NRC Report cautions that causation of health hazards has not been demonstrated in any study; even epidemiological studies reporting an association are not reporting causation.

The bottom line of the report appears to reflect an evolutionary point of the law in these areas. Rare damage awards in tort litigation reflect the lack of causal proof between EMF and adverse health effects.³⁷⁷ Since land value is affected by public opinion, and the

374. *See id.* at 207-08.

375. *See id.* Research in the areas of plausible biophysical mechanisms, signal-transduction, and gene expression would also likely be productive.

376. *See id.* at 208.

377. *But see Altoonian v. Atlantic City Electric Co.*, ELECTROMAGNETIC FIELD LITIG. REP. 7 (July 1996) (awarding judgment of \$946,267 in damages for emotional distress caused by the

public perception is that EMF is a risk to health, damages for property devaluation have been awarded in some cases. Power line siting controversies are often driven by public opinion of risk, and the law has sometimes responded to that public opinion. Given this, society must to assess the NRC Report's potential impact on public perception of EMF and its relative health risks.

Although the report reflects a comprehensive study of the issue and is the latest scientific consensus on the issue, the NRC Report is not likely to have a great effect on the public perception that EMF is a health hazard because public perception is driven by emotion and often varies from reality. Even if electric and magnetic fields do not present a substantial risk to public health, land values near power lines will be affected because the public is unlikely to believe the report.

Public perception of risk is influenced by several factors including: voluntariness, control, fairness, process, morality, familiarity, memorability, dread, and diffusion in time and space.³⁷⁸ If a person acts voluntarily, such as smoking a cigarette or using a cellular telephone, that person is less likely to perceive a risk from those acts. Related to voluntariness is control. A person is less likely to perceive risk from sources of exposure over which that person exercises control.

When a result seems unfair, a person is likely to associate it with risk. For example, having the air that the public breathes polluted by a factory seems unfair, so the air pollution is more likely perceived as a risk. When morality is involved, as in child abuse, the action is more likely perceived as a risk. Familiarity also influences risk perception. The mysterious and complex nature of electric and magnetic fields make them more likely viewed as a risk because people tend to fear what they do not understand.

The memorability of an event, such as Three Mile Island or Chernobyl, causes a greater perception of risk. These memorable events heightened the public's fear of nuclear fallout. Dread of something also causes an increased perception of risk. The dread of contracting cancer underlies the public perception of the risk EMF cause. Moreover, electric and magnetic fields are here today. Unlike

presence of power cables, but refusing to find that EMF caused homeowner's cancer). After both parties appealed the *Altoonian* judgment, the parties reached an undisclosed settlement on the "non-EMF" issues. See *Altoonian v. Atlantic City Electric Co.*, ELECTROMAGNETIC FIELD LITIG. REP. 3 (Nov. 1996).

378. See Walter Appling, Senior Engineer for Alabama Power Co., Address at the Institute of Electrical and Electronic Engineers (IEEE) (Feb. 4, 1994).

risks occurring in the past or at a distant place, the exposure to these fields is ongoing, increasing the perception of risk.³⁷⁹

Ultimately, as long as the public believes that electric and magnetic fields are a health risk, effects of that perception will remain. The devaluation of land located near electric and magnetic fields will likely continue because the perception makes the land less desirable. Controversies over power line siting will continue because of the public perception of risk associated with the EMF emanating from them. Moreover, the conclusions of the NRC Report tend to make proof of causation even more difficult.³⁸⁰ This will keep the number of damage awards in EMF-based tort litigation at a minimum.

Public perception about the risk of EMF exposure will change only when the public's underlying beliefs are changed. Power companies, health departments, and other entities with an interest in changing the public perception of risk must undertake information dissemination programs to educate the public about the true risks of electric and magnetic fields. Of course, no meaningful education programs can occur until further research is done to ascertain the true risk of electric and magnetic fields. Until research can prove conclusively that electric and magnetic fields pose no real threat to human health, fear, in all of its manifestations, will remain.

379. *See id.*

380. *See* Richard C. Reuben, *Utility Power Plays*, A.B.A. J. 18 (Dec. 1996) (identifying the difficulty in establishing a causal link between EMF and physical harm).

VI. APPENDIX

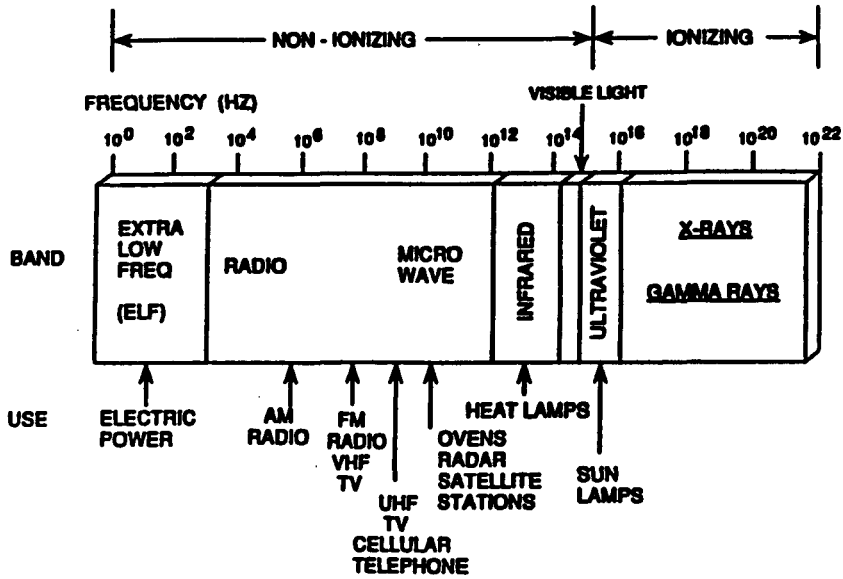


Figure 1: The electromagnetic spectrum

