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

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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.

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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) (invoking an amicus brief filed by fourteen scientists in which they argued that there is no scientific basis that electromagnetic fields harm human health).


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

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9. See id.
10. See infra notes 78-85 and accompanying text.
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
devolution of property located near power lines. 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. In the
area of litigation, concern about the health effect of EMF radiation
generated some tort litigation.

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. A utility may negotiate with the landowner to purchase the
property right, either in fee simple or as an easement. 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.

The exercise of the right of eminent domain requires that just
compensation be given for the property taken. 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
carried by a reduction in the value of the remaining property when
the condemned property is severed. The measure of damages for
the property actually condemned is the fair market value of that
property. 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
article provides a good discussion of utilities, their relationship to regulatory bodies, and their
right to condemn property.
22. See id.
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.\textsuperscript{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,\textsuperscript{28} began to introduce evidence in condemnation cases relating to EMF and the fear of exposure to EMF.\textsuperscript{29} Courts required expert testimony regarding biological effects of electric and magnetic fields,\textsuperscript{30} and expert or non-expert evidence of the public fear. Evidence of personal fear was inadmissible.\textsuperscript{31} One court excluded evidence of harmful effects of

\textsuperscript{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).

\textsuperscript{28} See Young, \textit{supra} note 21, at 158-59.

\textsuperscript{29} See Goody 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, 350 (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).


\textsuperscript{31} See, \textit{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.” 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, or to show how to calculate with reasonable certainty the effect of the public fear on the market value of the remaining property. 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.

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. 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). The school district then filed objections with the trial court. 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. 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.

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.

32. Linnebur, 716 P.2d at 1121-22.
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. She concluded that the children in the schools were at increased risk of cancer because of the electromagnetic fields. An oncologist testified similarly. 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. Testifying for the utility was an expert who critiqued the school district’s expert studies.

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. The lower court permanently enjoined the utility from using the transmission lines and ordered possession of the property restored to the school district.

The appellate court ultimately modified the trial court judgment, deleting the award of punitive damages, and affirming the actual damages. 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.

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.

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
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. 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.

Among the issues considered by a regulatory agency in an evidentiary hearing are the effects of electromagnetic fields on health and safety. 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

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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’n 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); Barenfeld 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. Some state regulatory agencies have adopted a strategy of "prudent avoidance" as a means of risk management. 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. 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.

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., 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. However, the court dismissed the complaint.

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. The town of East Greenwich, Rhode Island, is a party in two such cases: East Greenwich v. O'Neill and East Greenwich v. Narragansett Electric Co. 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.


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.


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).

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.\textsuperscript{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.\textsuperscript{75} At the PUC hearing, the utility argued that the rezoning would adversely affect its utility operations.\textsuperscript{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."\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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

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

\textsuperscript{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.").

\textsuperscript{76} See id.

\textsuperscript{77} Id. at 493.


\textsuperscript{79} See id.

\textsuperscript{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]eatured[ed] 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.\footnote{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,\footnote{82} emotional distress,\footnote{83} and chronic myelogenous leukemia.\footnote{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.\footnote{85} Since electric and magnetic fields have caused litigation and controversy, a discussion of these fields is helpful.

\section*{III. What Are Electric and Magnetic Fields?\footnote{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.\footnote{87}

\begin{footnotes}
\footnote{81. See Mark A. Hoffman, \textit{Study Debunks EMF Risks: Report Sees No Link to Illness}, \textit{Business Insurance} (Nov. 4, 1994), 1996 WL 12786305. For a survey of health and other claims related to EMF, see generally \textit{Electromagnetic Field Litig. Rep.} (reporting cases involving electromagnetic litigation).}
\footnote{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).}
\footnote{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).}
\footnote{85. See \textit{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.}
\footnote{86. The following explanation of electric and magnetic fields and their effects is gleaned from the National Research Council Committee’s report. See \textit{NRC Report}, \textit{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.}
\footnote{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 \textit{id}.}
\end{footnotes}
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. 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.

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. 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. 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. 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. 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. 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.
homes is measured at 115/230 volts. 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. The 115/230 volt wiring in houses is designed to carry currents of up to thirty amps.

Over 370,000 miles of transmission line and over two million miles of distribution line exist in the United States today. 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.

B. Frequency and the Electromagnetic Spectrum

Electric power is either alternating current (AC) or direct current (DC). Batteries produce direct current; power used in homes and workplaces is alternating current. Power line fields alternate from positive voltage to negative voltage. The number of times per second that the variation occurs is called the "frequency" of the current. One cycle per second is measured as one Hertz (Hz), an internationally accepted unit of frequency. For example, a power field that alternates sixty times per second is said to have a frequency of sixty Hz. 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.

96. See id.
97. See id.
98. See id.
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.” The relationship between frequency and wavelength is that higher frequencies have shorter wavelengths. 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. 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. The range of the electromagnetic spectrum frequencies is from zero to $10^{21}$. The extremely low frequencies or extra-low frequencies (ELF) include the fifty to sixty Hertz power associated with electric current in homes. In increasing frequencies, the spectrum includes radio waves at $10^4$ 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.

The electromagnetic spectrum ranges from “non-ionizing” radiation at the low end of the spectrum to “ionizing” radiation at the high end. 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. Gamma rays, X-rays, and some types of ultraviolet lights are ionizing radiation.

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

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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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{124} The manner in which ELF energy interacts with biological systems is "speculative,"\textsuperscript{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."\textsuperscript{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.\textsuperscript{127}

\begin{itemize}
\item \textsuperscript{121} See Tom Watson and Curtis S. Renner, \textit{The Scientific and Legal Bases for Litigating EMF Property Cases}, in \textit{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 \textit{et al.} \textit{v.} Kustom Signals, 18 ELECTROMAGNETIC FIELD LITIG. REP. 13 (concerning radar guns); \textit{Ward v. Motorola}, 18 ELECTROMAGNETIC FIELD LITIG. REP. 8 (concerning cellular telephones).
\item \textsuperscript{122} See NRC REPORT, supra note 3, at 12.
\item \textsuperscript{123} See Watson \& Renner, supra note 121, at 129.
\item \textsuperscript{124} See id.
\item \textsuperscript{125} See id.
\item \textsuperscript{126} Id. at 13.
\item \textsuperscript{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.
\end{itemize}
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. 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. 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." 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 body as well as charges on the surface of the body. 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. 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.

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.\textsuperscript{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.\textsuperscript{135} Because most materials have enough conductivity to sufficiently weaken electric fields, most materials can easily shield people from exposure to electric fields.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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).\textsuperscript{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.\textsuperscript{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).\textsuperscript{141} Since a thousand volts equals a kilovolt, a thousand volts per meter is a kilovolt per meter (kV/m).\textsuperscript{142} The intensity of an electric field decreases rapidly as distance from the source increases.\textsuperscript{143} Several different units are used to measure strength and intensity of a magnetic field. For instance, the ampere per meter (A/m) properly

\textsuperscript{134} See id.
\textsuperscript{135} See id.
\textsuperscript{136} See id.
\textsuperscript{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.
\textsuperscript{138} See NRC REPORT, supra note 3, at 12.
\textsuperscript{139} See id. at 13. The term “electromagnetic field” or “EMF” is used to generally describe electric and magnetic fields together.
\textsuperscript{140} See id.
\textsuperscript{141} See OTA BACKGROUND PAPER, supra note 56, at 7.
\textsuperscript{142} See id. at 7.
\textsuperscript{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. 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. The measured field of an ELF magnetic field, being unaffected by the presence of humans and animals, represents the actual exposure field.

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. The usual minimum time period that the instruments average is about one second.

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. 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.

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.I. 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.
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.\textsuperscript{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.\textsuperscript{162} The internal wiring usually is not a significant source of magnetic field exposure unless a problem with the wiring exists.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{169}

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

\textsuperscript{161} See id. at 27-28.
\textsuperscript{162} See id. at 28.
\textsuperscript{163} See id.
\textsuperscript{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.
\textsuperscript{165} See NRC REPORT, supra note 3, at 32. At peak usage the average figures given in note 118 could double.
\textsuperscript{166} See id. Of course, magnetic fields are strongly present within the substation itself.
\textsuperscript{167} See id.
\textsuperscript{168} See id.
\textsuperscript{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.
\textsuperscript{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.\textsuperscript{171} One study of 992 homes showed that only five percent of the homes had average background magnetic fields greater than 2.9 mG.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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).\textsuperscript{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.\textsuperscript{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.\textsuperscript{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

\textsuperscript{171} See NRC REPORT, supra note 3.
\textsuperscript{172} See id. at 28-29 (citing Geom 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.
\textsuperscript{173} See NRC REPORT, supra note 3, at 29-30 (citing EMF ENV'T, supra note 164).
\textsuperscript{174} See id.
\textsuperscript{175} See id. at 31 (citing GEOMET STUDY, supra note 172).
\textsuperscript{176} See id. at 30. For positive-temperature-coefficient blankets the fields average about one mG.
\textsuperscript{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.\textsuperscript{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.\textsuperscript{179}

\textbf{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.\textsuperscript{180} Under the charter of the NAS, the National Academy of Engineering was established in 1964 to share responsibility for advising the federal government.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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;

\begin{flushleft}
\textsuperscript{178} See id. at 33. \textsuperscript{179} See id. at 118-19. \textsuperscript{180} See id. at xix. \textsuperscript{181} See id. \textsuperscript{182} See id. \textsuperscript{183} See id. \textsuperscript{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.\end{flushleft}
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.\footnote{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.\footnote{186}

As the charge reflects, the NRC Committee was to evaluate three categories of health hazards: carcinogenic effects, neurobehavioral effects, and reproductive effects.\footnote{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.

\footnote{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.
- 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. STOLWITJ, Department of Epidemiology and Public Health, Yale University School of Medicine, New Haven, Conn.
- MARIO 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.

\footnote{186} See id.

\footnote{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. 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. Concluding that residential strength magnetic field exposures do not produce significant in vitro effects, the NRC Report also specifically discussed effects on genotoxicity, signal-transduction pathways, intracellular calcium concentrations, and general patterns of gene expression.

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. 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.

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.\textsuperscript{194}

\textit{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.\textsuperscript{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.\textsuperscript{196} Signal transduction changes are a common result in experiments and such changes alone do not

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\textsuperscript{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.

\textsuperscript{195} See id. at 58.

\textsuperscript{196} See id. at 6.
indicate an adverse effect. Studies indicate that changes in membrane-transduction pathways are caused by low frequency electric and magnetic fields. 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.

One study that has been independently replicated by at least two laboratories observed that magnetic field exposure produces changes in ornithine decarboxylase (ODC) activity, an enzyme involved as a cell membrane signal transduction pathway. 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.

197. See id.


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 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. 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. 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. 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.

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. 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 fields probably do have an effect on signal-transduction-related pathways in cells, essentially no evidence exists for such effects at residential field strengths.

b. Gene Expression Changes

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

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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.\textsuperscript{212} Other studies showing changes in gene expression followed,\textsuperscript{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.\textsuperscript{214} The criticisms led two groups to attempt replication studies using improved experimental techniques and elaborate precautions.\textsuperscript{215} Despite those efforts, the groups failed to replicate the gene expression effects that had been previously reported.\textsuperscript{216} The NRC Committee concluded, “[e]vidence for electric- and magnetic-field effects on gene expression at residential field strengths is completely lacking.”\textsuperscript{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.\textsuperscript{218} The concentration of calcium inside a cell regulates enzyme catalysts, thus serving as a second messenger in neural function.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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,
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 studies\textsuperscript{230} that were confirmed in peer-reviewed literature.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{235} The assumptions regarding dose-response relationships include the following: the agent administered caused the response;\textsuperscript{236} a relationship exists between the measurement of the dose and the response;\textsuperscript{237} and means are available to measure and

\textsuperscript{230} See id. at 156. A study is conducted blindly when the researchers are without knowledge 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.

\textsuperscript{231} See id. at 74.

\textsuperscript{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.

\textsuperscript{233} See id. at 74.

\textsuperscript{234} See id. at 75-76 (citing C.D. Klaassen & 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)).

\textsuperscript{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.

\textsuperscript{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.

\textsuperscript{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.\textsuperscript{238} The foregoing assumptions are presumed to hold true for ELF fields if they indeed are found to be toxic agents.\textsuperscript{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,\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{243} Such a study would need one and a half to two years of exposure of rats or mice to the field.\textsuperscript{244} This would allow the animals to be observed for most of their life-spans, during which time exposure to confounding agents\textsuperscript{245} 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.\textsuperscript{246}

\begin{footnotes}
\item 238. See id.
\item 239. See id.
\item 240. See id. at 73.
\item 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.
\item 242. See id. at 79-80.
\item 243. See id. at 79.
\item 244. See id. at 80.
\item 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.
\item 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
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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.\textsuperscript{247} Initiation is a genotoxic event where a carcinogen affects the DNA directly.\textsuperscript{248} Promotion is responsible for initiated cells changing to cancerous cells.\textsuperscript{249} Initiation and promotion studies use less time, fewer animals, and are less expensive than complete carcinogenesis studies.\textsuperscript{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.\textsuperscript{251}

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

\textsuperscript{247} See id. at 80.
\textsuperscript{248} See id.
\textsuperscript{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.
\textsuperscript{250} See id.
\textsuperscript{251} See id. at 81.
\textsuperscript{252} See id. at 81-82 (citing M. Mevissen et al., \textit{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. Beriashvili & M.Z. Merabde, \textit{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. L"oscher et al., \textit{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)).
\textsuperscript{253} See id.
\textsuperscript{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.  

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 fish, and chicken; effects of electric fields on mammals such as mice, rats, swine, and cattle; effects of magnetic fields on non-mammals such as chicken; and effects of magnetic fields on mammals such as mice and rats. 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. Rommenseim et al., Reproduction, Growth, and Development of Rats During Chronic Exposure to Multiple Field Strength of 60-Hz Electric Fields, 14 FUNDAM. APPL. TOXICOLO. 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 Etrous 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. Neuroendocrine\textsuperscript{272} Effects

Neuroendocrines consist of various glands in the body that produce hormones which influence nerve activity.\textsuperscript{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.\textsuperscript{274} Melatonin is a hormone in humans, and possibly all animals, produced mainly by the pineal gland.\textsuperscript{275} The pineal gland, an end-organ of the visual system, has nerves whose activity is determined by light perception at the retina.\textsuperscript{276} More melatonin is present during the night than during the day because more is produced in darkness than in light.\textsuperscript{277} Melatonin is associated with circadian or biological rhythms of organisms.\textsuperscript{278}

Visible light, as well as some ultraviolet wavelengths and some infrared wavelengths, have been shown to alter pineal melatonin production.\textsuperscript{279} Residential strength electric and magnetic fields are of extremely low frequency, have long wavelengths, and are below the visible light range.\textsuperscript{280} Studies considering the effects of electric fields on melatonin production in animals report suppression of melatonin concentrations,\textsuperscript{281} as do studies considering the effects of magnetic fields\textsuperscript{282} and studies considering the effects of combined

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\textsuperscript{272} See 10 THE OXFORD ENGLISH DICTIONARY 348 (2d ed. 1989).
\textsuperscript{273} See NRC REPORT, supra note 3, at 95, 103. For example, the pineal gland produces melatonin and stress hormones such as pituitary adrenocorticotropic ("ACTH"), corticosterone, cortisol, norepinephrine, and epinephrine are released from the adrenal medulla.
\textsuperscript{274} See id. at 95.
\textsuperscript{275} See id.
\textsuperscript{276} See id. at 95 (Fig. 4-1).
\textsuperscript{277} See id.
\textsuperscript{278} See id.
\textsuperscript{280} See id. at 96.
\textsuperscript{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.
\textsuperscript{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)).

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electric and magnetic fields. Humans have been found to have melatonin rhythms that are similar to those in other mammals. 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).

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:

\[ \text{Reduced melatonin concentrations lead to an increased secretion of prolactin and gonadal steroids. That increase causes proliferation of cell division in breast or prostate tissue and stimulates growth of initiated cancer cells.} \]

\[ \text{Melatonin suppression reduced the total antioxidative potential of the organism, thereby increasing the likelihood of damage by a carcinogen to the DNA of any cell. DNA damage can increase the risk of cancer particularly if electric- and magnetic-field exposure also increases the half-life production of free radicals.} \]

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.

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 animals and humans. In vitro studies of those effects have also

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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 Nonhuman Primates, 3 BIOELECTROMAGNETICS SUPPL. 119 (1995) (reporting baboons showed nighttime depressed melatonin)).
284. See id. at 102.
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. 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, but the mechanism by which this healing occurs is not clearly established.

Bone in living organisms is known to possess an electric component, 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). 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. 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. This field strength is much higher than that ordinarily encountered in residential environments.

C. Epidemiology

Few of the laboratory experiments considering the effects of electric and magnetic field exposure on animals were studies of humans. 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. Friedenberg 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.


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; Schuffman et al., 1994; and Wilson et al., 1990.
disease in human populations to understand causes and identify methods of prevention.” Since 1979 when Nancy Wertheimer and Edward Leeper first reported an association between childhood leukemia and electric power distribution line configurations, 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. Consequently, the NRC Committee reviewed and evaluated more than fifteen years of epidemiological research providing data on cancer in its Report.

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.

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.
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.\textsuperscript{304} Other factors in the problem of determining causality are the potential sources of error in epidemiological studies, including random error,\textsuperscript{305} information bias or misclassification,\textsuperscript{306} selection bias,\textsuperscript{307} and confounding and effect modification.\textsuperscript{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

\textsuperscript{304} See NRC REPORT, supra note 3, at 119 (emphasis added).
\textsuperscript{305} See id. at 119-20. Statistical processes produce variable results in a given study.
\textsuperscript{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.
\textsuperscript{307} See id. at 122 (noting error in selecting the groups to be compared as one selection bias).
\textsuperscript{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 Leeper 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. 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. The homes were classified according to two wire codes, High Current Configuration (HCC) and Low Current Configuration (LCC). 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. 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. 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 (VLC). 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. Consequently, the study has been widely criticized, 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."

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. 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. 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.

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

322. See id.
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." 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. 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; 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. 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.

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. Nor was it clear whether the associations were really due to the exposure to magnetic fields or some other factor.

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 RADIOLICAL 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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{337} Another contradiction was the failure of the data to indicate a consistent dose-response relationship.\textsuperscript{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.\textsuperscript{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.\textsuperscript{340} The inconsistent dose-response relationship pattern might be caused by an imperfect correlation with the true risk factor.\textsuperscript{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."\textsuperscript{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."\textsuperscript{343} They also recognized suggestions of bias caused by

\begin{footnotesize}
\begin{enumerate}
\item \textsuperscript{335} See id. at 143.
\item \textsuperscript{336} See id. at 144.
\item \textsuperscript{337} See id.
\item \textsuperscript{338} See id.
\item \textsuperscript{339} See id. at 145-46. The NRC Committee noted that investigation of several possible risk factors failed to explain the association.
\item \textsuperscript{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.
\item \textsuperscript{341} See id.
\item \textsuperscript{342} Id.
\item \textsuperscript{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.
\end{enumerate}
\end{footnotesize}
control selection or too small a number of subjects in some studies.\footnote{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.}

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.\footnote{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.}

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.\footnote{See id.} 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.

\textbf{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
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.\textsuperscript{347} In the example above, the estimate might be that some specific number of persons ingesting a specific quantity of saccharin will develop cancer.\textsuperscript{348}

The four stages of risk assessment are hazard identification,\textsuperscript{349} dose-response assessment,\textsuperscript{350} exposure assessment,\textsuperscript{351} and risk characterization.\textsuperscript{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.\textsuperscript{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.\textsuperscript{354} At the conclusion of the assessment process, all evidence is weighed together to produce an overall conclusion about risk assessment.\textsuperscript{355} If all four stages of a risk assessment are used ending in a quantitative risk estimate, the risk assessment is a complete one.\textsuperscript{356} If only some of the stages are used, the assessment is said to be a partial one.\textsuperscript{357} Whether the assessment is complete or partial depends upon the available data and the purpose of the risk assessment.\textsuperscript{358}

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

\textsuperscript{347} See \textit{id. at 192.}

\textsuperscript{348} See \textit{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.

\textsuperscript{349} See \textit{id. at 192-93 (citing NATIONAL RESEARCH COUNCIL, \textit{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.

\textsuperscript{350} See \textit{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.

\textsuperscript{351} See \textit{id.} (estimating the amount of the hazardous agent that a typical person is likely to experience).

\textsuperscript{352} See \textit{id.} (estimating the overall risk to human health).

\textsuperscript{353} See \textit{id. at 15, 193.}

\textsuperscript{354} See \textit{id. at 15-16.}

\textsuperscript{355} See \textit{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.

\textsuperscript{356} See \textit{id. at 15.}

\textsuperscript{357} See \textit{id.}

\textsuperscript{358} See \textit{id.}
magnetic fields because of uncertain data.\textsuperscript{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.\textsuperscript{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;\textsuperscript{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;\textsuperscript{362} and "a moderately consistent, statistically significant association between wire codes, . . . and childhood leukemia" exists.\textsuperscript{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.\textsuperscript{364}

Under "Exposure Assessment," the NRC Committee acknowledged the universal and unavoidable daily exposure of the population to electric and magnetic fields.\textsuperscript{365} This universal exposure would mandate the consideration of how even a very small proven adverse effect would affect public health.\textsuperscript{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

\textsuperscript{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.

\textsuperscript{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.

\textsuperscript{361} Id. at 194-95.

\textsuperscript{362} Id. at 195.

\textsuperscript{363} Id.

\textsuperscript{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.

\textsuperscript{365} See id.

\textsuperscript{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."\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{373}

\textsuperscript{367} Id. at 197.

\textsuperscript{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.

\textsuperscript{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.

\textsuperscript{370} See id. at 199 (providing a relative risk of 1.5 as an example).

\textsuperscript{371} See id. at 197-200.

\textsuperscript{372} See id.

\textsuperscript{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. 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.

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.

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. 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 Altonian 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. 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 Altonian judgment, the parties reached an undisclosed settlement on the "non-EMF" issues. See Altonian 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.

VI. APPENDIX

Figure 1: The electromagnetic spectrum