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Data Collected and Reviewed Regarding a Health Study for People Living Near a Nuclear Facility

Report to the Minnesota Legislature 2004

Minnesota Department of Health

February 9, 2004

MINNESOTA MDH DEPARTMENT OF HEALTH

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This report is produced as required by Minnesota Session Laws 2003, 1st Special Session, Chapter 11, Article 1, Sec. 5. As requested by Minnesota Statute 3.197: This report cost approximately $1,000 to prepare, including staff time, printing and mailing expenses.

Dear Interested Party:

The 2003 1st Special Session Chapter 11 Article 1, Sec. 5 requested that the Commissioner of Health "review data collected by the department, and in the context of other relevant information developed by the National Institutes of Health and other entities, report to the legislature by January 1, 2004 on whether a further health study funded by the owner of the Prairie Island nuclear facility is necessary." Based on discussions with the author of this Section, the data reviewed focused on exposure to electric and magnetic fields.

Research on the health effects of electric and magnetic fields (EMF) have been carried out since the 1970s. Epidemiological studies have mixed results. Some have shown no statistically significant association between exposure to EMF and health effects, and some have shown a weak association. Recent laboratory studies have failed to show such an association, or to establish a biological mechanism for how magnetic fields may cause cancer. Scientific panels have been convened by national and international health agencies and have reviewed the research carried out to date. Most concluded that there is insufficient evidence to prove an association between EMF and health effects; however, many of them also concluded that there is insufficient evidence to prove that EMF exposure is safe.

Starting in 1998, an interagency work group with representatives from the Minnesota Department of Health, Department of Commerce, Public Utilities Commission, Pollution Control Agency, and the Environmental Quality Board evaluated the more recent scientific literature to prepare a document that the Environmental Quality Board (EQB) could use to help guide their deliberations on the issues relating to electric power lines and their impact on human health. The report of this effort was presented to EQB (White Paper on Electric and Magnetic Field (EMF) Policy and Mitigation Options, September, 2002, attached) and the conclusion was that the current weight of scientific evidence does not support a cause and effect relationship between EMF and cancer or between EMF and any other adverse health effects. This conclusion is based upon:

1. the failure of laboratory studies to support an etiologic role of magnetic fields and leukemia (even at high exposure levels);
2. the lack of an understood biological mechanism for how magnetic fields may initiate or promote the growth of cancer; and
3. the limitations of epidemiological studies, which have reported mixed and weak associations.

MDH staff continue to speak regularly with leading EMF scientists around the country, including researchers affiliated with the National Institute of Environmental Health Sciences (NIEHS) EMF RAPID Program, the National

Toxicology Program, the U.S. Environmental Protection Agency, state health departments, and academic institutions.

Staff have also committed to maintaining a Web site that lists new scientific research findings and has links to the actual reports. The White Paper can also be downloaded directly from that site. The Web address for our EMF Web Page is:

http://www.health.state.mn.us/divs/eh/radiation/emf/index.html

Also included with the state report is a 2002 report from NIEHS entitled: "EMF Electric and Magnetic Fields Associated with the Use of Electric Power." It is also available electronically at the following site:

http://www.niehs.nih.gov/emfrapid/booklet/

Based on the materials prepared and reviewed on the issue of EMF, the Minnesota Department of Health does not recommend a health study be conducted for persons living near a nuclear facility at this time.

Questions and comments on the materials can be directed to George Johns, Jr. of the MDH Environmental Health Division at (651) 642-0492.

Sincerely,

Agnes T. Leitheiser

Aggie Leitheiser,
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A White Paper On
Electric And Magnetic Field (EMF) Policy And Mitigation Options

Prepared By

The Minnesota State
Interagency Working Group
On EMF Issues

September 2002

EXECUTIVE SUMMARY

Over the last two decades concern about the health effects of electric and magnetic fields (EMF) has increased. Early scientific studies reported a weak association between increased rates of cancer and closeness to certain kinds of power lines that can cause strong electric and magnetic fields. As more electric facilities are built to meet growing demands for electricity, policy makers will increasingly be faced with questions regarding the potential health impacts of EMF. This report is the result of an interagency work group that was formed to examine these issues and provide useful, science-based information to policy makers in Minnesota.

Electric and magnetic fields are a basic force of nature generated by electricity from both natural and human sources. Exposure to EMF comes from high voltage transmission lines and distribution lines, wiring in buildings, and electric appliances. Electric fields are easily shielded by common objects such as trees, fences, and walls. Magnetic fields are difficult to shield; this is why magnetic fields produced by power lines can extend into people's homes.

Transmission and distribution lines are part of the complete electric power system. Transmission lines carry between 69 and 500 kilovolts (kV) of electricity and transport it from generation sources to regions of the state needing electricity. Primary distribution lines generally carry less than 69 kV of electricity and bring it from transmission lines to homes, offices, and other sites where there are end users of electricity.

Based on forecasts of future electrical use, Minnesota has now reached the point at which new generation and transmission capacity is needed. Over the ten years from 1990 to 2000, total annual electric consumption in the State grew by 27 percent; summer peak demand is predicted to grow by 16 percent over the next ten years. Several transmission expansion projects are planned over the next ten years to meet this demand. These projects will need to be reviewed and approved by the Public Utilities Commission and the Environmental Quality Board.

Research on the health effects of EMF has been carried out since the 1970s. Epidemiological studies have mixed results – some have shown no statistically significant association between exposure to EMF and health effects, and some have shown a weak association. More recently, laboratory studies have failed to show such an association, or to establish a biological mechanism for how magnetic fields may cause cancer. A number of scientific panels convened by national and international health agencies and the U.S. Congress have reviewed the research carried out to date. Most concluded that there is insufficient evidence to prove an association between EMF and health effects; however, many of them also concluded that there is insufficient evidence to prove that EMF exposure is safe.

In deciding whether or how much to regulate EMF, decision-makers have several possible options. Each approach has advantages and disadvantages. At one extreme, regulators can require virtual certainty of harm before they address it. At the other extreme, proposers of a project would need to demonstrate its safety before regulators would allow them to proceed. Several options along this continuum are presented below for regulators to consider when routing power lines.

Several EMF exposure mitigation options are available. Mitigation options for transmission lines include increasing distance to the EMF source, phase cancellation by changing the proximity of the conductors, shielding the EMF source, and reducing voltage or current levels on the lines. Principles for decreasing EMF from primary distribution lines are similar and include increasing the right-of-way around distribution lines, phase cancellation, and burying the lines. There are also several options for mitigating EMF exposure in the home, including increasing distance to operating appliances and properly following electrical codes for wiring the home.

The Minnesota Department of Health (MDH) concludes that the current body of evidence is insufficient to establish a cause and effect relationship between EMF and adverse health effects. However, as with many other environmental health issues, the possibility of a health risk from EMF cannot be dismissed. Construction of new generation and transmission facilities to meet increasing electrical needs in the State is likely to increase public exposure to EMF and public concern regarding potential adverse health effects.

Given the questions and controversy surrounding this issue, several Minnesota agencies that regularly deal with electric generation and transmission formed an Interagency Work Group to provide information and options to policy makers. Work Group members included representatives from the Department of Commerce, the Department of Health, the Pollution Control Agency, the Public Utilities Commission, and the Environmental Quality Board. Based on its review, the Work Group believes the most appropriate public health policy is to take a prudent avoidance approach to regulating EMF. Based on this approach, policy recommendations of the Work Group include:

- Apply low-cost EMF mitigation options in electric infrastructure construction projects;
- Encourage conservation;
- Encourage distributed generation;
- Continue to monitor EMF research;
- Encourage utilities to work with customers on household EMF issues; and
- Provide public education on EMF issues.

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INTRODUCTION

Over the last two decades concern about the health effects of electric and magnetic fields has increased. Early scientific studies reported a weak association between increased rates of cancer and closeness to certain kinds of power lines that can cause strong electric and magnetic fields (EMF). However, other studies conducted since then refute those results. Given this uncertainty, there has been considerable public debate about the potential health risks from exposures to EMF. Questions include: Does EMF cause cancer or any other adverse health effects? Is there a safe level of exposure for EMF?

Additionally, there has been interest in mitigating exposures to EMF. Questions asked in this regard include: What are the ways that exposures to EMF can be reduced? What are the costs? What are the current policies and regulations in Minnesota and other states?

State and local policy makers will increasingly be faced with questions regarding the potential impact of EMF. Consumption of electricity has been growing in Minnesota in recent years and is projected to grow more in the future. Given this increased demand for electricity, it is expected that more electric facilities will need to be built, thus increasing potential EMF exposure.

In an attempt to provide state and local decision-makers with guidance on EMF research and public policy, an interagency work group was established.[1] The group focused on evaluating the current state of EMF health effects research, reviewing policies and mitigation strategies from other states, and providing a framework for decision-making on various regulatory options. This report is the result of that effort.

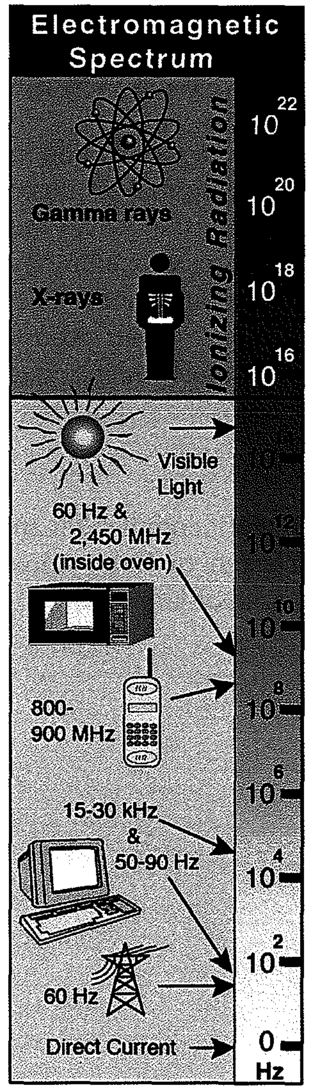
Chapter 1 of this report explains basic concepts related to EMF. Chapter 2 describes the electrical infrastructure in Minnesota, the increasing demand for electricity in the State, and projected new construction of electric facilities. Chapter 3 discusses the current state of the health effects research on EMF. Chapter 4 outlines various regulatory approaches in considering EMF issues, while Chapter 5 describes methods for reducing EMF exposure. Finally, Chapter 6 contains conclusions and policy recommendations developed by the work group. A survey of other states' activities and policies related to EMF regulation is included in the Appendix.

The scope of this report is limited to extremely low frequency fields from electrical sources such as power lines and substations, household wiring, and appliances. It does not address research or policies related to radio frequency fields such as AM/FM radio, television, cellular phones, or any other frequencies. This report also does not address issues related to occupational EMF exposures or stray voltage.

[1] Work Group representatives included staff from the Minnesota Department of Health, Department of Commerce, Public Utilities Commission, Pollution Control Agency, and Environmental Quality Board.

CHAPTER 1: A PRIMER ON ELECTRIC AND MAGNETIC FIELDS

Electric and magnetic fields (EMFs) are a basic force of nature (like gravity) generated by electricity. EMFs are found in nature, where they are created by such things as lightning and static electricity. Man-made fields are found wherever people use electricity. Electric fields arise from voltage on conductors. They are measured in volts/meter or kilovolts/meter and are easily shielded by common objects such as trees, fences, and walls. Magnetic fields arise from the current flowing through the conductors. They are measured in units of milligauss (mG) and are very difficult to shield. This is why the magnetic fields produced by power lines can extend into people's homes



Like sound, electric and magnetic fields are made of a mixture of components and so can be described in many different ways. The fields can be strong or weak, have a high or low frequency, have sudden increases in strength (transients) or a constant strength, and consist of one pure frequency or several (called harmonics). Power lines and wiring in buildings and appliances generate 50 and 60 Hertz fields, sometimes referred to as "power frequency" fields. (Frequency is measured in cycles/second). Power frequency fields are low frequency fields and have low energy levels.

Sources of EMF Exposure

We are exposed to EMF from many sources, including high voltage transmission lines (usually on metal towers) carrying electricity from generating plants to communities, and distribution lines (usually on wooden poles) that bring electricity to our homes, schools and workplaces. We are also exposed to magnetic fields from wiring in buildings and from all our electric appliances like TV sets, radios, hair dryers, electric blankets and electric tools.

Average Levels of EMF Exposure

The strength of magnetic fields varies depending on many different factors, including the magnitude of the current and the proximity to an EMF source. Because magnetic fields decrease with distance from the source, the magnitude of the magnetic field is higher in homes near a power line than those further away. Similarly, levels near appliances or interior electrical wiring may be higher than an average mid-room reading.

The electric field under a high voltage transmission line is usually not more than 10 kV/meter when measured 1 meter above ground. (In Minnesota the lines subject to permits from the

Environmental Quality Board have been restricted to a maximum of 8 kV/m). Because most materials shield the electric field the typical electric field in a house does not exceed 100 V/m.

In a study conducted by the Electrical Power Research Institute, spot measurements in 992 homes throughout the U.S. showed that half (50%) of them had magnetic field measurements of 0.6 mG or less, when the average of measurements from all the rooms in the home was calculated. These measurements primarily reflect the fields from internal household wiring, electrical grounding sources, and power lines. Exposures in occupational settings (e.g., working on a computer or operating a machine/tool) are typically much higher than residential settings.

In 1998 a nationwide random survey of 1000 individuals was conducted to measure 24-hour time-weighted average exposures to magnetic fields (Zaffanella & Kalton, 1998). The geometric mean for this survey was 0.9 mG. Approximately 15% of the population was estimated to have exposures exceeding 2 mG; 2.4% had exposures exceeding 5 mG, and 0.4% had exposures exceeding 10 mG. The last value indicates that about 1 million people in the U.S. have an average 24-hour exposure greater than 10 mG. Peak exposures at a single point in time are often considerably higher due to peoples' exposures to appliances, wiring, and other sources. About 0.5% of the population had an estimated maximum (peak) exposure to magnetic fields of 1000 mG.

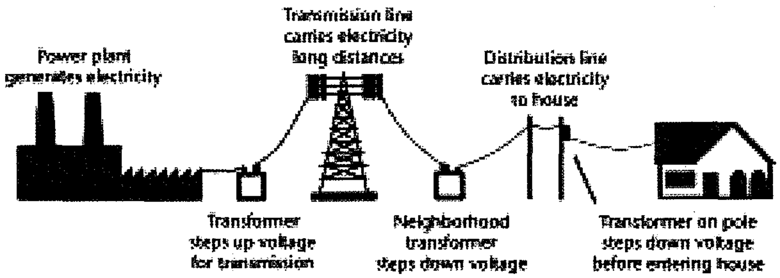
Overall, commercial and residential power distribution systems can be a more significant source of magnetic field exposure than transmission lines, but they are usually not a very significant source of large electric fields.

CHAPTER 2: MINNESOTA'S ELECTRIC SYSTEM INFRASTRUCTURE

How the Electrical System Works

The complete electric power system is a complex mix of generation, transmission lines, and distribution lines, interspersed with substations and transformers that adjust the voltages between the various lines and the end user. The transmission and distribution lines are also referred to as conductors because they conduct the electricity along the lines to the end user. As commonly used in Minnesota, transmission lines are lines that carry between 69 and 500 kilovolts (kV) of electricity and transport it from generation sources to regions of the state needing electricity. Primary distribution lines bring electricity to homes, schools, offices, and other sites where there are end users of the electricity and generally carry less than 69 kV of electricity. The actual voltage depends on the need; common voltages for primary distribution are 4 kV, 12.5 kV, and 24.9 kV. Voltage on primary distribution lines is stepped down by either a pole-mounted transformer for overhead primary lines or by pad-mounted transformers for underground primary lines. The electricity is then delivered to the end user via secondary distribution lines.

TRANSPORTING ELECTRICITY



Building the Electrical Infrastructure

Construction of Generation Facilities

Electric generation facilities have generally been constructed to meet forecasted demand for electricity. Minnesota utilities constructed a great deal of generation capacity in the 1960's and early 1970's, with the expectation that electricity use was going to grow significantly during the following decades. A combination of factors, including the 1973 oil embargo, led to a significant slowing in the growth of electricity use, which provided Minnesota with excess generation and major transmission line capacity for about 20 years. The last major baseload generation facility constructed in Minnesota was the Sherco 3 unit in 1987; the last major transmission line was constructed in 1981.[2]

[2] For a complete list of recent electric facilities, please see the Department of Commerce's State Energy Plan, which can be found at http://www.commerce.state.mn.us/pages/Energy/MainEnergyPolicy.htm

Construction of Transmission Lines

The construction of major transmission lines in the State has generally followed the construction of major electric generation facilities. In addition, land-use patterns and the sites chosen for new generation have affected the configuration and need for transmission lines. For example, generation may be located away from populated areas for environmental reasons, or to have access to railroad locations, water, or other facilities needed to generate electricity. However, the farther away generation facilities are located from customers, the more transmission facilities are needed to deliver electricity to consumers. Moreover, location of businesses and homes in more rural areas can also increase the need for transmission facilities.

Construction of Distribution Lines

Although the construction of major transmission lines has been slow, construction of distribution lines and associated facilities has continued to grow. Construction of distribution facilities is tightly coincident with construction of new housing and commercial development, which have grown significantly in several parts of the state. Upgrades of older distribution facilities also occur as a response to changing customer uses, such as larger appliances and computers, that place additional demands on the electric system.

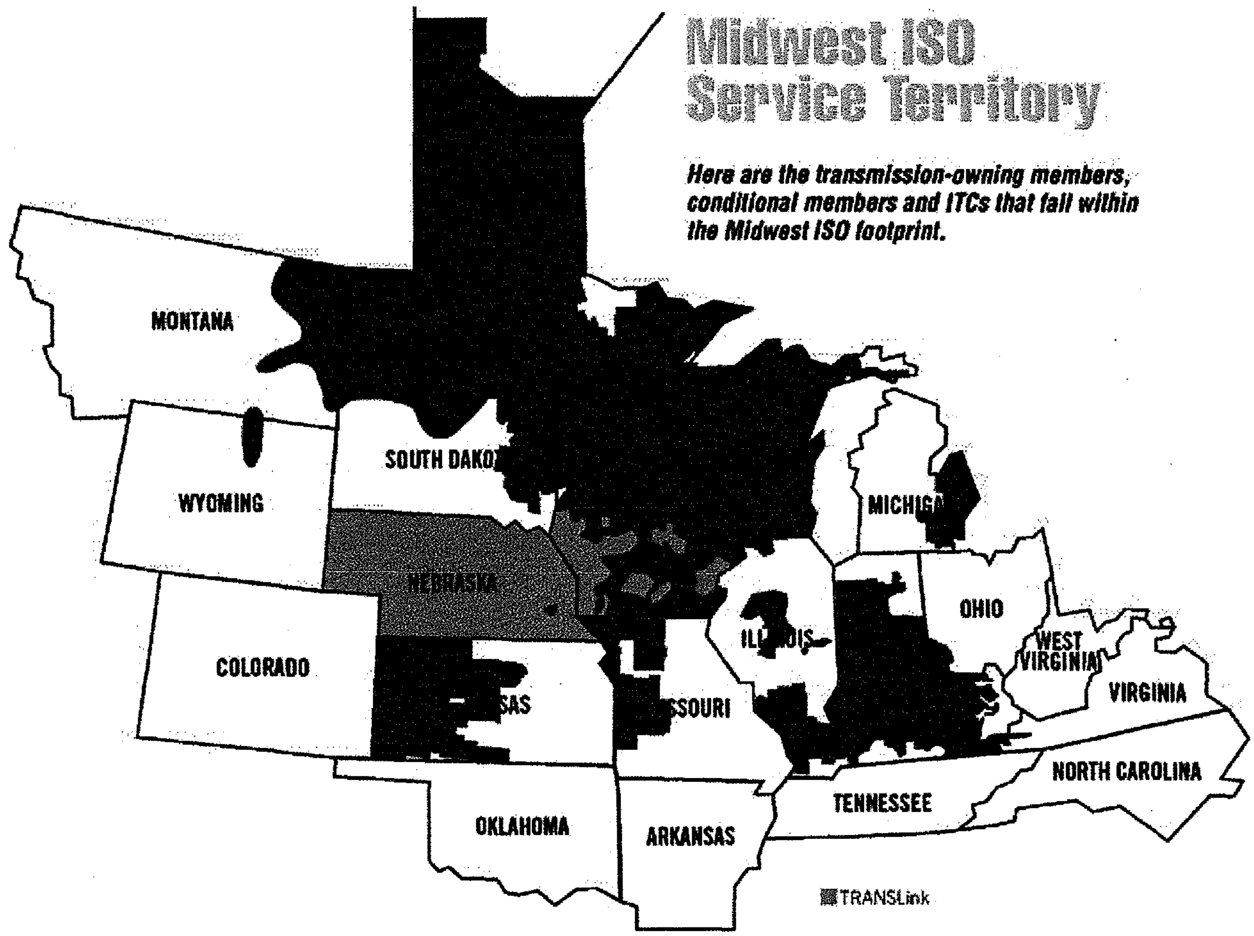
Planning and Approving New Infrastructure

The production of electricity has generally been subject to a public review of the need for generation and transmission facilities. Since production is controlled by a variety of private entities, the public and private sectors interact to determine the need for new electric generation and transmission systems.

The North American Electric Reliability Council (NERC) is the electric reliability organization for all of North America. Its members are its subregional reliability organizations. The Mid-Continent Area Power Pool (MAPP) is the NERC subregional organization that includes Minnesota. MAPP has had three main functions: 1. a reliability council, responsible for the safety and reliability of the bulk electric system including system-wide planning functions; 2. a regional transmission group, responsible for facilitating open access of the transmission system; and, 3. a power and energy market, where MAPP members and non-members may buy and sell electricity.

At the end of 2001, MAPP's operational and planning functions for most of its members were transferred into a much larger regional transmission organization, called the Midwest Independent System Operator (MISO). MISO will take over the facilities planning (100 kV and above) for its member utilities. MAPP retains its reliability council function. When assessing transmission options for meeting the needs of the region, MISO planners are expected to look at a number of factors, including location of need, cost effectiveness, the ability to accommodate the diversity of generation sources, impact on the environment, and reliability.

Figure1: The Midwest Independent System Operator (MISO) Region



While MAPP has been, and MISO will be, responsible for regional long-range planning, the ultimate decision on whether a Minnesota-based project is needed to meet electric demand lies with the Minnesota Public Utilities Commission (PUC). The PUC must approve a Certificate of Need application before a major electric generation or transmission project can be built in Minnesota. Under the provisions of the Energy Security and Reliability Act, passed during the 2001 legislative session, utilities are required, every two years, to submit a transmissions project report to the PUC. The report is required to list the present and reasonably foreseeable future inadequacies in the transmission system in Minnesota and identify alternative means of addressing each inadequacy listed. The first transmission plan was submitted to the PUC on November 1, 2001. While the state's utilities submitted a joint report, none listed specific projects for approval at that time. The utilities indicated that they plan to submit certain transmission line projects individually for approval, as has been done in the past. The next plan is due on November 1, 2003.

Once the Minnesota Public Utilities Commission has issued a Certificate of Need for a project, the proposer must obtain a site or route permit from the Environmental Quality Board. Under limited circumstances, the proposer may opt to seek a site or route permit from local governmental units. Both processes involve environmental review with citizen and other stakeholder input.

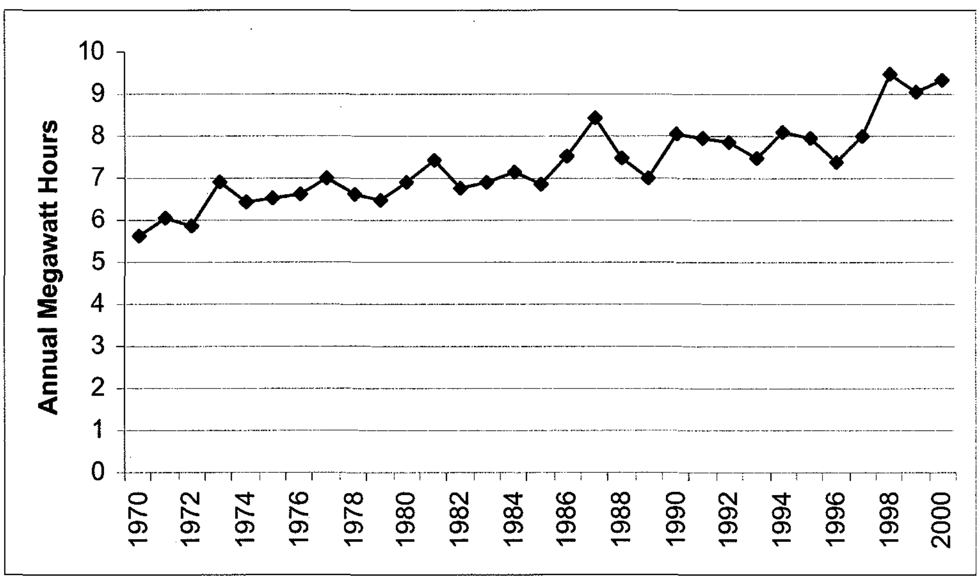
Current Needs for New Infrastructure

Growth in Electric Consumption

Since the mid-1960's, electric use in Minnesota homes has nearly doubled, from an average of 5 megawatt-hours (MWh) to 10 MWh per customer, per year (see Figure 2). While there have been extensive conservation measures used during this time, electrical use increased due to increased use of air conditioning, computers, larger refrigerators, and other appliances.

The growth in electricity use by all customers has increased even more in recent years. For example, over the ten years from 1990 to 2000, total annual electric consumption in the State grew from 49,355 gigawatt-hours to 62,532 gigawatt-hours, a 27 percent increase (Minnesota Dept. of Commerce, 2001).[3] Forecasts of future load growth indicate that the summer peak demand in the MAPP-U.S. region is expected to increase at an average rate of 1.9% per year during the 2001 – 2010 planning period (NERC, 2001). Given this level of growth, Minnesota has now reached the point at which new generation and transmission capacity is needed.

Figure 2: Weather-Normalized Electric Consumption per Minnesota Residential Customer 1970 - 2000



Proposed New Infrastructure

As noted above, MAPP forecasts of future load growth indicate that the summer peak demand in the MAPP region is expected to grow by an additional 16 percent in the next ten years. To meet this expected growth, the data reported to the MAPP planning process in the year 2000 show approximately 64 transmission expansion projects planned for Minnesota over the next ten years.

[3] These figures are not adjusted for abnormally warm or cool weather in either year.

The planned construction activity for lines 115 kV and higher, as reported to MAPP, will result in approximately 434 miles of new or upgraded lines in Minnesota (See Table 1).

TABLE 1

Planned Transmission Lines and Transformers Reported to the MAPP Transmission Planning Subcommittee

Planned Transmission Lines and Transformers							Line Mile Estimates					Need Estimate (Sum = 100%)					
In Service Date (m/d/y)	MAPP Sub-region or Other Region	From:	To:	Circuit #	Voltage(s) (kV)	Number of Alternatives or None Reported (NR)	Reconductor or Thermal Increase	Rebuild or Conversion	New	Total Miles	Summer Rating (MVA)	Network	Gen Outlet	Transfer Capability	Improvement (Losses, Maint, Availability, etc)	A=Authorized P=Planned C=Completed W=Withdrawn	Reporting Source
11/1/05	RRV	Winger	Bemidji		115	NR	55.0			55.0	144	100				P	OTP
12/31/05	RRV	Frazee	Audubon		115	NR			48.0	48.0	161	100				P	OTP
5/1/00	UMV	Benton Co.	Benton Co. Tap		115	NR	4.1			4.1	300	80		20		A	NSP
5/1/00	UMV	Benton Co. Tap	Granite City		115	NR			1.0	1.0	300	80		20		A	NSP
10/1/00	UMV	I94 Ind Park	St. Cloud tap west	1	115	NR		6.0		6.0	224	100				A	GRE
11/1/00	UMV	Air Lake	Dodd Park		115	NR			4.0	4.0	300	100				A	GRE
11/1/00	UMV	Air Lake	Lake Marion		115	NR			6.5	6.5	337	100				A	GRE
12/1/00	UMV	Loon Tap	Waterville		161	1			5.0	5.0	191	100				A	NSP
12/1/00	UMV	Waterville	Loon Lake		161	1			11.0	11.0	191	100				A	NSP
5/1/01	UMV	Rutland	Winnebago	1	161	NR	15.0			15.0	225	100				A	ALT
5/1/01	UMV	Lakefield	Fox Lake	1	161	NR	22.0			22.0	225	100				A	ALT
5/1/01	UMV	Pleasant Valley	Austin	1	161	NR		17.0	6.0	23.0	444		100			A	GRE
5/1/01	UMV	Fox Lake	Rutland	1	161	NR	16.0			16.0	224	100				A	ALT
5/1/01	UMV	Fifth St	Main St		115	NR	0.7			0.7	300	100				P	NSP
5/1/01	UMV	Lakefield	Fox Lake	1	161	NR	22.3			22.3	219	100				P	ALT
5/1/01	UMV	Fox Lake	Winnebago	1	161	NR	31.6			31.6	224	100				P	ALT
6/1/01	UMV	Hutchinson	McLeod		115	NR			7.0	7.0	200	100				A	GRE
6/1/01	UMV	Champlin	Champlin Tap		115	NR	0.7			0.7	318	100				P	NSP
6/1/01	UMV	Gleason Lake	Gleason Lake Tap		115	NR	0.0				267	100				P	NSP
6/1/01	UMV	Goose Lake	Lexington		115	NR	9.2			9.2	318	100				P	NSP
6/1/01	UMV	Terminal	Rose Place		115	NR	2.9			2.9	318	100				P	NSP
10/1/01	UMV	Red Rock	(Stockyards)	2	115	3	0.5			0.5	318	100				P	NSP
10/1/01	UMV	(Stockyards)	Rogers Lake	2	115	3		5.8		5.8	318	100				P	NSP
5/1/02	UMV	Westgate	Glen Lake		115	2		3.6		3.6	318	100				P	NSP
5/1/02	UMV	Glen Lake	Gleason Lake		115	2		6.6		6.6	318	100				P	NSP
5/1/02	UMV	Willow Creek	Bamber Valley	1	161	3	2.7			2.7	202				100	A	RPU

5/1/02	UMV	Bamber Valley	Cascade Creek	1	161	3		4.3		4.3	202				100	A	RPU
5/1/02	UMV	Wilson	Bloomington	1	115	NR		2.2		2.2	192	100				A	NSP
5/1/02	UMV	Wilson	Bloomington	2	115	NR		2.2		2.2	192	100				A	NSP
6/1/02	UMV	Long Lake	Baytown		115	NR	6.9			6.9	318	100				P	NSP
6/1/02	UMV	Vermillion River	Empire		115	NR			6.0	6.0	200	100				P	GRE
6/1/02	UMV	Alma	Wabaco		161	NR	20.0			20.0	314			100		P	NSP
6/1/02	UMV	Silver Lk.	Rochester		161	NR	10.0			10.0	268			100		P	NSP
5/1/03	UMV	Arrowhead	Tripoli	1	345	5			165.0	165.0	900	100				P	MP
5/1/03	UMV	Chisago	Lawrence Creek		115	6			15.0	15.0	797	100				P	NSP
5/1/03	UMV	Lawrence Creek	Apple River		115	NR			23.0	23.0	797	100				P	NSP
5/1/03	UMV	Arden Hills	Lawrence Creek	1	115	NR		35.6		35.6	310	100				P	NSP
5/1/03	UMV	Parkers Lake	Plymouth	1	115	NR			4.3	4.3	300	100				A	GRE
5/1/03	UMV	Plymouth	Elm Creek	1	115	NR	3.5	6.0	2.5	12.0	300	100				A	GRE
5/1/03	UMV	Willmar	Paynesville	1	230	NR		27.0		27.0	600	82		9	9	P	NSP
6/1/03	UMV	Aldrich	Garfield		115	NR			2.0	2.0	70	100				P	NSP
6/1/03	UMV	Tanners Lake	Woodbury		115	NR	3.5			3.5	318	100				P	NSP
6/1/03	UMV	Rochester	Wabaco		161	NR	13.0			13.0	314	100				P	NSP
10/1/03	UMV	Big Swan	Hutchinson		115	NR			13.0	13.0	200	100				P	GRE
5/1/04	UMV	Bloomington	Airport	1	115	NR		2.8		2.8	318	100				A	NSP
5/1/04	UMV	Bloomington	Rogers Lake	1	115	NR		3.4		3.4	318	100				A	NSP
5/1/04	UMV	Airport	Rogers Lake	1	115	NR		3.4		3.4	318	100				A	NSP
5/1/04	UMV	Air Lake	Vermillion River		115	4			4.2	4.2	200	100				P	GRE
6/1/04	UMV	Terminal	Fairview		115	NR			2.9	2.9	318	100				P	NSP
6/1/04	UMV	Fairview	Western		115	NR			2.9	2.9	318	100				P	NSP
6/1/04	UMV	Aldrich	St. Louis Park		115	NR	5.4			5.4	318	100				P	NSP
6/1/05	UMV	Prairie Island	Alma		161	NR			54.0	54.0	445	100				P	NSP
5/1/06	UMV	Crooked Lake	Champlin Tap		115	NR	3.1			3.1	318	100				P	NSP
6/1/06	UMV	Elm Creek Xfmr		2	345-115	NR					448	100				P	NSP
6/1/07	UMV	Elm Creek	Crystal		115	NR			6.5	6.5	318	100				P	NSP
6/1/07	UMV	Crystal	Indiana		115	NR			6.5	6.5	318	100				P	NSP
6/1/07	UMV	Wilson	Nicollet		115	NR			2.5	2.5	70	100				P	NSP
6/1/07	UMV	Nicollett	Garfield (normal open)		115	NR			2.5	2.5	70	100				P	NSP
6/1/07	UMV	Panther	Franklin		115	NR			20.6	20.6	200	100				P	NSP
5/1/08	UMV	Loon Tap	Wilmarth		161	1		30.0		30.0	200	100				P	NSP
6/1/08	UMV	Inver Hills	Koch	2	115	NR			1.8	1.8	318	100				P	NSP
6/1/09	UMV	Eden Prairie	Edina		115	NR	3.4			3.4	318	100				P	NSP
6/1/09	UMV	Eden Prairie	Wilson		115	NR			8.0	8.0	318	100				P	NSP
6/1/10	UMV	Parkers Lake	Gleason Lk		115	NR	2.5			2.5	267	100				P	NSP

CHAPTER 3: ASSESSMENT OF EMF HEALTH EFFECTS RESEARCH

The Minnesota Department of Health (MDH) tracks EMF health effects research on a regular and ongoing basis to monitor for any new developments in EMF science and policy. This effort includes reviewing the latest research published in scientific journals; participating in conferences related to EMF, exposure assessment, and risk assessment; and consulting with leading EMF scientists affiliated with federal and international health agencies.

Staff of the Minnesota Department of Health conducted an evaluation of EMF health effects research. MDH's evaluation covered three areas: The historical body of published research on the topic; conclusions drawn by various scientific review committees based on review of the historical research; and more recent scientific studies published since the review committees developed their conclusions. Each of these is discussed below. MDH staff also consulted with leading EMF researchers at the National Institute of Environmental Health Sciences (NIEHS) EMF Research and Public Information Dissemination (RAPID) Program, the U.S. Environmental Protection Agency, and the National Toxicology Program to complete this evaluation. For additional information about EMF health effects research, refer to the web sites at the end of this chapter and references listed at the end of this report.

Overview of Historical EMF Health Effects Research

It is beyond the scope of this evaluation to conduct a historical review of all EMF research. Therefore, an overview is provided, primarily on the health effects of magnetic fields, to provide context for the discussion of review committee conclusions and the most recent research.

Epidemiological Studies

Research on the health effects of EMF began in the late 1960's and was originally focused on electric fields. In 1979, an epidemiological study reported a statistical association between surrogate indicators of residential magnetic field exposure (e.g., wire coding, the practice of estimating someone's exposure to magnetic fields based on the size of power line, type of line, and distance between a power line and someone's home) and two- to three-fold increases in leukemia risk among U.S. children (Wertheimer et al., 1979). A second study found similar results (Savitz et al., 1988). This early research brought the issue of magnetic field-related health risks to the attention of scientists and the public. More recent studies have used direct measurements (e.g., personal monitors, which participants wear all day to take regular measurements of the magnetic fields to which the person is exposed) to estimate magnetic field exposures. These studies show mixed results – i.e., some have reported no statistically significant association (Linet et al., 1997; Dockerty et al., 1998; McBride et al., 1999) and others have reported a weak association (Green et al., 1999; Schuz et al., 2001).

The inconsistencies in the epidemiological research have raised questions and concerns about whether there is a true "cause and effect" relationship between magnetic fields and leukemia or any other adverse health effects. Scientists generally have agreed that the epidemiological studies, by themselves, cannot establish a cause and effect relationship, and that additional evidence (e.g., laboratory studies) is needed to determine if there is a true relationship between magnetic fields and adverse effects.

Laboratory Studies

In recent years there have been several laboratory studies in animals conducted under controlled experimental conditions (NIEHS, 1999; NTP, 1999; Takebe et al., 2001). These studies have failed to provide support for a relationship between magnetic fields and adverse human health effects, even at high exposure levels. In addition, studies of isolated cells have failed to establish an understood biological mechanism of action for how magnetic fields may cause cancer (NIEHS, 1999; Takebe et al., 2001). These factors have raised doubt in the scientific community about what relationship, if any, exists between magnetic field exposure and childhood leukemia or any other adverse health effect.

Discussion

Many researchers have determined that important elements to confirm causality are currently lacking for EMF and human disease, including strength of association, consistency and specificity of observations, appropriate temporal relationship, dose response relationship, biological plausibility, and experimental verification. Researchers also have widely acknowledged the limitations of many magnetic field epidemiological studies, including the use of surrogate indicators (e.g., wiring code configurations) to estimate magnetic field levels; the small number of cases or subjects, particularly in high exposure categories; and the potential for bias due to factors related to selection, misclassification, recall, and confounding.

While some researchers disagree about the possibility of EMF causing adverse health effects, it is known that EMF associated with electrical power is extremely low frequency (60 hertz) relative to other types of fields commonly found in our environment (e.g., AM/FM radio, television, and cellular phone frequencies). Very high frequency fields, such as gamma rays, can break molecular bonds. Human exposure to gamma rays can cause direct DNA damage. Lower frequency fields such as microwaves do not cause direct DNA damage, but can have significant heating effects. Electrical power EMFs are not capable of causing direct DNA damage and are generally considered to have no thermal effects. Researchers continue to investigate possible mechanisms for how low frequency EMF may cause indirect biological effects. However, to date, there is limited evidence to conclude that indirect biological effects cause adverse health effects.

Conclusions of Scientific Review Committees

Several EMF scientific review committees have been convened by the U.S. Congress and by federal and international health agencies (NRC, 1996; NIEHS, 1999; NRPB, 2001;

IARC, 2001) to review and evaluate the extensive historical body of scientific literature on EMF health effects and to draw conclusions. The committees included leading EMF researchers and experts in multiple disciplines in the U.S. and abroad. The most prominent of the review committees and their conclusions are described and summarized below, starting with the earliest reviews and ending with the most recent.

American Physical Society (1995)

In 1995 the American Physical Society (APS), which is a national professional organization of U.S. physical scientists, concluded the following:

> Physicists are frequently asked to comment on the potential dangers of cancer from electromagnetic fields that emanate from common power lines and electrical appliances. While recognizing that the connection between power line fields and cancer is an area of continuing study by research workers in many disciplines in the United States and abroad, we believe that it is possible to make several observations based on the scientific evidence at this time. We also believe that, in the interest of making the best use of the finite resources available for environmental research and mitigation, it is important for professional organizations to comment on this issue.
>
> The scientific literature and the reports of reviews by other panels show no consistent, significant link between cancer and power line fields. This literature includes epidemiological studies, research on biological systems, and analyses of theoretical interaction mechanisms. No plausible biophysical mechanisms for the systematic initiation or promotion of cancer by these power line fields have been identified. Furthermore, the preponderance of the epidemiological and biophysical/biological research findings have failed to substantiate those studies that have reported specific adverse health effects from exposure to such fields. While it is impossible to prove that no deleterious health effects occur from exposure to any environmental factor, it is necessary to demonstrate a consistent, significant, and causal relationship before one can conclude that such effects do occur. From this standpoint, the conjectures relating cancer to power line fields have not been scientifically substantiated.
>
> These unsubstantiated claims, however, have generated fears of power lines in some communities, leading to expensive mitigation efforts and, in some cases, to lengthy and divisive court proceedings. The costs of mitigation and litigation relating to the power line/cancer connection have risen into the billions of dollars and threaten to go much higher. The diversion of these resources to eliminate a threat which has no persuasive scientific basis is disturbing to us. More serious environmental problems are neglected for lack of funding and public attention, and the burden of cost placed on the American public is incommensurate with risk, if any.

National Research Council (1997)

In 1991 the National Research Council convened an expert committee with experience in several scientific disciplines. The committee reviewed and evaluated the existing scientific information on the possible effects of exposure to electric and magnetic fields on the incidence of cancer, on reproduction and developmental abnormalities, and on neurobiological response, as reflected in learning and behavior. The committee summarized its conclusions in its 1997 report, "Possible Health Effects of Exposure to Residential Electric and Magnetic Fields:"

> Based on a comprehensive evaluation of published studies relating to the effects of power frequency electric and magnetic fields on cells, tissues, and organisms (including humans), the conclusion of the committee is that the current body of evidence does not show that exposure to these fields presents a human-health hazard. Specifically, no conclusive and consistent evidence shows that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive developmental effects.
>
> The committee reviewed residential exposure levels to electric and magnetic fields, evaluated the available epidemiologic studies, and examined laboratory investigations that used cells, isolated tissues, and animals. At exposure levels well above those normally encountered in residences, electric and magnetic fields can produce biologic effects (promotion of bone healing is an example), but these effects do not provide a consistent picture of a relationship between the biological effects of these fields and health hazards. An association between residential wiring configurations (called wire codes) and childhood leukemia persists in multiple studies, although the causative factor responsible for that statistical association has not been identified. No evidence links contemporary measurements of magnetic-field levels to childhood leukemia.

National Institute of Environmental Health Sciences (1999)

In 1992 the U.S. Congress instructed the National Institute of Environmental Health Sciences (NIEHS) to direct a program of research and analysis to evaluate the potential for health risks from EMF exposure. In 1999 the NIEHS released its report, "Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields." It is based on both review of the historical literature and results of NIEHS-sponsored studies. The NIEHS concluded:

> The scientific evidence suggesting that ELF-EMF [Extremely Low Frequency Electric and Magnetic Fields] exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults. While the support from individual studies is weak, the

epidemiological studies demonstrate, for some methods of measuring exposure, a fairly consistent pattern of small increased risk with increasing exposure that is somewhat weaker for chronic lymphocytic leukemia than for childhood leukemia. In contrast, the mechanistic studies and the animal toxicology literature fail to demonstrate any consistent pattern across studies although sporadic findings of biological effects (including increased cancers in animals) have been reported. No indication of increased leukemias in experimental animals has been observed.

The lack of connection between the human data and the experimental data (animal and mechanistic) severely complicates the interpretation of these results. The human data are in the "right" species, are tied to "real life" exposures and show some consistency that is difficult to ignore. This assessment is tempered by the observation that given the weak magnitude of these increased risks, some other factor or common source of error could explain these findings. However, no consistent explanation other than exposure to ELF-EMF has been identified.

Epidemiological studies have serious limitation in their ability to demonstrate a cause and effect relationship whereas laboratory studies, by design, can clearly show that cause and effect are possible. Virtually all of the laboratory evidence in animals and humans and most of the mechanistic work done in cells fail to support a causal relationship between exposure to ELF-EMF at environmental levels and changes in biological function or disease status. The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but cannot completely discount the epidemiological findings.

The NIEHS concludes that ELF-EMF exposure cannot be recognized at this time as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard. In our opinion, this finding is insufficient to warrant aggressive regulatory concern. However, because virtually everyone in the United States uses electricity and therefore is routinely exposed to ELF-EMF, passive regulatory action is warranted such as continued emphasis on educating both the public and the regulated community on means aimed at reducing exposures. The NIEHS does not believe that other cancers or non-cancer health outcomes provide sufficient evidence of risk to currently warrant concern.

Institute of Electrical and Electronics Engineers, Committee on Man and Radiation (2000)

In 1999 the Institute of Electrical and Electronics Engineers, Engineering in Medicine and Biology Society convened the Committee on Man and Radiation (COMAR). This committee included experts on health and safety issues related to electromagnetic fields, from power line through microwave frequency ranges. The committee concluded in their technical information statement:

In recent years concerns have been raised about the biological effects of exposure to electric and magnetic fields at extremely low frequencies (ELF), particularly those associated with the distribution and utilization of electric power. In 1989, the Institute of Electrical and Electronics Engineers (IEEE) issued an "Entity Position Statement" which stated that "there is not enough relevant scientific data to establish whether common exposure to power-frequency fields should be considered a health hazard" and that "there is general agreement that more research is needed to define safe limits of human exposure to power-frequency fields." After examination of relevant research reports published during the last ten years, COMAR concludes that it is highly unlikely that health problems can be associated with average 24-hour field exposure to power frequency magnetic fields of less than 1 microT (10 mG). Good laboratory evidence shows that magnetic fields 100 to 10,000 times higher than this level, either ELF sinusoidal or pulsed, can induce a variety of biological effects, including beneficial health effects such as bone or tissue healing. Many of the reports of effects of weaker fields should be considered preliminary, as some observations have not been reproduced in different laboratories, while others, observed in cells, have not been clearly connected to effects in intact animals. Also, the means of interaction of low-level ELF fields with cells, tissues or laboratory animals is not fully understood; therefore the health impacts of such weak fields on intact animals and humans, if any, cannot be predicted or explained. Further research is needed to confirm or negate reports of effects of weak fields, and to determine mechanisms and relevance of these effects to actual health hazards. Continued study in this complicated area will enhance our understanding of biological systems, as well as help identify levels and types of ELF exposure that may be deleterious to human health.

National Radiological Protection Board (Advisory Group on Non-Ionizing Radiation) (2001)

In March 2001, the British National Radiological Protection Board, Advisory Group on Non-Ionizing Radiation, conducted an extensive review of the EMF research. The Advisory Group concluded:

> Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK [United Kingdom]. In the absence of clear evidence of a carcinogenic effect in adults, or of a plausible explanation from experiments on animals or isolated cells, the epidemiological evidence is currently not strong enough to justify a firm conclusion that such fields cause leukaemia in children. Unless, however, further research indicates that the finding is due to chance or some currently unrecognized artifact, the possibility remains that intense and

prolonged exposures to magnetic fields can increase the risk of leukemia in children.

International Agency for Research on Cancer (2001)

In June 2001, the International Agency for Research on Cancer (IARC) convened a meeting of 21 scientific experts from 10 countries to evaluate possible carcinogenic hazards to humans from exposures to EMF. They concluded:

> Since the first report suggesting an association between residential electric and magnetic fields and childhood cancer, notably leukemia, was published in 1979, dozens of studies have examined this association. Overall, for the vast majority of children who are exposed to residential ELF [extremely low frequency] magnetic fields less than 0.4 microtesla [4 milligauss], there is little evidence of any increased risk for leukemia. There is no evidence that electric fields are associated with childhood leukemia, and there is no consistent relationship between childhood brain tumors and residential ELF electric and magnetic fields. However, pooled analyses of data from a number of well conducted studies show a fairly consistent statistical association between childhood leukemia and power-frequency residential magnetic field strengths above 0.4 microtesla, with an approximately two-fold increase in risk. This is unlikely to be due to chance, but may be affected by selection bias. Therefore, this association between childhood leukemia and high residential magnetic field strengths was judged *limited evidence* for excess cancer risk in exposed humans. [Emphasis in original.]
>
> There is no consistent evidence that residential or occupational exposures of adults are related to excess risks of cancer at any site [in the body], although in one Swedish study combined residential and occupational exposures were associated with a significantly increased risk for leukemia subtypes except chronic lymphocytic leukemia. Evidence for excess cancer risks of all other kinds, in children and in adults, as a result of exposure to ELF electric and magnetic fields was considered *inadequate*. [Emphasis in original.]
>
> Numerous studies to investigate carcinogenicity of magnetic fields have been conducted in experimental animals. These have included long-term bioassays of exposures to magnetic fields alone, and exposures of rats and mice to magnetic fields in combination with known carcinogens. Bioassays of magnetic fields alone generally were negative, although one study that was conducted in both mice and rats of both sexes showed non-exposure related increases in thyroid C-cell tumors in male rats only. Multistage carcinogenesis studies showed no consistent enhancement of chemically initiated mammary tumors in rats or of skin tumors in mice. Magnetic fields had no effects on the incidence of chemically initiated liver tumors in rats or of leukemia/lymphoma in mice or rats. Overall, evidence of carcinogenicity of ELF magnetic fields in experimental animals was judged inadequate. No data on carcinogenicity to animals of static magnetic fields, or of static or ELF electric fields, were available to the working group.

> Although many hypotheses have been put forward to explain possible carcinogenic effects of ELF electric or magnetic fields, no scientific explanation for carcinogenicity of these fields has been established.
>
> Overall, extremely low frequency magnetic fields were evaluated as possibly carcinogenic to humans (Group 2B), based on the statistical association of higher level residential ELF magnetic fields and increased risks for childhood leukemia. Static magnetic fields and static and extremely low frequency electric fields could not be classified as to carcinogenicity to humans (Group 3).

Note that the term "possibly carcinogenic to humans" is a classification used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals. This classification is the weakest of three categories used by IARC to classify potential carcinogens.

Japan EMF Research Program (2001)

In the 1990's Japan conducted an EMF research program comparable in scope and magnitude to the NIEHS EMF RAPID program. The focus of this program was laboratory testing for possible cancer effects such as changes in gene expression or increased risks for tumors. In 2001 the results of this research program were published in the book, *Biological and Health Effects from Exposure to Power-Line Frequency Electromagnetic Fields: Confirmation of Absence of Any Effects at Environmental Field Strengths* (Takebe et al., 2001). The researchers concluded:

> By the middle of 1999, as mentioned in the EMF RAPID report, there was little evidence for any adverse health effects from EMF exposure. About half of the epidemiological studies have suggested possible health effects, but almost all of the experimental studies with animals have been negative. Thus it appears there is little possibility of finding new adverse health effects from EMF in the future. Very high intensity EMF can have certain biological effects, but they occur only with EMF more than 10,000 times higher than those found in real-world environments. Furthermore, even with the biological indicator which gave the positive results with 400 mT [4,000,000 milligauss] for 1 hour, elongated exposure with 5 mT [50,000 milligauss] for 6 weeks did not yield any effect. We conclude that adverse human health effects as a result of environmental power-frequency EMF either do not occur or that they are undetectable because they occur so rarely they cannot be separated by other processes.

Health Council of the Netherlands (2001)

In May 2001 the Health Council of the Netherlands, Electromagnetic Fields Committee, completed an annual review of the research on possible health effects of exposure to electromagnetic fields (HCN, 2001). This review included several recently published EMF studies, including two meta-analyses (Ahlbom et al., 2000 and Greenland et al., 2000).

The committee concludes that these recent meta-analyses show a consistent association between relatively high measured or calculated magnetic field strengths and an increased risk of childhood leukemia. However, from an epidemiological point of view, an association with a relative risk of smaller than 2 is to be considered weak. Furthermore, the committee does not think that either 0.3 uT [3 mG] or 0.4 uT [4 mG] should be regarded as a definite threshold field strength, above which the risk is suddenly increased. This view is based upon the belief that it is not appropriate to consider measured and calculated fields strengths in the same light. Where researchers have obtained field strength data by measurement, the contributions made by all sources inside and outside the home are taken into account, with the result that the study data is reasonably consistent with overall exposure. Where calculated data is used, however, only the strength of the field generated by a single external source (typically a high voltage power line) is considered. In studies using calculated field strength data actual exposure is therefore underestimated. Furthermore, it is apparent from research carried out in the UK and elsewhere that in a large proportion of homes where relatively high field strengths occur, the fields are not primarily attributable to external sources such as high-voltage power lines (Day 99).

The committee would emphasise that there is no known mechanism that could account for the association referred to above. Because the association is only weak and with out a reasonable biological explanation, it is not unlikely that it could also be explained by chance or by an artefact. The committee therefore sees no reason to modify its earlier conclusion that the association is not likely to be indicative of a causal relationship.

It therefore remains the committee's belief that it is not likely that children (or adults) living near to high-voltage power lines are at risk through exposure to electromagnetic fields generated by those lines. This view is consistent with that of the Advisory Group on Non-ionising Radiation – a committee of the UK's National Radiological Protection Board, chaired by Sir Richard Doll – as published in early March 2001.

MDH Review of Recent Scientific Literature

As part of its ongoing evaluation of EMF research, MDH completed a literature review of research published since the 1999 NIEHS scientific review committee report. This review included over 50 studies published in scientific journals and/or presented at the June 2001 International Bioelectromagnetics Society Meeting. It is beyond the scope of this assessment for MDH to comment on all reviewed EMF studies. The comments below focus on selected recent EMF studies that are most prominent. It is important to recognize that these studies are a small fraction of the total EMF research published to date and of EMF research reviewed by the scientific committees convened by federal and international health agencies to date.

Canadian Studies

Two Canadian studies published in 1999 demonstrate the inconsistencies observed in the EMF epidemiological research (Green et al., 1999; McBride et al., 1999). Green et al., evaluated childhood leukemia and EMF exposure in Ontario, Canada. This study showed a weak association between contemporary measured fields outside residences and childhood leukemia. This study also found a positive association when comparing fields measured with personal monitors and childhood leukemia. However, there was no association with childhood leukemia for contemporary fields inside residences. In addition, when using wire codes (as with Wertheimer and Leeper, and Savitz) there was no association with cancer. At the same time in 1999, McBride conducted a much larger study in Ontario. This study found no association with childhood leukemia for personal monitors, contemporary measured fields inside residences, historic magnetic fields or wire codes.

National Toxicology Program Studies

In 1999 the National Toxicology Program conducted a two-year whole body exposure animal study to investigate possible effects from 50-60 hertz magnetic fields (NTP, 1999). The highest field intensity (10,000 milligauss) was considered approximately 5,000 fold greater than what was considered high intensity for homes in epidemiological studies in humans. Results showed no effects on survival and body weights and no increased incidences of neoplasms at sites for which epidemiological studies have suggested an association with magnetic fields.

British Journal of Cancer

In September 2000 researchers published a pooled analysis of EMF studies in the British Journal of Cancer (Ahlbom et al., 2000). The analysis included data from nine studies that had been conducted in Europe, Canada, New Zealand, and the U.S., including data from the 1999 McBride et al. study. Pooling data in this fashion provides a greater number of subjects and yields greater statistical power when conducting analyses.

The study reported a weak association between exposure to power frequency magnetic fields greater than 4 milligauss and childhood leukemia. Specifically, the study found that children with residential exposures to magnetic fields greater than 4 milligauss had a statistically significant relative risk estimate of two for childhood leukemia. The authors attempted to adjust for several possible confounding factors, including socioeconomic status, type of dwelling, urban or rural setting, and several others. Adjustment for these factors made little difference in the relative risk values. If there are confounding factors that would influence the result, they have yet to be identified. The authors pointed out that selection bias probably accounted for some of the elevated risk estimates, and concluded that future research should address selection bias, confounding factors, and the fact that their results were based on a very small number (0.8 percent) of leukemia cases in the high exposure groups. A second analysis of some of the same pooled studies reported similar results and limitations in a separate publication (Greenland et al., 2000).

The two analyses of pooled data include many of the same studies and their conclusions are similar – there appears to be a statistically significant increased risk of childhood leukemia at the highest exposure categories. However, authors in both studies acknowledged that these results were based on small numbers of subjects in the highest exposure category, and both recommend that future EMF studies include more subjects at these levels, since there is little or no evidence of an association at levels to which most people are exposed. MDH staff conducted an evaluation of these studies and concluded that these studies represent no new data, but a recombining and re-analysis of data from selected studies that have been previously published.

California EMF Program – Risk Evaluation Report

In 2001 the California Department of Health Services (CDHS), California EMF Program, released a *draft* EMF Risk Evaluation Report (CDHS 2001). This report was based on an evaluation conducted by three CDHS reviewers who examined possible associations between magnetic fields and 13 health conditions. The reviewers reported their opinions regarding the degree of confidence that the statistical associations between magnetic fields and the various health conditions might be causal. (For their conclusions, see the CDHS report: http://www.dhs.ca.gov/ps/deodc/ehib/emf/RiskEvaluation/riskeval.html)

Following the release of the draft report, CDHS solicited public comments and convened meetings with stakeholders and a scientific review panel. Comments were received from concerned citizens, electrical utilities, advocacy organizations, and several U.S. and international scientists (CDHS 2002).

While some scientists praised the California reviewers for using a novel approach, other researchers raised substantial concerns regarding the report's conclusions, and more fundamentally, the process used to conduct the evaluation (CDHS 2002). Based on these comments and a review of the report, MDH concluded that there is no scientific consensus at this time on the report's conclusions, including the degrees of confidence that the reviewers assigned regarding a causal relationship between EMF and adverse health effects.

MDH also concluded that there are some significant limitations in California's EMF evaluation. For example, the California reviewers failed to adequately address the lack of supporting data from animal laboratory studies and the lack of a plausible biological mechanism of how EMF may cause harm in their evaluation. Furthermore, they failed to adequately address several well-recognized limitations (e.g., selection bias, confounding, exposure misclassification) in EMF epidemiological research.

In contrast with the California evaluation, recent scientific EMF panels (i.e., International Agency for Research on Cancer, National Radiological Protection Board (UK), National Institute of Environmental Health Sciences, and Netherlands Health Council) have all considered the lack of supporting data in animals and cellular studies to be an important factor in evaluating a possible causal relationship between EMF and adverse health effects. These panels also have recognized the importance of elucidating a plausible biological mechanism to determine causality, particularly in light of the limitations of EMF epidemiological research.

MDH also has concluded that there are several important distinctions between California's evaluation process and the processes used by other scientific EMF review panels. The California evaluation was conducted by three reviewers, all from the same agency, and all with primary expertise in epidemiology. Other recent scientific EMF panels (listed above) have taken advantage of a broader review panel selected from leading U.S. and international health agencies and research organizations, representing expertise in a wide variety of disciplines (e.g., epidemiology, cellular biology, physics, statistics).

At this time it is not clear how California decision-makers will use the CDHS EMF Risk Evaluation report. A revised report is expected to be completed in 2002. MDH will continue to track EMF developments in California, as well as other states. (For more information about EMF activities in California and other states, see the Appendix).

Future Research

EMF research is continuing in the U.S. and abroad, as new methods for studies are developed to improve exposure assessment, to control for confounding and other types of bias, and to investigate possible biological mechanisms. NIEHS supports some limited extramural EMF research; however, their 5-year EMF RAPID Program has concluded, and there do not appear to be any plans to expand EMF (60 hertz) federal research at this time (NIEHS, 2001). Japan has also concluded their EMF research program; however there are some isolated studies that are ongoing.

In 2003 the World Health Organization (WHO) International EMF Project is expected to complete an assessment of non-cancer EMF health risks (WHO, 2001). This project is working in collaboration with international agencies and organizations to pool resources and knowledge about EMF; to identify gaps in knowledge; recommend focused research programs; conduct updated critical reviews of the scientific literature; and develop materials for risk communication. Note that WHO defines EMF broadly to include static, extremely low, intermediate, and radio frequency fields (up to 300 gigahertz). (For more information about the World Health EMF Research Project, see the web site: http://www.who.int/peh-emf).

MDH will continue to monitor important EMF health effects research. Future research efforts should focus on identifying possible biological mechanisms and identifying what aspect of a field may be hazardous. Without this information, scientists will be unable to provide policy guidance about what aspect of a field (e.g., frequency, intensity, polarization, harmonization), if any, would be appropriate to mitigate.

For More Information

For more information about EMF health risks, refer to the web sites listed below:

Minnesota Department of Health, Environmental Health Division
http://www.health.state.mn.us/divs/eh/radiation/emf/index.html

National Institute of Environmental Health Sciences, EMF RAPID Program
http://www.niehs.nih.gov/emfrapid/home.htm

World Health Organization, International EMF Research Project
http://www.who.int/peh-emf/

Medical College of Wisconsin, Electromagnetic Fields and Human Health
http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ/toc.html

Bioelectromagnetics Journal, EMF Research Abstracts (see link at bottom of web page for BEMS 23rd annual meeting, St Paul, Minnesota)
http://www.bioelectromagnetics.org/pubs.html

Wisconsin Public Service Commission, EMF Background (adobe acrobat)
http://psc.wi.gov/consumer/electric/document/brochure/6002b.pdf

Health Council of the Netherlands
http://www.gr.nl/engels/welcome/index.htm

California Department of Health Services, EMF Program
http://www.dhs.ca.gov/ps/deodc/ehib/emf/

Virginia Department of Health, Monitoring of Ongoing Research on the Health Effects of High Voltage Transmission Lines, 2000 (Final Report)
http://www.vdh.state.va.us/hhcontrol/highfinal.pdf

CHAPTER 4: REGULATORY APPROACHES TO ADDRESS EMF ISSUES

The questions surrounding EMF present a common but difficult challenge to government regulators: Should government officials limit exposure to an agent for which there is only limited evidence of public harm? And if so, what guidelines should be used to determine the extent and type of government regulation? This chapter outlines several possible frameworks for making regulatory decisions regarding the potential for harm from EMF and presents the advantages and disadvantages of applying them to EMF exposure.

The Range of Regulatory Principles

This section outlines the range of regulatory principles that could be used as a basis for regulating EMF exposure. It refers to a "range" of principles because there is a spectrum of possible frameworks for making public policy decisions. Especially in the face of uncertainty (such as the health effects of EMF), the underlying principle on which a decision is based will have a great effect on the final decision.

The following principles are listed from those that would require the least government oversight to those that would require the most.

Virtual Certainty

Virtual certainty is based primarily on the idea of limited government. Under this viewpoint government should not regulate activities in the private sector unless the vast majority of scientists are virtually certain that there is a problem. This framework would tend to require a high degree of confidence on the part of most scientists that the harm occurs and that exposure is likely to result in harm. A lack of confidence by most scientists would indicate that no action should be taken by regulators.

Advantages:	Does not expend government resources on issues that may have no real environmental impact. Encourages technological innovation by allowing all but clearly dangerous products to be used and marketed.
Disadvantages:	Has the potential to cause great environmental harm before "virtual certainty" of harm is attained (e.g., DDT, PCBs). The correction of the harm may cost more than prior prevention. The burden of proof is on those being harmed.

Buyer Beware

This is a common concept (also known as *caveat emptor*) most often applied to the market for commercial goods. This principle places much of the burden for what is sold on consumers themselves, assuming that producers will not supply something for which there is no demand. In the context of electrical power, this principle assumes that consumers would choose to use less electricity, or would pay more to have power lines buried or moved, if they felt these actions were more advantageous than exposure to EMF. Government regulation under this principle is primarily used to ensure that the markets work correctly. This is accomplished by ensuring that buyers have all information necessary to make an informed decision and by equalizing the market power of the participants.

Advantages:	Maximizes individual rights and choices. Consistent with the principles of capitalism. Does not impose government solutions on producers or consumers.
Disadvantages:	Expects citizens to remain informed on a wide variety of possible harms, which is not realistic. Assumes that consumers can make choices that avoid the harm, which is not always true. Does not allocate costs properly when the person experiencing the harm (e.g., harm from production or distribution practices) is not the same as the person buying the product.

Utilitarian Perspective

This perspective emphasizes results and seeks to promote choices that provide the most good for the most people at the least cost. This principle is closely linked to cost/benefit analysis, since the most obvious way to demonstrate utility is to quantify variables into monetary units and tally the results. This approach works best when the variables can be readily quantified and the distribution of costs and benefits is spread fairly evenly throughout a population. This approach encounters increasing difficulty when there are valuation problems (e.g., valuing death or disability), uncertainty of risk, and uneven distribution of costs and benefits throughout society.

Advantages:	Attempts to compare true benefits to true costs. Attempts to maximize the collective good. Recognizes that government resources are limited and money should be spent in ways that can make the biggest impact on public welfare.
Disadvantages:	Often creates controversy when trying to place monetary value on human life or quality of life. Must rely on assumptions and estimates when levels of risk are unknown. This can greatly increase the range of possible values and make application of cost/benefit principles less useful. Cannot adequately address issues of justice when certain segments of the population are asked to bear a harm (or potential harm) in order to achieve an overall public good.

Precautionary Principle

The precautionary principle has been around in the form of maxims for a long time. "Better safe than sorry" and "Look before you leap" could be considered succinct versions of the precautionary principle. The application of this principle to environmental issues has happened more recently, primarily in European law and International law. Some version of the principle has been included in several conventions and treaties, including the 1985 Vienna Convention of Ozone Depleting Substances and the Rio Declaration on Environment and Development.

Because there are a variety of governments and citizens discussing this principle and how it should be applied, there are variations in how the principle is stated. One of the recent and often-quoted versions of the precautionary principle was developed during a 1998 conference held at the Wingspread Conference Center in Racine, Wisconsin:

> When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically. In this context the proponent of an activity, rather than the public, should bear the burden of proof. The process of applying the Precautionary Principle must be open, informed, and democratic, and must include potentially affected parties. It must also involve an examination of the full range of alternatives, including no action.

While this principle has received less attention in the United States than in Europe, U.S. officials are discussing it. In an October 2000 speech at the National Academy of Sciences in Washington, D.C., then-governor of New Jersey (now EPA Administrator) Christine Todd Whitman stated that:

> Policymakers need to take a precautionary approach to environmental protection.... We must acknowledge that uncertainty is inherent in managing natural resources, recognize it is usually easier to prevent environmental damage than to repair it later, and shift the burden of proof away from those advocating protection toward those proposing an action that may be harmful.

A similar concept, commonly called prudent avoidance, has often been used in the context of EMF exposure. This concept is very similar to the precautionary principle in suggesting that one should avoid any activity or exposure about which there are questions of safety or health, at least to the extent that the activity can be avoided easily or cheaply. However, prudent avoidance generally does not carry the same connotations of shifting the burden of proof to the proposer of the activity in question.

While there appears to be some agreement that the precautionary principle is needed, important questions remain as to how it will be applied to various health and environmental issues.

Advantages: Protects the public from harms that are suspected but not yet proven.

	Shifts the burden of proof to those who stand to benefit from the use of a new technology, chemical, or drug. Emphasizes the inclusion of all affected parties in deciding the extent of any regulation.
Disadvantages:	May stifle development of new technologies and products that are ultimately shown to be safe. Science cannot prove the null hypothesis - it could be a high burden to prove no harm, depending on how that condition is applied. More difficult to apply this principle to existing technologies that are common and on which people rely heavily, such as electricity.

Environmental justice

Other considerations may impact the regulatory approach taken, regardless of which perspective one applies. A prime example is the concept of environmental justice. In 1994, President Clinton issued Executive Order 12898 regarding federal actions to address environmental justice in minority and low-income populations. The order states that "each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations ...." While there is no similar directive at the state level, policy makers have expressed an interest in incorporating this concept into state-level decisions as well.

This principle relies on a democratic or egalitarian view of the world, recognizing that there are certain rights that all citizens should be able to enjoy. According to the U.S. Environmental Protection Agency, one of these rights is the right of "all people to live in clean, healthy, and sustainable communities."

As with the regulatory principles above, there are certain advantages and disadvantages in applying this concept:

Advantages:	Strives to provide all people with a basic level of environmental protection. Puts the resources of government to work for people who are the least likely to have resources to protect themselves from harm. Emphasizes the education and inclusion of affected communities in deciding the need for, and extent of, any regulation.
Disadvantages:	Not clear how to apply this principle when environmental harm is distributed throughout society rather than concentrated in minority or low-income communities.

How one defines "clean, healthy, and sustainable" is a matter of interpretation, and therefore does little to address certain core issues.

Does not answer the question of what to do in the face of harms that are possible but not yet proven.

In summary, decision-makers have several possible options in deciding whether or how much to regulate EMF. Each approach has advantages and disadvantages. At one extreme, regulators can require virtual certainty of harm before they address it. At the other extreme, proposers of a project would need to demonstrate its safety before regulators would allow them to proceed. Choosing an approach at any point along this continuum depends largely on how lawmakers and regulators view the role of government and how it should apply to a regulated good like electricity.

CHAPTER 5: EMF EXPOSURE MITIGATION OPTIONS

Electric and magnetic field exposures in individual residences can be attributed to fields from adjacent power lines, fields from electrical wiring in the home, fields from the operation of electrical appliances, or a combination of all three. In most cases the fields originating from within the house are not the subject of public regulation (with the possible exception of building code violations). Since this paper is focused on public policy decisions regarding EMF, most of this chapter will focus on mitigating fields from transmission and distribution lines. However, internal sources of EMF can contribute as much or more to EMF exposure than power lines.

Mitigation of EMF from Transmission Lines

Electric utilities have a variety of methods for reducing EMF exposures when they upgrade or install transmission and distribution lines. The main methods for mitigating EMF include increasing distance from the line, using phase cancellation, shielding, and limiting voltage and current flow levels.

Distance

The amount of EMF exposure is related to the distance from a power line source. The strength of both the electric and magnetic fields from traditional overhead transmission lines is inversely proportional to the square of the distance from the source. Therefore the level of exposure decreases rapidly with increasing distance from the source conductors. Utilities' primary methods of increasing distance include increasing the conductor height above ground, increasing the width of the right of way, or relocating the line to a route more distant from inhabited areas.

Phase cancellation

Phase cancellation can significantly reduce EMF from transmission lines. This can be accomplished by bringing the conductors closer together, vertical double circuiting, or placing independent wire conductors between the transmission line and an area of exposure. Phase cancellation is most effective when the three phases have the same current flow.

<u>Conductor separation</u>**.** A commonly used method to reduce EMF is to decrease the distance between the conductors (the three wires seen between the poles and towers). This reduces the magnetic fields created by each of the three conductors because the fields are out of phase with each other and thus cancel each other. However, bringing the conductors closer together requires the supporting structures to be closer together to prevent arcing and shorting out between conductors. This adds additional construction and material cost to the line.

There has been some research to develop an overhead 110-kV transmission line with insulated conductors. Instead of the conventional bare conductors, the transmission lines use those covered with a thin layer of plastic. As a result, they are able to touch each other in high winds without shorting. Consequently, phase conductors can be situated closer to each other, allowing transmission towers to be more compact. EMF from this configuration has been measured as much as one-third below those from existing horizontally configured lines. The main goal of the research was to find a solution for upgrading lines in densely populated regions; the reduction of EMF is an added bonus. Since this technology is still in the testing phase, its effectiveness and costs are not known.

Undergrounding. Undergrounding (burying) transmission lines always reduces the electric field and reduces the magnetic field if the conductors are placed in close proximity to each other (see conductor separation). The electric field is reduced by the electrical insulation around the conductor. The magnetic field is not reduced by the insulation, but the insulation allows the conductors to be placed close to each other, which significantly reduces the magnetic field through phase cancellation. This requires equal current flow in each phase.

If there is not balanced current flow, the magnetic field from underground lines increases. This can be significant even with minor imbalances in current flow, because the underground line is usually only three and a half to five feet underground. An overhead line usually has a minimum of twenty-five to thirty-five feet of clearance above ground and an average clearance between structures of thirty-five to fifty feet. While utility engineers prefer to have balanced current flow through the lines, it is not always possible to achieve this result. Generally, transmission lines are more likely to maintain balanced current flow than are distribution lines.

Undergrounding has not been used for transmission lines for several reasons. First, the cost is two to five times or more the cost of an overhead line, depending on location and circumstances. Second, such circuits are more difficult and costly to maintain and repair. Third, an underground line poses system operational limits because the insulation does not allow efficient cooling of the conductors and the high capacitance of the closely spaced conductors in the pipe can reduce its current-carrying capacity.

Vertical configuration. Lines with current-carrying conductors positioned vertically on power line structures produce lower magnetic fields than power lines with conductors positioned horizontally.

Vertical double circuiting. A common transmission line configuration is the vertical double-circuit, where a set of three conductors is attached, one above the other, to each side of the transmission tower. The three cables comprise the three phases of the power network, with each conductor carrying current. Electric utilities use the letters A, B and C to denote a three-phase circuit, with each letter representing one cable and its phase. At little extra cost, electromagnetic fields can be reduced by 50 percent or more by reversing the phase order of the other circuit (i.e., C-B-A). Partial cancellation of both magnetic and electric fields is thus achieved. The effectiveness of this arrangement is also dependent on the current flowing through each circuit.

Independent out-of-phase fields. Another less used approach is to generate out-of-phase fields from a separate conductor placed between the transmission line and the area where field reduction is desirable. Fields equal to and opposite in magnitude from those emitted by the power line would be generated to cancel the fields from the power line. This approach is not very practical except for specific locations.

Shielding

The electric field component of EMF is easily shielded by most structures. However, the magnetic fields are difficult to contain with shielding. Some materials exist that have magnetic shielding characteristics, but the expense of these items is such that the application is mostly limited to small projects and specific locations.

Reduction in voltage or current levels

Electric field levels are proportionate to the operating voltage of the power line. Downsizing the voltage class of the facility will reduce electric field levels. Reducing voltages is not a very practical alternative for limiting electric fields because the capacity of the line is also reduced and all the transformers connected to the line would have to be replaced.

Magnetic fields are proportionate to the level of amperage on a given conductor. The amperage will normally fluctuate according to system loading activity and any line will have a daily profile of loading levels, and a corresponding fluctuating magnetic field generation level. The maximum current flow is normally limited by the thermal limit of the conductor or some other system limitation such as the rating of a transformer or switch. Limiting the current to limit the maximum magnetic field would also limit the power carrying capacity of the line. Adding an additional parallel line would reduce the current on the existing line but would add additional right of way.

Deliberately reducing the voltage or the amperage of a transmission line below its designed capability results in a reduced return on investment and increases the need for additional lines. Underutilization of infrastructure can ultimately lead to higher utility rates for customers.

Conservation

Encouraging conservation is a non-regulatory way to reduce electrical demand, resulting in lower power flow levels and reduced EMF. Conservation may also delay or eliminate the need for additional power lines in certain areas.

Mitigation of EMF from Primary Distribution Lines

The principles for managing EMF for primary distribution lines are identical to that noted above for transmission lines, including increasing distance, phase cancellation, and undergrounding.

Primary distribution right-of-way is normally much narrower than transmission right-of-way, usually 10 feet wide compared to 50 or 100 feet for transmission right-of-way. Minimum clearances of distribution lines to other facilities are dictated by the National Electric Safety Code. These easements are normally located along streets or rear lot lines and alleys adjacent to the homes and businesses obtaining service. Because of the narrow right of way and the lower clearance, homes and businesses are closer to the distribution line and thus are likely to experience higher magnetic fields.

The size of the magnetic field from a distribution line depends on the amount of current flowing on that line, which again is dependent on the use of electricity. Generally current flows on primary distribution lines are lower than on transmission lines, thus creating lower magnetic field levels. With the lower voltages of distribution power lines, conductors can be located much closer together. This allows greater magnetic field cancellation between phase wires of a three phase feeder line.

If there is a concern about magnetic fields from overhead circuits, the conductors can be mounted on higher poles and/or moved from eight foot wooden cross arms to post insulators (armless construction) for a reduction in magnetic fields. In addition, municipal governments can mandate greater clearances of distribution lines from streets, alleys, and other structures. In the case of newly platted subdivisions, primary distribution circuit layout is designed and reviewed by municipal authorities before being built. As a result, utilities can be made aware of the planned location of new schools and other municipal facilities before the circuits are built.

In most new urban subdivisions, primary distribution conductors are buried. The conductors are normally buried along the same routes where overhead lines would have been placed due to the fact that transformers must be located adjacent to property lines for electric service to individual homes and commercial customers. With the closer spacing of the insulated conductors used in direct burial cable, magnetic fields at approximately ten feet or more from the line are significantly less than equivalent overhead lines carrying the same current level. Fields directly over a buried line are higher than the fields directly under an overhead line, since the buried line is only a few feet underground. As with transmission, if the current flow is not balanced in all three phases, cancellation will not be as effective.

Mitigation of EMF from within the Home

Common contributing sources of magnetic fields within the home are improper grounding and improper wiring of the home electrical system, which can often be addressed by properly following electrical codes. Older homes may have higher ambient exposures due to the type of wiring, for example knob and tube wiring. These types of issues must be assessed on a case-by-case basis.

Additional sources of EMF include many common household appliances, including microwave ovens, vacuum cleaners, analog clock radios, hair dryers, and electric blankets. For example, household appliances with some of the highest magnetic field readings at a six inch distance include hair dryers (as high as 700 milligauss (mG)), microwaves (up to 300 mG), and vacuum cleaners (up to 700 mG). However, the magnetic fields drop off significantly when one increases the distance to the source. Those same high-field appliances have measured fields of 10 mG, 30 mG, and 50 mG at two feet.

Individuals who are concerned about magnetic fields can clearly minimize their exposures by increasing the distance from these appliances when they are operating. Minnesota electrical utilities provide magnetic field measurements in customers' homes to help them to identify the sources and strength of magnetic fields. This type of information can pinpoint specific sources that could be mitigated.

Electric fields are much more easily shielded than are magnetic fields. Thus, electric fields within the home are generally quite low. The most prevalent sources are televisions and computer monitors so minimizing the amount of time being near them and turning them off when not in use will reduce the average electric field exposure.

For more information about EMF health effects research, refer to the web sites on page 25.

CHAPTER 6: CONCLUSIONS AND POLICY RECOMMENDATIONS

Conclusions

Some epidemiological results do show a weak but consistent association between childhood leukemia and increasing exposure to EMF (see the conclusions of IARC and NIEHS). However, epidemiological studies alone are considered insufficient for concluding that a cause and effect relationship exists, and the association must be supported by data from laboratory studies. Existing laboratory studies have not substantiated this relationship (see NTP, 1999; Takebe et al., 2001), nor have scientists been able to understand the biological mechanism of how EMF could cause adverse effects. In addition, epidemiological studies of various other diseases, in both children and adults, have failed to show any consistent pattern of harm from EMF.

The Minnesota Department of Health concludes that the current body of evidence is insufficient to establish a cause and effect relationship between EMF and adverse health effects. However, as with many other environmental health issues, the possibility of a health risk from EMF cannot be dismissed. Construction of new generation and transmission facilities to meet increasing electrical needs in the State is likely to increase public exposure to EMF. Based on these considerations, the Work Group considers it prudent public health policy to take a prudent avoidance approach to mitigating EMF exposures.

Policy Recommendations: Prudent Avoidance Measures

The uncertainty surrounding EMF health effects presents a difficult context in which to make regulatory decisions. Because adverse health effects resulting from EMF cannot be proven or disproven, the Work Group considers it prudent public health policy to take a prudent avoidance approach. This approach suggests that one should avoid any activity or exposure about which there are questions of safety or health, at least to the extent that the activity can be avoided easily or cheaply. This is similar to the findings of the NIEHS report, which states: "...because virtually everyone in the United States uses electricity and therefore is routinely exposed to ELF-EMF, passive regulatory action is warranted such as continued emphasis on educating both the public and the regulated community on means aimed at reducing exposures."

Based on this approach, the Work Group developed several policy recommendations that aim to balance protecting public health with the uncertainty surrounding EMF health effects. The recommendations are outlined below. Implementation of the recommendations will ultimately depend on decision-makers' underlying regulatory philosophy.

Apply EMF mitigation options to new or upgraded electric transmission and distribution lines

There are several options for minimizing or avoiding EMF in the construction and operation of new or upgraded transmission and distribution lines, as discussed in Chapter 5. These options should be applied wherever possible in infrastructure construction projects. For example, utilities seeking to site new transmission lines in Minnesota should use low-cost engineering methods to decrease EMF wherever possible. The kinds of avoidance measures that may be considered prudent can only be determined on a case-by-case basis. Each project's technical specifications and performance requirements will define the parameters of the project.

Encourage conservation

Lowering electric consumption ultimately results in reduced need for new and updated generation facilities, transmission lines, and distribution lines, and hence reduces exposure to EMF. Both the Minnesota Public Utilities Commission and the Department of Commerce use various ways to encourage cost-effective conservation, including using financial incentives, encouraging utilities to improve conservation programs under funding required by law, and setting conservation goals. Within the Department of Commerce, the State Energy Office provides direct outreach, through various educational and technical assistance programs, to help Minnesotans save energy. These efforts are intended to result in reduced energy use, lower energy bills for consumers and fewer negative environmental effects of electricity production and transmission. They should continue to be encouraged and supported.

Encourage distributed generation

There is growing interest in generating electricity with small plants at many locations, commonly referred to as distributed generation. Through the use of cogeneration plants (those producing both heat and electricity and located near the load) and small production facilities like microturbines, power can be generated and used in a fairly localized area. Distributed generation can help reduce the need to build new lines or upgrade existing lines through residential neighborhoods.

Continue to monitor EMF research

Future research will continue to shed light on the health effects of EMF. The Minnesota Department of Health should continue to monitor EMF research and put updated information on the MDH Web site, so that the most recent data are available to policy makers and the public.

Encourage utilities to work with customers on household EMF issues

EMF is emitted at various levels of electric power transmission, generation, and end use. While most people associate EMF with power lines, it is also emitted from most household appliances and household wiring. Upon request, most Minnesota electric utilities will conduct magnetic field measurements in customers' homes or businesses at no cost. This information can identify fields that seem particularly strong and may pinpoint specific sources that can be attenuated. When there are concerns about EMF exposures and health risks, customers and utilities are encouraged to evaluate sources and strength of EMF in places where people live and work.

Provide public education

Public education efforts are necessary to inform the public of the state of current scientific knowledge. The nature, multiple sources, and potential risks associated with electric and magnetic fields, the range of fields one may experience in daily life, and the simple measures one may take to reduce exposures (e.g., distancing oneself from sources of the fields) are probably not common knowledge among the general public. Public education efforts would help support rational dialogue and involvement of stakeholders in EMF discussions, and help people minimize EMF exposure in their home and work environments.

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APPENDIX: EMF POLICIES AND ACTIVITIES IN OTHER STATES

Exposure Standards

Currently there are no federal or state health-based exposure standards for magnetic fields. This is due to the fact that there is insufficient scientific evidence at this time to develop a health-based standard.

Some states have established maximum limits for electric and/or magnetic fields (see table below). The states that have established magnetic field standards did not base them on human or environmental impacts, but merely established the levels found on existing lines as the maximum values for new lines. There are no Federal standards for magnetic fields. For power line permitting purposes, the Minnesota Environmental Quality Board has restricted, on a project-by-project basis, the maximum level for electric fields to 8 kilovolts per meter (kV/m), as measured one meter above ground level.

State	Electric Field On ROW	Electric Field Edge, ROW	Magnetic Field Edge, ROW
Florida	8 kV/m[a] 10Kv/m[b]	2 kV/m	150 mG[a] (max load) 200 mG[b] (max load) 250 mG[c] (max load)
Minnesota	8 kV/m		
Montana	7 kV/m[d]	1 kV/m	
New Jersey		3 kV/m	
New York	11.8 kV/m 11 kV/m[c] 7 kV/m[d]	1.6 kV/m	200 mG (max load)
Oregon	9 kV/m		

a-for lines of 69-230 kV
b-for 500 kV lines
c-for 500 kV lines on certain existing ROW
d-maximum for highway crossings
d-maximum for private road crossings
Key: ROW = right of way; mG = milligauss; kV/m = kilovolts per meter

Source: *Questions and Answers About EMF.* National Institute of Environmental Health Sciences and U.S. Department of Energy, 1995.

Other EMF Policies and Activities

A number of states have developed policies with regard to electric and magnetic fields. These policies usually are of two types: those that identify the agency responsible for approving new electrical facilities and lines, and those that request regular review of new EMF research. Of those states that have an established policy, most established the policy 5 to 10 years ago and are not actively engaged in developing new policy. Only one state, California, has been actively engaged in sponsoring research and developing policies that go beyond the two types described above.

California

In 1993 the California Public Utilities Commission mandated that the California Department of Health Services (CDHS) oversee a program of research and policy analysis about power frequency EMFs. CDHS created the California EMF Program which sponsored projects on EMF exposures in schools and the workplace; research on EMF and miscarriages; and analyses of EMF policy options.

In 2001 the California EMF Program released a *draft* Risk Evaluation report (CDHS 2001). This report summarized the conclusions of three CDHS reviewers regarding possible associations between EMFs and 13 health conditions. The Program also produced fact sheets and other documents which are available on the CDHS web site (see link below).

While some scientists praised the California reviewers for using a novel approach to conduct their Risk Evaluation, several other researchers raised concerns regarding their report's conclusions, and more fundamentally, the process used to conduct the evaluation (CDHS 2002). MDH reviewed the report and public comments, and has concluded that there is no scientific consensus at this time on the report's conclusions, including the degrees of confidence that the reviewers assigned regarding a causal relationship between EMF and adverse health effects. MDH also has concluded that there are significant limitations in California's evaluation, including the failure to adequately address the lack of supporting data from animal laboratory studies and the lack of a plausible biological mechanism of how EMF causes harm.

The California EMF Program is expected to complete a revised Risk Evaluation report in June 2002. The overall Program is expected to conclude in 2002. At this time, it is not clear how the conclusions of the Risk Evaluation and policy analyses will be used by California decision-makers. MDH will continue to track EMF developments in California and other states. (For more information about the California EMF Program, see the CDHS site: http://www.dhs.ca.gov/ps/deodc/ehib/emf/).

Florida

The Transmission Line Siting Act of Florida requires certification (licensing) of electrical transmission lines which are 230 kV or larger and which cross a county line and are 15 miles or more in length. There are exceptions if certain rights-of-way are used.

Certification is an umbrella permit for all affected state, regional and local agencies, and includes any regulatory activity that would be applicable under these agency regulations for the facility. The Department of Environmental Protection is the lead agency responsible for coordinating the interagency review and certification (licensing). The Siting Coordination Office, in conjunction with the Office of General Counsel, has been assigned by the Department to perform the administrative and legal tasks of the certification process. However, the actual licensing entity under the statutes is the Siting Board (governor and cabinet), not the Department or the other lead agencies.

In 1989, the Environmental Regulation Commission (ERC) adopted a rule limiting EMF from electrical transmission lines and substations. Due to the lack of scientific evidence that exposure to power line EMF would produce adverse health effects, the ERC based the field strength standards on the premise that new transmission lines and substations should not produce fields greater than the EMF from existing lines.

The ERC also required the Department of Environmental Protection to monitor EMF scientific research and to submit annual reports on the findings. The most recent report on EMF research (2001) concluded with the following statement:

> We seem to be approaching a time when some aspects of EMF exposure may be deemed a slight risk, but we are still lacking knowledge of EMF impact mechanisms and adequate scientific proof to allow a valid estimate of risk to the public and the knowledge to set a regulatory standard to manage the risk. We therefore do not recommend any change in the current EMF Rule.

Maryland

The Power Plant Research Program (PPRP) is responsible for managing a consolidated review of all issues related to power generation in Maryland. This provides a framework for the comprehensive review of all electric power issues with the goal of balancing need, cost, and impacts. The PPRP was established in 1971 and is supported by an Environmental Trust Fund; funding is provided through an environmental surcharge that is assessed on all electricity used in the State.

Electric power generators must obtain a Certificate of Public Convenience and Necessity from the Maryland Public Service Commission to build or modify power plants and transmission lines in the State. As part of the review, PPRP analyzes the need, consolidates issue analysis from several agencies, and evaluates potential environmental impacts.

PPRP's ongoing assessments involve plant-specific studies and more general monitoring, research and modeling projects. These projects cover a spectrum of issues, such as environmental impact assessments, technology evaluations and demonstrations, and economic studies. One of the projects is tracking the research on potential human health effects associated with electric and magnetic fields.

The most recent report from the PPRP (October 2001) reviewed the EMF health risk assessments current at that time and reached the following conclusion:

> None of the assessments determined EMF to be a confirmed cause of human cancer, instead calling EMF a possible human carcinogen, based on the epidemiological evidence. The lack of complementary confirmatory evidence from animal and other laboratory studies bears on the distinction between a known vs. probable vs. possible carcinogen classification. All assessments commented on the uncertainties in determining causality, particularly because causative exposure and dose characteristics had not yet been clearly identified from the research. In summary, EMF exposures remain suspect but remaining unknowns are the reason for continued lack of firm clear affirmation of health risks from EMF exposure.

For more information about EMF-related activities and publications in Maryland, contact PPRP by phone at 410-260-8660 or visit the PPRP web site: http://www.dnr.state.md.us/bay/pprp/.

New Jersey

The New Jersey Department of Environmental Protection has a Radiation Protection Program that includes a Non-ionizing Radiation Section (NRS). The NRS provides information to the public concerning radio frequency and electromagnetic fields through distribution of U.S. Environmental Protection Agency, Federal Communications Commission, and U.S. Department of Energy documents. With regard to magnetic fields the NRS currently states on their web site:

> It is not known at this point whether exposure to magnetic fields from power frequency sources constitutes a health hazard. Therefore, it cannot be determined what levels of exposure are "safe" or "unsafe." Some studies have shown that exposure to higher levels of this radiation is not necessarily worse than exposure to lower levels. More research is required to identify dose-response relationships. There is some evidence from laboratory studies to suggest that there may be "windows" for effects. This means that biological effects are observed at some frequencies and intensities but not at others. Also, it is not known if continuous exposure to a given field intensity causes a biological effect, or if repeatedly entering and exiting of the field causes effects. In light of all this uncertainty, it is impossible to say what is a "safe" distance from any magnetic field source or what is a "safe" exposure.

For more information about New Jersey's EMF-related activities, refer to the New Jersey Department of Environmental Protection web site: http://www.state.nj.us/dep/rpp/nrs/index.htm.

New York

The Department of Public Service has a broad mandate to ensure that all New Yorkers have access to reliable and low-cost utility services. The Department is the staff arm of the Public Service Commission, which regulates the state's utilities and has jurisdiction over the siting of major gas and electric transmission facilities. Within the Department, the Office of Electricity and Environment coordinates review of applications for new power plants and major transmission lines, and monitors the construction of such facilities to ensure compliance with technical and environmental requirements.

In 1991, the Public Service Commission established an interim measure that requires new high voltage transmission lines in New York to be designed so that the maximum magnetic fields at the edge of the right-of-way will not exceed the maximum magnetic field levels produced by the average of 345 kV lines now in operation. This interim magnetic field standard of 200 milligauss, at one meter above the ground at the edge of the right-of-way, applies when the line is operating at its highest continuous current rating.

The New York Department of Health has issued the following response to the question of what is a safe level of magnetic field:

> There is no number to which we can point and say, "that is a safe or dangerous level of EMF exposure." We don't know if EMF exposure is harmful. We don't know if certain levels of EMFs are safer or less safe than other exposures. We do not know if continuous exposure to a given field intensity causes a biological effect, or if rapid changes in exposures cause effects.

Utah

The Radiation Control Board (RCB) guides development of radiation control policy and rules in the state. Members are appointed by the Utah governor with the consent of the Utah Senate. In December 1993 the Utah Radiation Control Board adopted a position statement on health effects from Extremely Low Frequency Electromagnetic Fields:

> . . .while there may be indications for further biomedical research on this question, the existing scientific evidence is not sufficient to warrant legislation or regulation at this time.
>
> The Board strongly recommends, however, that the Division of Radiation Control (DRC) establish an efficient program to monitor reputable scientific literature dealing with the biomedical effects of ELF/EMF. Further, the DRC should notify the Board immediately whenever reviewers believe that significant new scientific evidence has been published.

No further action regarding EMF has been taken by the RCB.

Virginia

The State Corporation Commission (SCC) is vested with regulatory authority over many business and economic interests in Virginia. One of its major responsibilities is to consider the environmental impact of certain electric generating and transmission facilities proposed for construction in Virginia by regulated utilities.

The Division of Energy Regulation assists the SCC's three commissioners in regulating Virginia's utilities. Its responsibilities include monitoring utility construction projects and reviewing applications for construction of transmission lines exceeding 150 kilovolts and electric generating units exceeding 100 megawatts.

In May 2001 the SCC approved a 57-mile, 765 kV transmission line proposed by American Electric Power (AEP). While the SCC does not have a formal policy on EMF, AEP offered to purchase any home that is within 100 feet of the edge of the right-of-way, which is 200 feet.

In October 2000, the Virginia Department of Health, in cooperation with the SCC, prepared the report "Monitoring of Ongoing Research on Health Effects of High Voltage Transmission Lines." The report concluded that:

> There is no conclusive and convincing evidence that exposure to extremely low frequency EMF emanated from nearby high voltage transmission lines is causally associated with an increased incidence of cancer or other detrimental health effects in humans.

For a copy of the October 2000 report, see the Virginia Department of Health web site: http://www.vdh.state.va.us/HHControl/highfinal.PDF.

Wisconsin

The Public Service Commission of Wisconsin (PSC) is an independent regulatory agency responsible for the regulation of Wisconsin public utilities, including those that are municipally owned. The Electric Division is responsible for all major aspects of the PSC regulation of electric utilities. Utilities need PSC approval for their rates, and for building large power plants or power lines.

A utility must get approval from the Commission to build an electric transmission line if:

- The proposed line is 230 kilovolts (kV) or more;
- The proposed line is 100 kV or more, is over one mile in length, and needs new right-of-way (ROW); or
- The proposed line's cost will be above a certain percent of the utility's annual revenue.

The Commission decides whether a power line can be built, how it should be designed, and where it must be located.

Since 1989, the Commission has periodically reviewed the science on EMF and has held hearings to consider the topic of EMF and human health effects. The most recent hearings on EMF were held in July 1998. As a result of these hearings, the Commission has ordered Wisconsin utilities to enact several measures, including contributing to the national research effort and providing measurements and information to the public on EMF.

The Commission recently updated its information brochure (22 pages) entitled "PSC Overview Series... EMF – Electric & Magnetic Fields." The summary paragraphs are as follows:

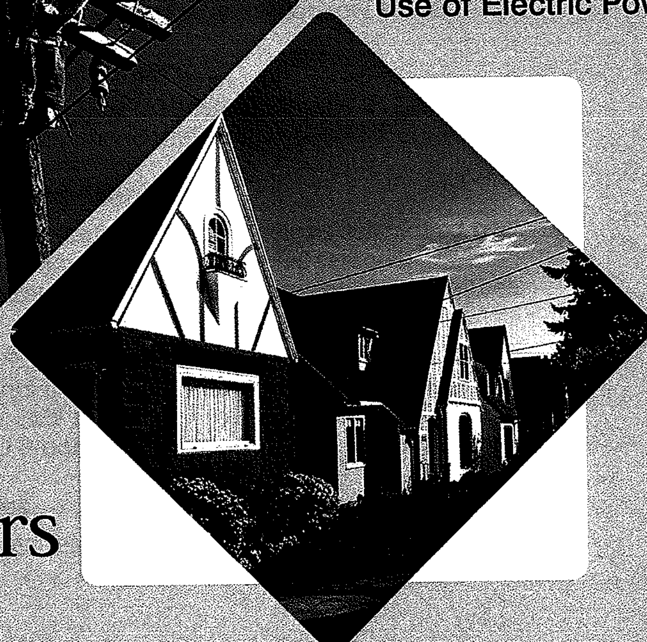
> Many scientists believe the potential for health risks for exposure to EMF is very small. This is supported, in part, by weak epidemiological evidence and the lack of a plausible biological mechanism that explains how exposure to EMF could cause disease. The magnetic fields produced by electricity are weak and do not have enough energy to break chemical bonds or to cause mutations in DNA. Without a mechanism, scientists have no idea what kind of exposure, if any, might be harmful. In addition, whole animal studies investigating long-term exposure to power-frequency EMF have shown no connection between exposure and cancer of any kind.
>
> While scientific consensus appears to be forming, there are still some unanswered questions about EMF exposure and human health. The Commission will continue to consider EMF in its power line siting decisions. But the Commission must balance the likelihood of health effects from exposure to power line EMF with issues of need, cost, and environmental impact. The PSC will base its EMF policy on a continuing review of scientific research.

For more about the EMF overview fact sheet prepared by the Wisconsin PSC, see the web site: http://www.psc.state.wi.us/pdffiles/brochures/emf.pdf.

June 2002

EMF

Electric and Magnetic Fields Associated with the Use of Electric Power



Questions & Answers

prepared by the
National Institute of Environmental Health Sciences
National Institutes of Health

EMF RAPID

sponsored by the
NIEHS/DOE EMF RAPID Program

Introduction

Since the mid-twentieth century, electricity has been an essential part of our lives. Electricity powers our appliances, office equipment, and countless other devices that we use to make life safer, easier, and more interesting. Use of electric power is something we take for granted. However, some have wondered whether the electric and magnetic fields (EMF) produced through the generation, transmission, and use of electric power [power-frequency EMF, 50 or 60 hertz (Hz)] might adversely affect our health. Numerous research studies and scientific reviews have been conducted to address this question.

Unfortunately, initial studies of the health effects of EMF did not provide straightforward answers. The study of the possible health effects of EMF has been particularly complex and results have been reviewed by expert scientific panels in the United States and other countries. This booklet summarizes the results of these reviews. Although questions remain about the possibility of health effects related to EMF, recent reviews have substantially reduced the level of concern.

The largest evaluation to date was led by two U.S. government institutions, the National Institute of Environmental Health Sciences (NIEHS) of the National Institutes of Health and the Department of Energy (DOE), with input from a wide range of public and private agencies. This evaluation, known as the Electric and Magnetic Fields Research and Public Information Dissemination (EMF RAPID) Program, was a six-year project with the goal of providing scientific evidence to determine whether exposure to power-frequency EMF involves a potential risk to human health.

In 1999, at the conclusion of the EMF RAPID Program, the NIEHS reported to the U.S. Congress that the overall scientific evidence for human health risk from EMF exposure is weak. No consistent pattern of biological effects from exposure to EMF had emerged from laboratory studies with animals or with cells. However, epidemiological studies (studies of disease incidence in human populations) had shown a fairly consistent pattern that associated potential EMF exposure with a small increased risk for leukemia in children and chronic lymphocytic leukemia in adults. Since 1999, several other assessments have been completed that support an association between childhood leukemia and exposure to power-frequency EMF. These more recent reviews, however, do not support a link between EMF exposures and adult leukemias. For both childhood and adult leukemias, interpretation of the epidemiological findings has been difficult due to the absence of supporting laboratory evidence or a scientific explanation linking EMF exposures with leukemia.

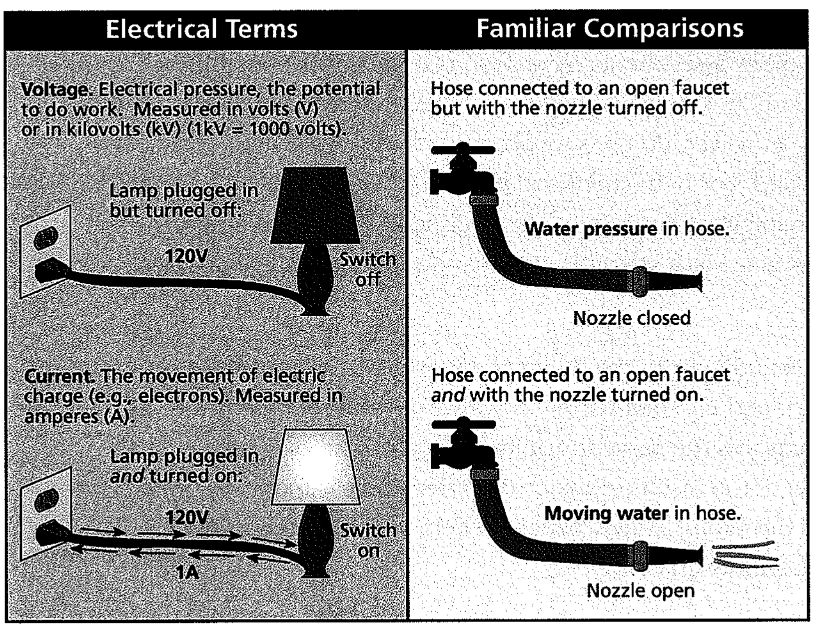
EMF exposures are complex and exist in the home and workplace as a result of all types of electrical equipment and building wiring as well as a result of nearby power lines. This booklet explains the basic principles of electric and magnetic fields, provides an overview of the results of major research studies, and summarizes conclusions of the expert review panels to help you reach your own conclusions about EMF-related health concerns.

1 EMF Basics

This chapter reviews terms you need to know to have a basic understanding of electric and magnetic fields (EMF), compares EMF with other forms of electromagnetic energy, and briefly discusses how such fields may affect us.

Q What are electric and magnetic fields?

A Electric and magnetic fields (EMF) are invisible lines of force that surround any electrical device. Power lines, electrical wiring, and electrical equipment all produce EMF. There are many other sources of EMF as well (see pages 33–35). The focus of this booklet is on power-frequency EMF—that is, EMF associated with the generation, transmission, and use of electric power.



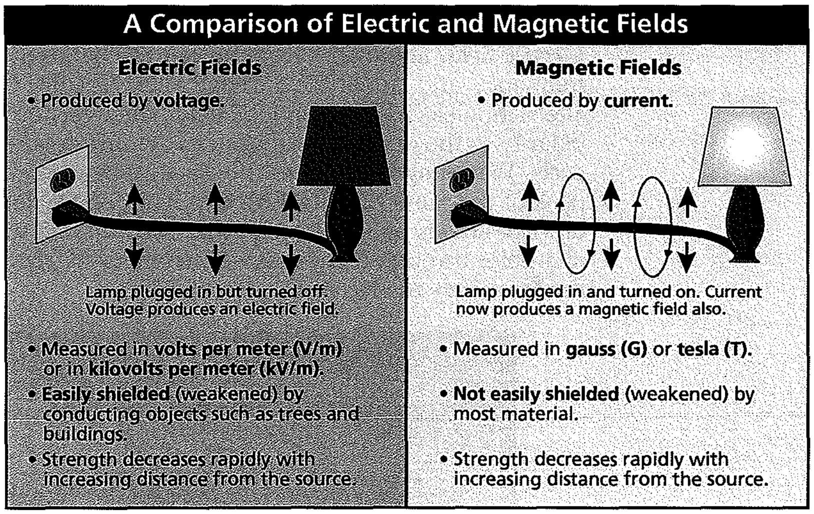
Voltage produces an electric field and current produces a magnetic field.

Electric fields are produced by voltage and increase in strength as the voltage increases. The electric field strength is measured in units of volts per meter (V/m). Magnetic fields result from the flow of current through wires or electrical devices and increase in strength as the current increases. Magnetic fields are measured in units of gauss (G) or tesla (T).

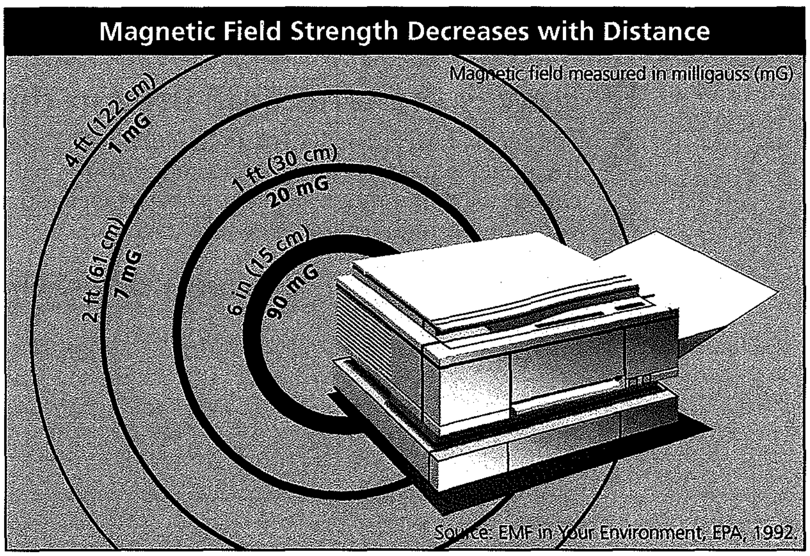
Most electrical equipment has to be turned on, i.e., current must be flowing, for a magnetic field to be produced. Electric fields are often present even when the equipment is switched off, as long as it remains connected to the source of electric power. Brief bursts of EMF (sometimes called "transients") can also occur when electrical devices are turned on or off.

Electric fields are shielded or weakened by materials that conduct electricity—even materials that conduct poorly, including trees, buildings, and human skin. Magnetic fields, however, pass through most materials and are therefore more difficult to shield. Both electric fields and magnetic fields decrease rapidly as the distance from the source increases.

Even though electrical equipment, appliances, and power lines produce both electric and magnetic fields, most recent research has focused on potential health effects of magnetic field exposure. This is because some epidemiological studies have reported an increased cancer risk associated with estimates of magnetic field exposure (see pages 19 and 20 for a summary of these studies). No similar associations have been reported for electric fields; many of the studies examining biological effects of electric fields were essentially negative.



An appliance that is plugged in and therefore connected to a source of electricity has an electric field even when the appliance is turned off. To produce a magnetic field, the appliance must be plugged in and turned on so that the current is flowing.



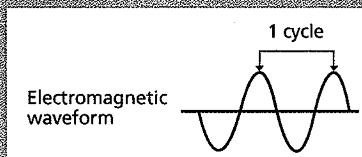
You cannot see a magnetic field, but this illustration represents how the strength of the magnetic field can diminish just 1–2 feet (30–61 centimeters) from the source. This magnetic field is a 60-Hz power-frequency field.

Characteristics of electric and magnetic fields

Electric fields and magnetic fields can be characterized by their wavelength, frequency, and amplitude (strength). The graphic below shows the waveform of an alternating electric or magnetic field. The direction of the field alternates from one polarity to the opposite and back to the first polarity in a period of time called one cycle. Wavelength describes the distance between a peak on the wave and the next peak of the same polarity. The frequency of the field, measured in hertz (Hz), describes the number of cycles that occur in one second. Electricity in North America alternates through 60 cycles per second, or 60 Hz. In many other parts of the world, the frequency of electric power is 50 Hz.

Frequency and Wavelength

Frequency is measured in hertz (Hz).
1 Hz = 1 cycle per second.



Examples:

Source	Frequency	Wavelength
Power line (North America)	60 Hz	3100 miles (5000 km)
Power line (Europe and most other locations)	50 Hz	3750 miles (6000 km)

Q How is the term EMF used in this booklet?

A The term "EMF" usually refers to electric and magnetic fields at extremely low frequencies such as those associated with the use of electric power. The term EMF can be used in a much broader sense as well, encompassing electromagnetic fields with low or high frequencies (see page 8).

Measuring EMF: Common Terms

Electric fields

Electric field strength is measured in volts per meter (V/m) or in kilovolts per meter (kV/m). 1 kV = 1000 V

Magnetic fields

Magnetic fields are measured in units of gauss (G) or tesla (T). Gauss is the unit most commonly used in the United States. Tesla is the internationally accepted scientific term. 1 T = 10,000 G

Since most environmental EMF exposures involve magnetic fields that are only a fraction of a tesla or a gauss, these are commonly measured in units of microtesla (µT) or milligauss (mG). A milligauss is 1/1,000 of a gauss. A microtesla is 1/1,000,000 of a tesla. 1 G = 1,000 mG; 1 T = 1,000,000 µT

To convert a measurement from microtesla (µT) to milligauss (mG), multiply by 10.
1 µT = 10 mG; 0.1 µT = 1 mG

When we use EMF in this booklet, we mean extremely low frequency (ELF) electric and magnetic fields, ranging from 3 to 3,000 Hz (see page 8). This range includes power-frequency (50 or 60 Hz) fields. In the ELF range, electric and magnetic fields are not coupled or interrelated in the same way that they are at higher frequencies. So, it is more useful to refer to them as "electric and magnetic fields" rather than "electromagnetic fields." In the popular press, however, you will see both terms used, abbreviated as EMF.

This booklet focuses on extremely low frequency EMF, primarily power-frequency fields of 50 or 60 Hz, produced by the generation, transmission, and use of electricity.

Q How are power-frequency EMF different from other types of electromagnetic energy?

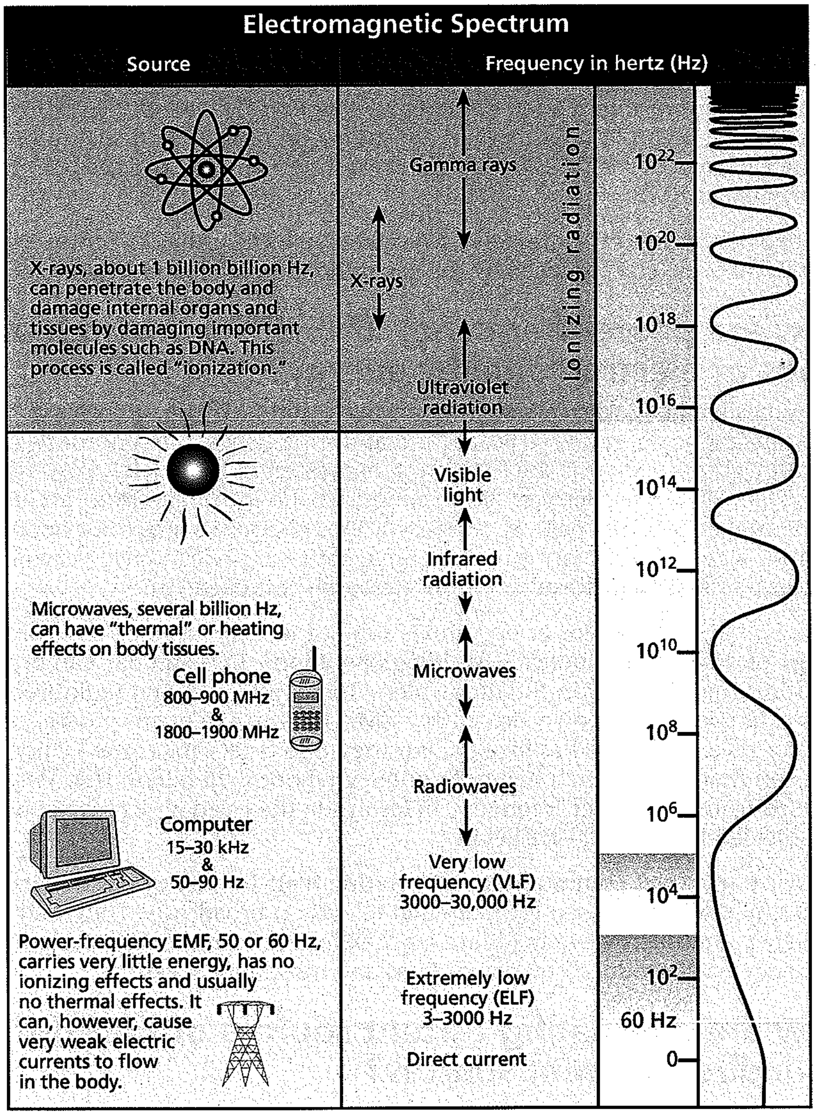
A X-rays, visible light, microwaves, radio waves, and EMF are all forms of electromagnetic energy. One property that distinguishes different forms of electromagnetic energy is the frequency, expressed in hertz (Hz). Power-frequency EMF, 50 or 60 Hz, carries very little energy, has no ionizing effects, and usually has no thermal effects (see page 8). Just as various chemicals affect our bodies in different ways, various forms of electromagnetic energy can have very different biological effects (see "Results of EMF Research" on page 16).

Some types of equipment or operations simultaneously produce electromagnetic energy of different frequencies. Welding operations, for example, can produce electromagnetic energy in the ultraviolet, visible, infrared, and radio-frequency ranges, in addition to power-frequency EMF. Microwave ovens produce 60-Hz fields of several hundred milligauss, but they also create microwave energy inside the oven that is at a much higher frequency (about 2.45 billion Hz). We are shielded from the higher frequency fields inside the oven by its casing, but we are not shielded from the 60-Hz fields.

Cellular telephones communicate by emitting high-frequency electric and magnetic fields similar to those used for radio and television broadcasts. These radio-frequency and microwave fields are quite different from the extremely low frequency EMF produced by power lines and most appliances.

Q How are alternating current sources of EMF different from direct current sources?

A Some equipment can run on either alternating current (AC) or direct current (DC). In most parts of the United States, if the equipment is plugged into a household wall socket, it is using AC electric current that reverses direction in the electrical wiring—or alternates—60 times per second, or at 60 hertz (Hz). If the equipment uses batteries, then electric current flows in one direction only. This



The wavy line at the right illustrates the concept that the higher the frequency, the more rapidly the field varies. The fields do not vary at 0 Hz (direct current) and vary trillions of times per second near the top of the spectrum. Note that 10^4 means 10 x 10 x 10 x 10 or 10,000 Hz. 1 kilohertz (kHz) = 1,000 Hz. 1 megahertz (MHz) = 1,000,000 Hz.

produces a "static" or stationary magnetic field, also called a direct current field. Some battery-operated equipment can produce time-varying magnetic fields as part of its normal operation.

Q What happens when I am exposed to EMF?

A In most practical situations, DC electric power does not induce electric currents in humans. Strong DC magnetic fields are present in some industrial environments, can induce significant currents when a person moves, and may be of concern for other reasons, such as potential effects on implanted medical devices (see page 47 for more information on pacemakers and other medical devices).

AC electric power produces electric and magnetic fields that create weak electric currents in humans. These are called "induced currents." Much of the research on how EMF may affect human health has focused on AC-induced currents.

Electric fields

A person standing directly under a high-voltage transmission line may feel a mild shock when touching something that conducts electricity. These sensations are caused by the strong electric fields from the high-voltage electricity in the lines. They occur only at close range because the electric fields rapidly become weaker as the distance from the line increases. Electric fields may be shielded and further weakened by buildings, trees, and other objects that conduct electricity.

Magnetic fields

Alternating magnetic fields produced by AC electricity can induce the flow of weak electric currents in the body. However, such currents are estimated to be smaller than the measured electric currents produced naturally by the brain, nerves, and heart.

Q Doesn't the earth produce EMF?

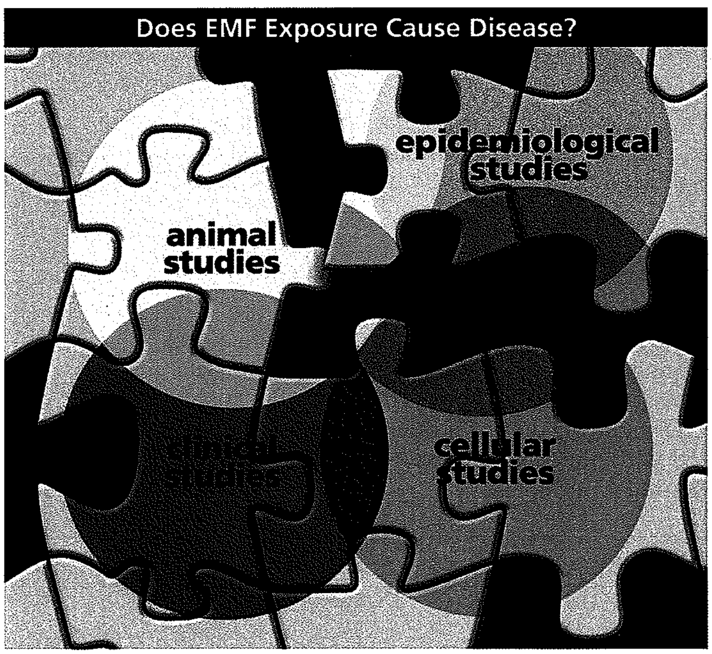
A Yes. The earth produces EMF, mainly in the form of static fields, similar to the fields generated by DC electricity. Electric fields are produced by air turbulence and other atmospheric activity. The earth's magnetic field of about 500 mG is thought to be produced by electric currents flowing deep within the earth's core. Because these fields are static rather than alternating, they do not induce currents in stationary objects as do fields associated with alternating current. Such static fields can induce currents in moving and rotating objects.

2 Evaluating Potential Health Effects

This chapter explains how scientific studies are conducted and evaluated to assess potential health effects.

Q How do we evaluate whether EMF exposures cause health effects?

A Animal experiments, laboratory studies of cells, clinical studies, computer simulations, and human population (epidemiological) studies all provide valuable information. When evaluating evidence that certain exposures cause disease, scientists consider results from studies in various disciplines. No single study or type of study is definitive.



Laboratory studies and human studies provide pieces of the puzzle, but no single study can give us the whole picture.

Laboratory studies

Laboratory studies with cells and animals can provide evidence to help determine if an agent such as EMF causes disease. Cellular studies can increase our understanding of the biological mechanisms by which disease occurs. Experiments with animals provide a means to observe effects of specific agents under carefully controlled conditions. Neither cellular nor animal studies, however, can recreate the complex nature of the whole human organism and its environment. Therefore, we must use caution in applying the results of cellular or animal studies directly to humans or concluding that a lack of an effect in laboratory studies proves that an agent is safe. Even with these limitations, cellular and animal studies have proven very useful over the years for identifying and understanding the toxicity of numerous chemicals and physical agents.

Very specific laboratory conditions are needed for researchers to be able to detect EMF effects, and experimental exposures are not easily comparable to human exposures. In most cases, it is not clear how EMF actually produces the effects observed in some experiments. Without understanding how the effects occur, it is difficult to evaluate how laboratory results relate to human health effects.

Some laboratory studies have reported that EMF exposure can produce biological effects, including changes in functions of cells and tissues and subtle changes in hormone levels in animals. It is important to distinguish between a biological effect and a health effect. Many biological effects are within the normal range of variation and are not necessarily harmful. For example, bright light has a biological effect on our eyes, causing the pupils to constrict, which is a normal response.

Clinical studies

In clinical studies, researchers use sensitive instruments to monitor human physiology during controlled exposure to environmental agents. In EMF studies, volunteers are exposed to electric or magnetic fields at higher levels than those commonly encountered in everyday life. Researchers measure heart rate, brain activity, hormonal levels, and other factors in exposed and unexposed groups to look for differences resulting from EMF exposure.

Epidemiology

A valuable tool to identify human health risks is to study a human population that has experienced the exposure. This type of research is called epidemiology.

The epidemiologist observes and compares groups of people who have had or have not had certain diseases and exposures to see if the risk of disease is different between the exposed and unexposed groups. The epidemiologist does not control the exposure and cannot experimentally control all the factors that might affect the risk of disease.

Most researchers agree that epidemiology—the study of patterns and possible causes of diseases—is one of the most valuable tools to identify human health risks.

Q How do we evaluate the results of epidemiological studies of EMF?

A Many factors need to be considered when determining whether an agent causes disease. An exposure that an epidemiological study associates with increased risk of a certain disease is not always the actual cause of the disease. To judge whether an agent actually causes a health effect, several issues are considered.

Strength of association

The stronger the association between an exposure and disease, the more confident we can be that the disease is due to the exposure being studied. With cigarette smoking and lung cancer, the association is very strong—20 times the normal risk. In the studies that suggest a relationship between EMF and certain rare cancers, the association is much weaker (see page 19).

Dose-response

Epidemiological data are more convincing if disease rates increase as exposure levels increase. Such dose-response relationships have appeared in only a few EMF studies.

Consistency

Consistency requires that an association found in one study appears in other studies involving different study populations and methods. Associations found consistently are more likely to be causal. With regard to EMF, results from different studies sometimes disagree in important ways, such as what type of cancer is associated with EMF exposure. Because of this inconsistency, scientists cannot be sure whether the increased risks are due to EMF or other factors.

Biological plausibility

When associations are weak in an epidemiological study, results of laboratory studies are even more important to support the association. Many scientists remain skeptical about an association between EMF exposure and cancer because laboratory studies thus far have not shown any consistent evidence of adverse health effects, nor have results of experimental studies revealed a plausible biological explanation for such an association.

Reliability of exposure information

Another important consideration with EMF epidemiological studies is how the exposure information was obtained. Did the researchers simply estimate people's EMF exposures based on their job titles or how their houses were wired, or did they actually conduct EMF measurements? What did they measure (electric fields, magnetic fields, or both)? How often were the EMF measurements made and at what time? In how many different places were the fields measured? More recent studies have included measurements of magnetic field exposure. Magnetic fields measured at the time a study is conducted can only estimate exposures that occurred in previous years (at the time a disease process may have begun). Lack of comprehensive exposure information makes it more difficult to interpret the results of a study, particularly considering that everyone in the industrialized world has been exposed to EMF.

Confounding

Epidemiological studies show relationships or correlations between disease and other factors such as diet, environmental conditions, and heredity. When a disease is correlated with some factor, it does not necessarily mean that the correlated factor causes the disease. It could mean that the factor occurs together with some other factor, not measured in the study, that actually causes the disease. This is called confounding.

For example, a study might show that alcohol consumption is correlated with lung cancer. This could occur if the study group consists of people who drink and also smoke tobacco, as often happens. In this example, alcohol use is correlated with lung cancer, but cigarette smoking is a confounding factor and the true cause of the disease.

Statistical significance

Researchers use statistical methods to determine the likelihood that the association between exposure and disease is due simply to chance. For a result to be considered "statistically significant," the association must be stronger than would be expected to occur by chance alone.

Meta-analysis

One way researchers try to get more information from epidemiological studies is to conduct a meta-analysis. A meta-analysis combines the summary statistics of many studies to explore their differences and, if appropriate, calculates an overall summary risk estimate. The main challenge faced by researchers performing meta-analyses is that populations, measurements, evaluation techniques, participation rates, and potential confounding factors vary in the original studies. These differences in the studies make it difficult to combine the results in a meaningful way.

Pooled analysis

Pooled analysis combines the original data from several studies and conducts a new analysis on the primary data. It requires access to the original data from individual studies and can only include diseases or factors included in all the studies, but it has the advantage that the same parameters can be applied to all studies. As with meta-analysis, pooled analysis is still subject to the limitations of the experimental design of the original studies (for example, evaluation techniques, participation rates, etc.). Pooled analysis differs from meta-analysis, which combines the summary statistics from different studies, not their original data.

Q How do we characterize EMF exposure?

A No one knows which aspect of EMF exposure, if any, affects human health. Because of this uncertainty, in addition to the field strength, we must ask how long an exposure lasts, how it varies, and at what time of day or night it occurs. House wiring, for example, is often a significant source of EMF exposure for an individual, but the magnetic fields produced by the wiring depend on the amount of current flowing. As heating, lighting, and appliance use varies during the day, magnetic field exposure will also vary.

For many studies, researchers describe EMF exposures by estimating the average field strength. Some scientists believe that average exposure may not be the best measurement of EMF exposure and that other parameters, such as peak exposure or time of exposure, may be important.

Q What is the average field strength?

A In EMF studies, the information reported most often has been a person's EMF exposure averaged over time (average field strength). With cancer-causing chemicals, a person's average exposure over many years can be a good way to predict his or her chances of getting the disease.

There are different ways to calculate average magnetic field exposures. One method involves having a person wear a small monitor that takes many measurements over a work shift, a day, or longer. Then the average of those measurements is calculated. Another method involves placing a monitor that takes many measurements in a residence over a 24-hour or 48-hour period. Sometimes averages are calculated for people with the same occupation, people working in similar environments, or people using several brands of the same type or similar types of equipment.

Q How is EMF exposure measured in epidemiological studies?

A Epidemiologists study patterns and possible causes of diseases in human populations. These studies are usually observational rather than experimental. This means that the researcher observes and compares groups of people who have had certain diseases and exposures and looks for possible "associations." The epidemiologist must find a way to estimate the exposure that people had at an earlier time.

Association

In epidemiology, a positive association between an exposure (such as EMF) and a disease is not necessarily proof that the exposure *caused* the disease. However, the more often the exposure and disease occur together, the stronger the association, and the stronger is the possibility that the exposure may increase the risk of the disease.

Some exposure estimates for residential studies have been based on designation of households in terms of "wire codes." In other studies, measurements have been made in homes, assuming that EMF levels at the time of the measurement are similar to levels at some time in the past. Some studies involved "spot measurements." Exposure levels change as a person moves around in his or her environment, so spot measurements taken at specific locations only approximate the complex variations in exposure a person experiences. Other studies measured magnetic fields over a 24-hour or 48-hour period. Exposure levels for some occupational studies are measured by having certain employees wear personal monitors. The data taken from these monitors are sometimes used to estimate typical exposure levels for employees with certain job titles. Researchers can then estimate exposures using only an employee's job title and avoid measuring exposures of all employees.

Methods to Estimate EMF Exposure

Wire Codes

A classification of homes based on characteristics of power lines outside the home (thickness of the wires, wire configuration, etc.) and their distance from the home. This information is used to code the homes into groups with higher and lower predicted magnetic field levels.

Spot Measurement

An instantaneous or very short-term (e.g., 30-second) measurement taken at a designated location.

Time-Weighted Average

A weighted average of exposure measurements taken over a period of time that takes into account the time interval between measurements. When the measurements are taken with a monitor at a fixed sampling rate, the time-weighted average equals the arithmetic mean of the measurements.

Personal Monitor

An instrument that can be worn on the body for measuring exposure over time.

Calculated Historical Fields

An estimate based on a theoretical calculation of the magnetic field emitted by power lines using historical electrical loads on those lines.

3 Results of EMF Research

This chapter summarizes the results of EMF research worldwide, including epidemiological studies of children and adults, clinical studies of how humans react to typical EMF exposures, and laboratory research with animals and cells.

Q Is there a link between EMF exposure and childhood leukemia?

A Despite more than two decades of research to determine whether elevated EMF exposure, principally to magnetic fields, is related to an increased risk of childhood leukemia, there is still no definitive answer. Much progress has been made, however, with some lines of research leading to reasonably clear answers and others remaining unresolved. The best available evidence at this time leads to the following answers to specific questions about the link between EMF exposure and childhood leukemia:

Is there an association between power line configurations (wire codes) and childhood leukemia? No.

Is there an association between measured fields and childhood leukemia? Yes, but the association is weak, and it is not clear whether it represents a cause-and-effect relationship.

Q What is the epidemiological evidence for evaluating a link between EMF exposure and childhood leukemia?

A The initial studies, starting with the pioneering research of Dr. Nancy Wertheimer and Ed Leeper in 1979 in Denver, Colorado, focused on power line configurations near homes. Power lines were systematically evaluated and coded for their presumed ability to produce elevated magnetic fields in homes and classified into groups with higher and lower predicted magnetic field levels (see discussion of wire codes on page 15). Although the first study and two that followed in Denver and Los Angeles showed an association between wire codes indicative of elevated magnetic fields and childhood leukemia, larger, more recent studies in the central part of the United States and in several provinces of Canada did not find such an association. In fact, combining the evidence from all the studies, we can conclude with some confidence that wire codes are not associated with a measurable increase in the risk of childhood leukemia.

The other approach to assessing EMF exposure in homes focused on the measurements of magnetic fields. Unlike wire codes, which are only applicable in North America due to the nature of the electric power distribution system, measured fields have been studied in relation to childhood leukemia in research conducted around the world, including Sweden, England, Germany, New Zealand, and Taiwan. Large, detailed studies have recently been completed in the United States, Canada, and the United Kingdom that provide the most evidence for making an evaluation. These studies have produced variable findings, some reporting small associations, others finding no associations.

National Cancer Institute Study

In 1997, after eight years of work, Dr. Martha Linet and colleagues at the National Cancer Institute (NCI) reported the results of their study of childhood acute lymphoblastic leukemia (ALL). The case-control study involved more than 1,000 children living in 9 eastern and midwestern U.S. states and is the largest epidemiological study of childhood leukemia to date in the United States. To help resolve the question of wire code versus measured magnetic fields, the NCI researchers carried out both types of exposure assessment. Overall, Linet reported little evidence that living in homes with higher measured magnetic-field levels was a disease risk and found no evidence that living in a home with a high wire code configuration increased the risk of ALL in children.

United Kingdom Childhood Cancer Study

In December 1999, Sir Richard Doll and colleagues in the United Kingdom announced that the largest study of childhood cancer ever undertaken—involving nearly 4,000 children with cancer in England, Wales, and Scotland—found no evidence of excess risk of childhood leukemia or other cancers from exposure to power-frequency magnetic fields. It should be noted, however, that because most power lines in the United Kingdom are underground, the EMF exposures of these children were mostly lower than 0.2 microtesla or 2 milligauss.

After reviewing all the data, the U.S. National Institute of Environmental Health Sciences (NIEHS) concluded in 1999 that the evidence was weak, but that it was still sufficient to warrant limited concern. The NIEHS rationale was that no individual epidemiological study provided convincing evidence linking magnetic field exposure with childhood leukemia, but the overall pattern of results for some methods of measuring exposure suggested a weak association between increasing exposure to EMF and increasing risk of childhood leukemia. The small number of cases in these studies made it impossible to firmly demonstrate this association. However, the fact that similar results had been observed in studies of different populations using a variety of study designs supported this observation.

A major challenge has been to determine whether the most highly elevated, but rarely encountered, levels of magnetic fields are associated with an increased risk of leukemia. Early reports focused on the risk associated with exposures above 2 or 3 milligauss, but the more recent studies have been large enough to also provide some information on levels above 3 or 4 milligauss. It is estimated that 4.5% of homes in the United States have magnetic fields above 3 milligauss, and 2.5% of homes have levels above 4 milligauss.

What is Cancer?

Cancer

"Cancer" is a term used to describe at least 200 different diseases, all involving uncontrolled cell growth. The frequency of cancer is measured by the incidence—the number of new cases diagnosed each year. Incidence is usually described as the number of new cases diagnosed per 100,000 people per year.

The incidence of cancer in adults in the United States is 382 per 100,000 per year, and childhood cancers account for about 1% of all cancers. The factors that influence risk differ among the forms of cancer. Known risk factors such as smoking, diet, and alcohol contribute to specific types of cancer. (For example, smoking is a known risk factor for lung cancer, bladder cancer, and oral cancer.) For many other cancers, the causes are unknown.

Leukemia

Leukemia describes a variety of cancers that arise in the bone marrow where blood cells are formed. The leukemias represent less than 4% of all cancer cases in adults but are the most common form of cancer in children. For children age 4 and under, the incidence of childhood leukemia is approximately 6 per 100,000 per year, and it decreases with age to about 2 per 100,000 per year for children 10 and older. In the United States, the incidence of adult leukemia is about 10 cases per 100,000 people per year. Little is known about what causes leukemia, although genetic factors play a role. The only known causes are ionizing radiation, benzene, and other chemicals and drugs that suppress bone marrow function, and a human T-cell leukemia virus.

Brain Cancer

Cancer of the central nervous system (the brain and spinal cord) is uncommon, with incidence in the United States now at about 6 cases in 100,000 people per year. The causes of the disease are largely unknown, although a number of studies have reported an association with certain occupational chemical exposures. Ionizing radiation to the scalp is a known risk factor for brain cancer. Factors associated with an increased risk for other types of cancer—such as smoking, diet, and excessive alcohol use—have not been found to be associated with brain cancer.

To determine what the integrated information from all the studies says about magnetic fields and childhood leukemia, two groups have conducted pooled analyses in which the original data from relevant studies were integrated and analyzed. One report (Greenland et al., 2000) combined 12 relevant studies with magnetic field measurements, and the other considered 9 such studies (Ahlbom et al., 2000). The details of the two pooled analyses are different, but their findings are similar. There is weak evidence for an association (relative risk of approximately 2) at exposures above 3 mG. However, few individuals had high exposures in these studies; therefore, even combining all studies, there is uncertainty about the strength of the association.

The following table summarizes the results for the epidemiological studies of EMF exposure and childhood leukemia analyzed in the pooled analysis by Greenland et al. (2000). The focus of the summary review was the magnetic fields that occurred three months prior to diagnosis. The results were derived from either calculated historical fields or multiple measurements of magnetic fields. The North American

Residential Exposure to Magnetic Fields and Childhood Leukemia

	Magnetic field category (mG)					
	>1 – ≤2 mG		>2 – ≤3 mG		>3 mG	
First author	Estimate	95% CL	Estimate	95% CL	Estimate	95% CL
Coghill	0.54	0.17, 1.74	No controls		No controls	
Dockerty	0.65	0.26, 1.63	2.83	0.29, 27.9	No controls	
Feychting	0.63	0.08, 4.77	0.90	0.12, 7.00	4.44	1.67, 11.7
Linet	1.07	0.82, 1.39	1.01	0.64, 1.59	1.51	0.92, 2.49
London	0.96	0.54, 1.73	0.75	0.22, 2.53	1.53	0.67, 3.50
McBride	0.89	0.62, 1.29	1.27	0.74, 2.20	1.42	0.63, 3.21
Michaelis	1.45	0.78, 2.72	1.06	0.27, 4.16	2.48	0.79, 7.81
Olsen	0.67	0.07, 6.42	No cases		2.00	0.40, 9.93
Savitz	1.61	0.64, 4.11	1.29	0.27, 6.26	3.87	0.87, 17.3
Tomenius	0.57	0.33, 0.99	0.88	0.33, 2.36	1.41	0.38, 5.29
Tynes	1.06	0.25, 4.53	No cases		No cases	
Verkasalo	1.11	0.14, 9.07	No cases		2.00	0.23, 17.7
Study summary	0.95	0.80, 1.12	1.06	0.79, 1.42	1.69*	1.25, 2.29
	1 – <2 mG		2 – <4 mG		≥4 mG	
**United Kingdom	0.84	0.57, 1.24	0.98	0.50, 1.93	1.00	0.30, 3.37

95% CL = 95% confidence limits.
Source: Greenland et al., 2000.

* Mantel-Haenszel analysis (p = 0.01). Maximum-likelihood summaries differed by less than 1% from these summaries; based on 2,656 cases and 7,084 controls. Adjusting for age, sex, and other variables had little effect on summary results.

** These data are from a recent United Kingdom study not included in the Greenland analysis but included in another pooled analysis (Ahlbom et al. 2000). The United Kingdom study included 1,073 cases and 2,224 controls.

For this table, the column headed "estimate" describes the relative risk. Relative risk is the ratio of the risk of childhood leukemia for those in a magnetic field exposure group compared to persons with exposure levels of 1.0 mG or less. For example, Coghill estimated that children with exposures between 1 and 2 mG have 0.54 times the risk of children whose exposures were less than 1 mG. London's study estimates that children whose exposures were greater than 3 mG have 1.53 times the risk of children whose exposures were less than 1 mG. The column headed "95% CL" (confidence limits) describes how much random variation is in the estimate of relative risk. The estimate may be off by some amount due to random variation, and the width of the confidence limits gives some notion of that variation. For example, in Coghill's estimate of 0.54 for the relative risk, values as low as 0.17 or as high as 1.74 would not be statistically significantly different from the value of 0.54. Note there is a wide range of estimates of relative risk across the studies and wide confidence limits for many studies. In light of these findings, the pooling of results can be extremely helpful to calculate an overall estimate, much better than can be obtained from any study taken alone.

studies (Linet, London, McBride, Savitz) were 60 Hz; all other studies were 50 Hz. Results from the recent study from the United Kingdom (see page 17) are also included in the table. This study was included in the analysis by Ahlbom et al. (2000). The relative risk estimates from the individual studies show little or no association of magnetic fields with childhood leukemia. The study summary for the pooled analysis by Greenland et al. (2000) shows a weak association between childhood leukemia and magnetic field exposures greater 3 mG.

Q Is there a link between EMF exposure and childhood brain cancer or other forms of cancer in children?

A Although the earliest studies suggested an association between EMF exposure and all forms of childhood cancer, those initial findings have not been confirmed by other studies. At present, the available series of studies indicates no association between EMF exposure and childhood cancers other than leukemia. Far fewer of these studies have been conducted than studies of childhood leukemia.

Q Is there a link between residential EMF exposure and cancer in adults?

A The few studies that have been conducted to address EMF and adult cancer do not provide strong evidence for an association. Thus, a link has not been established between residential EMF exposure and adult cancers, including leukemia, brain cancer, and breast cancer (see table below).

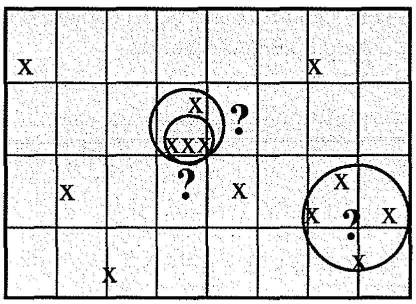
Residential Exposure to Magnetic Fields and Adult Cancer

First author	Location	Type of exposure data	Results (odds ratios) Leukemia	CNS tumors	All cancers
Coleman	United Kingdom	Calculated historical fields	0.92	NA	NA
Feychting and Ahlbom	Sweden	Calculated & spot measurements	1.5*	0.7	NA
Li	Taiwan	Calculated historical fields	1.4*	1.1	NA
Li	Taiwan	Calculated historical fields	1.1 (breast cancer)		
McDowall	United Kingdom	Calculated historical fields	1.43	NA	1.03
Severson	Seattle	Wire codes & spot measurements	0.75	NA	NA
Wrensch	San Francisco	Wire codes & spot measurements	NA	0.9	NA
Youngson	United Kingdom	Calculated historical fields	1.88	NA	NA

CNS = central nervous system.
*The number is statistically significant (greater than expected by chance).
Study results are listed as "odds ratios" (OR). An odds ratio of 1.00 means there was no increase or decrease in risk. In other words, the odds that the people in the study who had the disease (in this case, cancer) and were exposed to a particular agent (in this case, EMF) are the same as for the people in the study who did not have the disease. An odds ratio greater than 1 may occur simply by chance, unless it is statistically significant.

Q Have clusters of cancer or other adverse health effects been linked to EMF exposure?

A An unusually large number of cancers, miscarriages, or other adverse health effects that occur in one area or over one period of time is called a "cluster." Sometimes clusters provide an early warning of a health hazard. But most of the time the reason for the cluster is not known. There have been no proven instances of cancer clusters linked with EMF exposure.



The definition of a "cluster" depends on how large an area is included. Cancer cases (x's in illustration) in a city, neighborhood, or workplace may occur in ways that suggest a cluster due to a common environmental cause. Often these patterns turn out to be due to chance. Delineation of a cluster is subjective—where do you draw the circles?

Q If EMF does cause or promote cancer, shouldn't cancer rates have increased along with the increased use of electricity?

A Not necessarily. Although the use of electricity has increased greatly over the years, EMF exposures may not have increased. Changes in building wiring codes and in the design of electrical appliances have in some cases resulted in lower magnetic field levels. Rates for various types of cancer have shown both increases and decreases through the years, due in part to improved prevention, diagnosis, reporting, and treatment.

Q Is there a link between EMF exposure in electrical occupations and cancer?

A For almost as long as we have been concerned with residential exposure to EMF and childhood cancers, researchers have been studying workplace exposure to EMF and adult cancers, focusing on leukemia and brain cancer. This research began with surveys of job titles and cancer risks, but has progressed to include very large, detailed studies of the health of workers, especially electric utility workers, in the United States, Canada, France, England, and several Northern European countries. Some studies have found evidence that suggests a link between EMF exposure and both leukemia and brain cancer, whereas other studies of similar size and quality have not found such associations.

California
A 1993 study of 36,000 California electric utility workers reported no strong, consistent evidence of an association between magnetic fields and any type of cancer.

Canada/France
A 1994 study of more than 200,000 utility workers in 3 utility companies in Canada and France reported no significant association between all leukemias combined and cumulative exposure to magnetic fields. There was a slight, but not statistically significant, increase in brain cancer. The researchers concluded that the study did not provide clear-cut evidence that magnetic field exposures caused leukemia or brain cancer.

North Carolina
Results of a 1995 study involving more than 138,000 utility workers at 5 electric utilities in the United States did not support an association between occupational magnetic field exposure and leukemia, but suggested a link to brain cancer.

Denmark
In 1997 a study of workers employed in all Danish utility companies reported a small, but statistically significant, excess risk for all cancers combined and for lung cancer. No excess risk was observed for leukemia, brain cancers, or breast cancer.

United Kingdom
A 1997 study among electrical workers in the United Kingdom did not find an excess risk for brain cancer. An extension of this work reported in 2001 also found no increased risk for brain cancer.

Efforts have also been made to pool the findings across several of the above studies to produce more accurate estimates of the association between EMF and cancer (Kheifets et al., 1999). The combined summary statistics across studies provide insufficient evidence for an association between EMF exposure in the workplace and either leukemia or brain cancer.

Q Have studies of workers in other industries suggested a link between EMF exposure and cancer?

A One of the largest studies to report an association between cancer and magnetic field exposure in a broad range of industries was conducted in Sweden (1993). The study included an assessment of EMF exposure in 1,015 different workplaces and involved more than 1,600 people in 169 different occupations. An association was reported between estimated EMF exposure and increased risk for chronic lymphocytic leukemia. An association was also reported between exposure to magnetic fields and brain cancer, but there was no dose-response relationship.

Another Swedish study (1994) found an excess risk of lymphocytic leukemia among railway engine drivers and conductors. However, the total cancer incidence (all tumors included) for this group of workers was lower than in the general Swedish population. A study of Norwegian railway workers found no evidence for an association between EMF exposure and leukemia or brain cancer. Although both positive and negative effects of EMF exposure have been reported, the majority of studies show no effects.

Q Is there a link between EMF exposure and breast cancer?

A Researchers have been interested in the possibility that EMF exposure might cause breast cancer, in part because breast cancer is such a common disease in adult women. Early studies identified a few electrical workers with male breast cancer, a very rare disease. A link between EMF exposure and alterations in the hormone melatonin was considered a possible hypothesis (see page 24). This idea provided motivation to conduct research addressing a possible link between EMF exposure and breast cancer. Overall, the published epidemiological studies have not shown such an association.

Q What have we learned from clinical studies?

A Laboratory studies with human volunteers have attempted to answer questions such as,

Does EMF exposure alter normal brain and heart function?
Does EMF exposure at night affect sleep patterns?
Does EMF exposure affect the immune system?
Does EMF exposure affect hormones?

The following kinds of biological effects have been reported. Keep in mind that a biological effect is simply a measurable change in some biological response. It may or may not have any bearing on health.

Heart rate

An inconsistent effect on heart rate by EMF exposure has been reported. When observed, the biological response is small (on average, a slowing of about three to five beats per minute), and the response does not persist once exposure has ended.

Two laboratories, one in the United States and one in Australia, have reported effects of EMF on heart rate variability. Exposures used in these experiments were relatively high (about 300 mG), and lower exposures failed to produce the effect. Effects have not been observed consistently in repeated experiments.

Sleep electrophysiology

A laboratory report suggested that overnight exposure to 60-Hz magnetic fields may disrupt brain electrical activity (EEG) during night sleep. In this study subjects were exposed to either continuous or intermittent magnetic fields of 283 mG. Individuals exposed to the intermittent magnetic fields showed alterations in traditional EEG sleep parameters indicative of a pattern of poor and disrupted sleep. Several studies have reported no effect with continuous exposure.

Hormones, immune system, and blood chemistry

Several clinical studies with human volunteers have evaluated the effects of power-frequency EMF exposure on hormones, the immune system, and blood chemistry. These studies provide little evidence for any consistent effect.

Melatonin

The hormone melatonin is secreted mainly at night and primarily by the pineal gland, a small gland attached to the brain. Some laboratory experiments with cells and animals have shown that melatonin can slow the growth of cancer cells, including breast cancer cells. Suppressed nocturnal melatonin levels have been observed in some studies of laboratory animals exposed to both electric and magnetic fields. These observations led to the hypothesis that EMF exposure might reduce melatonin and thereby weaken one of the body's defenses against cancer.

Many clinical studies with human volunteers have now examined whether various levels and types of magnetic field exposure affect blood levels of melatonin. Exposure of human volunteers at night to power-frequency EMF under controlled laboratory conditions has no apparent effect on melatonin. Some studies of people exposed to EMF at work or at home do report evidence for a small suppression of melatonin. It is not clear whether the decreases in melatonin reported under environmental conditions are related to the presence of EMF exposure or to other factors.

Q What effects of EMF have been reported in laboratory studies of cells?

A Over the years, scientists have conducted more than 1,000 laboratory studies to investigate potential biological effects of EMF exposure. Most have been *in vitro* studies; that is, studies carried out on cells isolated from animals and plants, or on cell components such as cell membranes. Other studies involved animals, mainly rats and mice. In general, these studies do not demonstrate a consistent effect of EMF exposure.

Most *in vitro* studies have used magnetic fields of 1,000 mG (100 μT) or higher, exposures that far exceed daily human exposures. In most incidences, when one laboratory has reported effects of EMF exposure on cells, other laboratories have not been able to reproduce the findings. For such research results to be widely accepted by scientists as valid, they must be replicated—that is, scientists in other laboratories should be able to repeat the experiment and get similar results. Cellular studies have investigated potential EMF effects on cell proliferation and differentiation, gene expression, enzyme activity, melatonin, and DNA. Scientists reviewing the EMF research literature find overall that the cellular studies provide little convincing evidence of EMF effects at environmental levels.

Q Have effects of EMF been reported in laboratory studies in animals?

A Researchers have published more than 30 detailed reports on both long-term and short-term studies of EMF exposures in laboratory animals (bioassays). Long-term animal bioassays constitute an important group of studies in EMF research. Such studies have a proven record for predicting the carcinogenicity of chemicals, physical agents, and other suspected cancer-causing agents. In the EMF studies, large groups of mice or rats were continuously exposed to EMF for two years or longer and were then evaluated for cancer. The U.S. National Toxicology Program (http://ntp-server.niehs.nih.gov/) has an extensive historical database for hundreds of different chemical and physical agents evaluated using this model. EMF long-term bioassays examined leukemia, brain cancer, and breast cancer—the diseases some epidemiological studies have associated with EMF exposure (see pages 16–23).

Several different approaches have been used to evaluate effects of EMF exposure in animal bioassays. To investigate whether EMF could promote cancer after genetic damage had occurred, some long-term studies used cancer initiators such as ultraviolet light, radiation, or certain chemicals that are known to cause genetic damage. Researchers compared groups of animals treated with cancer initiators to groups treated with cancer initiators and then exposed to EMF, to see if EMF exposure promoted the cancer growth (initiation-promotion model). Other studies tested the cancer promotion potential of EMF using mice that were predisposed to cancer because they had defects in the genes that control cancer.

Animal Leukemia Studies: Long-Term, Continuous Exposure Studies, Two or More Years in Length			
First author	Sex/species	Exposure/animal numbers	Results
Babbitt (U.S.)	Female mice	14,000 mG, 190 or 380 mice per group. Some groups treated with ionizing radiation.	No effect
Boorman (U.S.)	Male and female rats	20 to 10,000 mG, 100 per group	No effect
McCormick (U.S.)	Male and female mice	20 to 10,000 mG, 100 per group	No effect
Mandeville (Canada)	Female rats	20 to 20,000 mG, 50 per group *In utero* exposure	No effect
Yasui (Japan)	Male and female rats	5,000 to 50,000 mG, 50 per group	No effect

10 milligauss (mG) = 1 microtesla (μT) = 0.001 millitesla (mT)

Leukemia

Fifteen animal leukemia studies have been completed and reported. Most tested for effects of exposure to power-frequency (60-Hz) magnetic fields using rodents. Results of these studies were largely negative. The Babbitt study evaluated the subtypes of leukemia. The data provide no support for the reported epidemiology findings of leukemia from EMF exposure. Many scientists feel that the lack of effects seen in these laboratory leukemia studies significantly weakens the case for EMF as a cause of leukemia.

Breast cancer

Researchers in the Ukraine, Germany, Sweden, and the United States have used initiation-promotion models to investigate whether EMF exposure promotes breast cancer in rats.

The results of these studies are mixed; while the German studies showed some effects, the Swedish and U.S. studies showed none. Studies in Germany reported effects on the numbers of tumors and tumor volume. A National Toxicology Program long-term bioassay performed without the use of other cancer-initiating substances showed no effects of EMF exposure on the development of mammary tumors in rats and mice.

The explanation for the observed difference among these studies is not readily apparent. Within the limits of the experimental rodent model of mammary carcinogenesis, no conclusions are possible regarding a promoting effect of EMF on chemically induced mammary cancer.

Other cancers

Tests of EMF effects on skin cancer, liver cancer, and brain cancer have been conducted using both initiation-promotion models and non-initiated long-term bioassays. All are negative.

Three positive studies were reported for a co-promotion model of skin cancer in mice. The mice were exposed to EMF plus cancer-causing chemicals after cancers had already been initiated. The same research team as well as an independent laboratory were unable to reproduce these results in subsequent experiments.

Non-cancer effects

Many animal studies have investigated whether EMF can cause health problems other than cancer. Researchers have examined many endpoints, including birth defects, immune system function, reproduction, behavior, and learning. Overall, animal studies do not support EMF effects on non-cancer endpoints.

Q Can EMF exposure damage DNA?

A Studies have attempted to determine whether EMF has genotoxic potential; that is, whether EMF exposure can alter the genetic material of living organisms. This question is important because genotoxic agents often also cause cancer or birth defects. Studies of genotoxicity have included tests on bacteria, fruit flies, and some tests on rats and mice. Nearly 100 studies on EMF genotoxicity have been reported. Most evidence suggests that EMF exposure is not genotoxic. Based on experiments with cells, some researchers have suggested that EMF exposure may inhibit the cell's ability to repair normal DNA damage, but this idea remains speculative because of the lack of genotoxicity observed in EMF animal studies.

4 Your EMF Environment

This chapter discusses typical magnetic field exposures in home and work environments and identifies common EMF sources and field intensities associated with these sources.

Q How do we define EMF exposure?

A Scientists are still uncertain about the best way to define "exposure" because experiments have yet to show which aspect of the field, if any, may be relevant to reported biological effects. Important aspects of exposure could be the highest intensity, the average intensity, or the amount of time spent above a certain baseline level. The most widely used measure of EMF exposure has been the time-weighted average magnetic field level (see discussion on page 15).

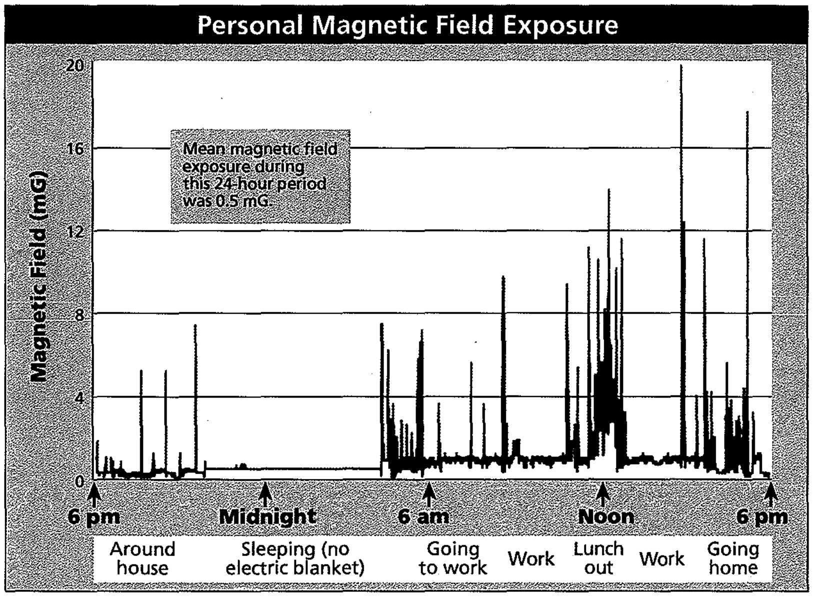
Q How is EMF exposure measured?

A Several kinds of personal exposure meters are now available. These automatically record the magnetic field as it varies over time. To determine a person's EMF exposure, the personal exposure meter is usually worn at the waist or is placed as close as possible to the person during the course of a work shift or day.

EMF can also be measured using survey meters, sometimes called "gaussmeters." These measure the EMF levels in a given location at a given time. Such measurements do not necessarily reflect personal EMF exposure because they are not always taken at the distance from the EMF source that the person would typically be from the source. Measurements are not always made in a location for the same amount of time that a person spends there. Such "spot measurements" also fail to capture variations of the field over time, which can be significant.

Q What are some typical EMF exposures?

A The figure below is an example of data collected with a personal exposure meter.



In the above example, the magnetic field was measured every 1.5 seconds over a period of 24 hours. For this person, exposure at home was very low. The occasional spikes (short exposure to high fields) occurred when the person drove or walked under power lines or over underground power lines or was close to appliances in the home or office.

Several studies have used personal exposure meters to measure field exposure in different environments. These studies tend to show that appliances and building wiring contribute to the magnetic field exposure that most people receive while at home. People living close to high voltage power lines that carry a lot of current tend to have higher overall field exposures. As shown on page 32, there is considerable variation among houses.

Q What are typical EMF exposures for people living in the United States?

A Most people in the United States are exposed to magnetic fields that average less than 2 milligauss (mG), although individual exposures vary.

The following table shows the estimated average magnetic field exposure of the U.S. population, according to a study commissioned by the U.S. government as part of the EMF Research and Public Information Dissemination (EMF RAPID) Program (see page 50). This study measured magnetic field exposure of about 1,000 people of all ages randomly selected among the U.S. population. Participants wore or carried with them a small personal exposure meter and kept a diary of their activities both at home and away from home. Magnetic field values were automatically recorded twice a second for 24 hours. The study reported that exposure to magnetic fields is similar in different regions of the country and similar for both men and women.

Estimated Average Magnetic Field Exposure of the U.S. Population

Average 24-hour field (mG)	Population exposed (%)	95% confidence interval (%)	People exposed* (millions)
> 0.5	76.3	73.8–78.9	197–211
> 1	43.6	40.9–46.5	109–124
> 2	14.3	11.8–17.3	31.5–46.2
> 3	6.3	4.7–8.5	12.5–22.7
> 4	3.6	2.5–5.2	6.7–13.9
> 5	2.42	1.65–3.55	4.4–9.5
> 7.5	0.58	0.29–1.16	0.77–3.1
> 10	0.46	0.20–1.05	0.53–2.8
> 15	0.17	0.035–0.83	0.09–2.2

*Based on a population of 267 million. This table summarizes some of the results of a study that sampled about 1,000 people in the United States. In the first row, for example, we find that 76.3% of the sample population had a 24-hour average exposure of greater than 0.5 mG. Assuming that the sample was random, we can use statistics to say that we are 95% confident that the percentage of the overall U.S. population exposed to greater than 0.5 mG is between 73.8% and 78.9%. Source: Zaffanella, 1993.

The following table shows average magnetic fields experienced during different types of activities. In general, magnetic fields are greater at work than at home.

Estimated Average Magnetic Field Exposure of the U.S. Population for Various Activities

Average field (mG)	Population exposed (%)				
	Home	Bed	Work	School	Travel
> 0.5	69	48	81	63	87
> 1	38	30	49	25	48
> 2	14	14	20	3.5	13
> 3	7.8	7.2	13	1.6	4.1
> 4	4.7	4.7	8.0	< 1	1.5
> 5	3.5	3.7	4.6		1.0
> 7.5	1.2	1.6	2.5		0.5
> 10	0.9	0.8	1.3		< 0.2
> 15	0.1	0.1	0.9		

Source: Zaffanella, 1993.

Q What levels of EMF are found in common environments?

A Magnetic field exposures can vary greatly from site to site for any type of environment. The data shown in the following table are median measurements taken at four different sites for each environment category.

EMF Exposures in Common Environments
Magnetic fields measured in milligauss (mG)

Environment	Median* exposure	Top 5th percentile	Environment	Median* exposure	Top 5th percentile
OFFICE BUILDING			MACHINE SHOP		
Support staff	0.6	3.7	Machinist	0.4	6.0
Professional	0.5	2.6	Welder	1.1	24.6
Maintenance	0.6	3.8	Engineer	1.0	5.1
Visitor	0.6	2.1	Assembler	0.5	6.4
SCHOOL			Office staff	0.7	4.7
Teacher	0.6	3.3	GROCERY STORE		
Student	0.5	2.9	Cashier	2.7	11.9
Custodian	1.0	4.9	Butcher	2.4	12.8
Administrative staff	1.3	6.9	Office staff	2.1	7.1
HOSPITAL			Customer	1.1	7.7
Patient	0.6	3.6			
Medical staff	0.8	5.6			
Visitor	0.6	2.4			
Maintenance	0.6	5.9			

*The median of four measurements. For this table, the median is the average of the two middle measurements. Source: National Institute for Occupational Safety and Health.

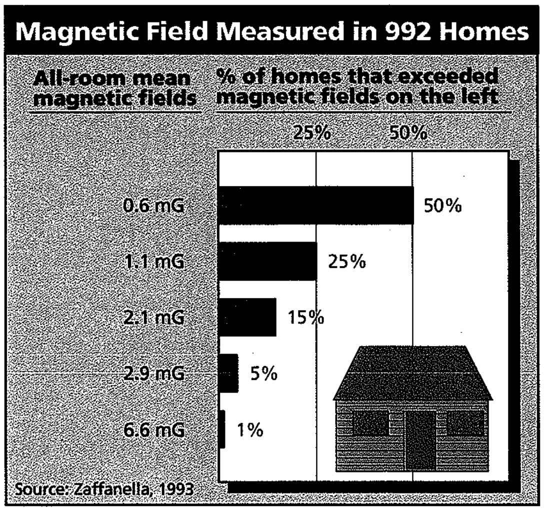
Q What EMF field levels are encountered in the home?

A Electric fields

Electric fields in the home, on average, range from 0 to 10 volts per meter. They can be hundreds, thousands, or even millions of times weaker than those encountered outdoors near power lines. Electric fields directly beneath power lines may vary from a few volts per meter for some overhead distribution lines to several thousands of volts per meter for extra high voltage power lines. Electric fields from power lines rapidly become weaker with distance and can be greatly reduced by walls and roofs of buildings.

Magnetic fields

Magnetic fields are not blocked by most materials. Magnetic fields encountered in homes vary greatly. Magnetic fields rapidly become weaker with distance from the source.



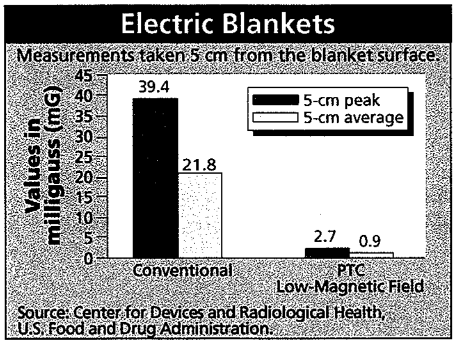
The chart on the left summarizes data from a study by the Electric Power Research Institute (EPRI) in which spot measurements of magnetic fields were made in the center of rooms in 992 homes throughout the United States. Half of the houses studied had magnetic field measurements of 0.6 mG or less, when the average of measurements from all the rooms in the house was calculated (the all-room mean magnetic field). The all-room mean magnetic field for all houses studied was 0.9 mG. The measurements were made away from electrical appliances and reflect primarily the fields from household wiring and outside power lines.

If you are comparing the information in this chart with measurements in your own home, keep in mind that this chart shows averages of measurements taken throughout the homes, not the single highest measurement found in the home.

Q What are EMF levels close to electrical appliances?

A Magnetic fields close to electrical appliances are often much stronger than those from other sources, including magnetic fields directly under power lines. Appliance fields decrease in strength with distance more quickly than do power line fields.

The following table, based on data gathered in 1992, lists the EMF levels generated by common electrical appliances. Magnetic field strength (magnitude) does not depend on how large, complex, powerful, or noisy the appliance is. Magnetic fields near large appliances are often weaker than those near small devices. Appliances in your home may have been redesigned since the data in the table were collected, and the EMF they produce may differ considerably from the levels shown here.



The graph shows magnetic fields produced by electric blankets, including conventional 110-V electric blankets as well as the PTC (positive temperature coefficient) low-magnetic-field blankets. The fields were measured at a distance of about 2 inches from the blanket's surface, roughly the distance from the blanket to the user's internal organs. Because of the wiring, magnetic field strengths vary from point to point on the blanket. The graph reflects this and gives both the peak and the average measurement.

Sources of Magnetic Fields (mG)*

Office Sources	6″	1′	2′	4′
AIR CLEANERS				
Lowest	110	20	3	–
Median	180	35	5	1
Highest	250	50	8	2
COPY MACHINES				
Lowest	4	2	1	–
Median	90	20	7	1
Highest	200	40	13	4
FAX MACHINES				
Lowest	4	–	–	–
Median	6	–	–	–
Highest	9	2	–	–
FLUORESCENT LIGHTS				
Lowest	20	–	–	–
Median	40	6	2	–
Highest	100	30	8	4
ELECTRIC PENCIL SHARPENERS				
Lowest	20	8	5	–
Median	200	70	20	2
Highest	300	90	30	30
VIDEO DISPLAY TERMINALS (see page 48) (PCs with color monitors)**				
Lowest	7	2	1	–
Median	14	5	2	–
Highest	20	6	3	–

Bathroom Sources	6″	1′	2′	4′
HAIR DRYERS				
Lowest	1	–	–	–
Median	300	1	–	–
Highest	700	70	10	1
ELECTRIC SHAVERS				
Lowest	4	–	–	–
Median	100	20	–	–
Highest	600	100	10	1

Workshop Sources	6″	1′	2′	4′
BATTERY CHARGERS				
Lowest	3	2	–	–
Median	30	3	–	–
Highest	50	4	–	–
DRILLS				
Lowest	100	20	3	–
Median	150	30	4	–
Highest	200	40	6	–
POWER SAWS				
Lowest	50	9	1	–
Median	200	40	5	–
Highest	1000	300	40	4
ELECTRIC SCREWDRIVERS (while charging)				
Lowest	–	–	–	–
Median	–	–	–	–
Highest	–	–	–	–

Living/Family Room Sources	1′	2′	4′
CEILING FANS			
Lowest	–	–	–
Median	3	–	–
Highest	50	6	1
WINDOW AIR CONDITIONERS			
Lowest	–	–	–
Median	3	1	–
Highest	20	6	4
COLOR TELEVISIONS**			
Lowest	–	–	–
Median	7	2	–
Highest	20	8	4

Continued

Sources of Magnetic Fields (mG)*

	Distance from source 6"	1'	2'	4'
Kitchen Sources				
BLENDERS				
Lowest	30	5	–	–
Median	70	10	2	–
Highest	100	20	3	–
CAN OPENERS				
Lowest	500	40	3	–
Median	600	150	20	2
Highest	1500	300	30	4
COFFEE MAKERS				
Lowest	4	–	–	–
Median	7	–	–	–
Highest	10	1	–	–
DISHWASHERS				
Lowest	10	6	2	–
Median	20	10	4	–
Highest	100	30	7	1
FOOD PROCESSORS				
Lowest	20	5	–	–
Median	30	6	2	–
Highest	130	20	3	–
GARBAGE DISPOSALS				
Lowest	60	8	1	–
Median	80	10	2	–
Highest	100	20	3	–
MICROWAVE OVENS* **				
Lowest	100	1	1	–
Median	200	4	10	2
Highest	300	200	30	20
MIXERS				
Lowest	30	5	–	–
Median	100	10	1	–
Highest	600	100	10	–

	Distance from source 6"	1'	2'	4'
Kitchen Sources				
ELECTRIC OVENS				
Lowest	4	1	–	–
Median	9	4	–	–
Highest	20	5	1	–
ELECTRIC RANGES				
Lowest	20	–	–	–
Median	30	8	2	–
Highest	200	30	9	6
REFRIGERATORS				
Lowest	–	–	–	–
Median	2	2	1	–
Highest	40	20	10	10
TOASTERS				
Lowest	5	–	–	–
Median	10	3	–	–
Highest	20	7	–	–
Bedroom Sources				
DIGITAL CLOCK******				
Lowest		–	–	–
Median		1	–	–
High		8	2	1
ANALOG CLOCKS (conventional clockface)******				
Lowest		1	–	–
Median		15	2	–
Highest		30	5	3
BABY MONITOR (unit nearest child)				
Lowest	4	–	–	–
Median	6	1	–	–
Highest	15	2	–	–

Continued

Sources of Magnetic Fields (mG)*

	6"	1'	2'	4'
Laundry/Utility Sources				
ELECTRIC CLOTHES DRYERS				
Lowest	2	–	–	–
Median	3	2	–	–
Highest	10	3	–	–
WASHING MACHINES				
Lowest	4	1	–	–
Median	20	7	1	–
Highest	100	30	6	–
IRONS				
Lowest	6	1	–	–
Median	8	1	–	–
Highest	20	3	–	–

	6"	1'	2'	4'
Laundry/Utility Sources				
PORTABLE HEATERS				
Lowest	5	1	–	–
Median	100	20	4	–
Highest	150	40	8	1
VACUUM CLEANERS				
Lowest	100	20	4	–
Median	300	60	10	1
Highest	700	200	50	10

SEWING MACHINES

Home sewing machines can produce magnetic fields of 12 mG at chest level and 5 mG at head level. Magnetic fields as high as 35 mG at chest level and 215 mG at knee level have been measured from industrial sewing machine models (Sobel, 1994).

Source: EMF In Your Environment, U.S. Environmental Protection Agency, 1992.

* Dash (–) means that the magnetic field at this distance from the operating appliance could not be distinguished from background measurements taken before the appliance had been turned on.

** Some appliances produce both 60-Hz and higher frequency fields. For example, televisions and computer screens produce fields at 10,000-30,000 Hz (10-30 kHz) as well as 60-Hz fields.

*** Microwave ovens produce 60-Hz fields of several hundred milligauss, but they also create microwave energy inside the appliance that is at a much higher frequency (about 2.45 billion hertz). We are shielded from the higher frequency fields but not from the 60-Hz fields.

**** Most digital clocks have low magnetic fields. In some analog clocks, however, higher magnetic fields are produced by the motor that drives the hands. In the above table, the clocks are electrically powered using alternating current, as are all the appliances described in these tables.

Q What EMF levels are found near power lines?

A Power transmission lines bring power from a generating station to an electrical substation. Power distribution lines bring power from the substation to your home. Transmission and distribution lines can be either overhead or underground. Overhead lines produce both electric fields and magnetic fields. Underground lines do not produce electric fields above ground but may produce magnetic fields above ground.

Power transmission lines

Typical EMF levels for transmission lines are shown in the chart on page 37. At a distance of 300 feet and at times of average electricity demand, the magnetic fields from many lines can be similar to typical background levels found in most homes. The distance at which the magnetic field from the line becomes indistinguishable from typical background levels differs for different types of lines.

Power distribution lines

Typical voltage for power distribution lines in North America ranges from 4 to 24 kilovolts (kV). Electric field levels directly beneath overhead distribution lines may vary from a few volts per meter to 100 or 200 volts per meter. Magnetic fields directly beneath overhead distribution lines typically range from 10 to 20 mG for main feeders and less than 10 mG for laterals. Such levels are also typical directly above underground lines. Peak EMF levels, however, can vary considerably depending on the amount of current carried by the line. Peak magnetic field levels as high as 70 mG have been measured directly below overhead distribution lines and as high as 40 mG above underground lines.

Q How strong is the EMF from electric power substations?

A In general, the strongest EMF around the outside of a substation comes from the power lines entering and leaving the substation. The strength of the EMF from equipment within the substations, such as transformers, reactors, and capacitor banks, decreases rapidly with increasing distance. Beyond the substation fence or wall, the EMF produced by the substation equipment is typically indistinguishable from background levels.

Q Do electrical workers have higher EMF exposure than other workers?

A Most of the information we have about occupational EMF exposure comes from studies of electric utility workers. It is therefore difficult to compare electrical workers' EMF exposures with those of other workers because there is less information about EMF exposures in work environments other than electric utilities. Early studies did not include actual measurements of EMF exposure on the job but used job titles as an estimate of EMF exposure among electrical workers. Recent studies, however, have included extensive EMF exposure assessments.

A report published in 1994 provides some information about estimated EMF exposures of workers in Los Angeles in a number of electrical jobs in electric utilities and other industries. Electrical workers had higher average EMF exposures (9.6 mG) than did workers in other jobs (1.7 mG). For this study, the category "electrical workers" included electrical engineering technicians, electrical engineers, electricians, power line workers, power station operators, telephone line workers, TV repairers, and welders.

Typical EMF Levels for Power Transmission Lines*

115 kV

		Approx. Edge of Right-of-Way 15 m (50 ft)	30 m (100 ft)	61 m (200 ft)	91 m (300 ft)
Electric Field (kV/m)	1.0	0.5	0.07	0.01	0.003
Mean Magnetic Field (mG)	29.7	6.5	1.7	0.4	0.2

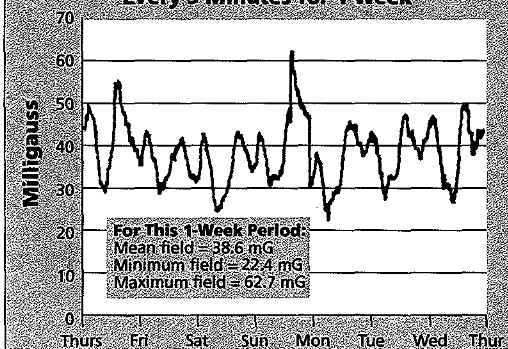
230 kV

		Approx. Edge of Right-of-Way 15 m (50 ft)	30 m (100 ft)	61 m (200 ft)	91 m (300 ft)
Electric Field (kV/m)	2.0	1.5	0.3	0.05	0.01
Mean Magnetic Field (mG)	57.5	19.5	7.1	1.8	0.8

500 kV

		Approx. Edge of Right-of-Way 20 m (65 ft)	30 m (100 ft)	61 m (200 ft)	91 m (300 ft)
Electric Field (kV/m)	7.0	3.0	1.0	0.3	0.1
Mean Magnetic Field (mG)	86.7	29.4	12.6	3.2	1.4

Magnetic Field from a 500-kV Transmission Line Measured on the Right-of-Way Every 5 Minutes for 1 Week



Electric fields from power lines are relatively stable because line voltage doesn't change very much. Magnetic fields on most lines fluctuate greatly as current changes in response to changing loads. Magnetic fields must be described statistically in terms of averages, maximums, etc. The magnetic fields above are means calculated for 321 power lines for 1990 annual mean loads. During peak loads (about 1% of the time), magnetic fields are about twice as strong as the mean levels above. The graph on the left is an example of how the magnetic field varied during one week for one 500-kV transmission line.

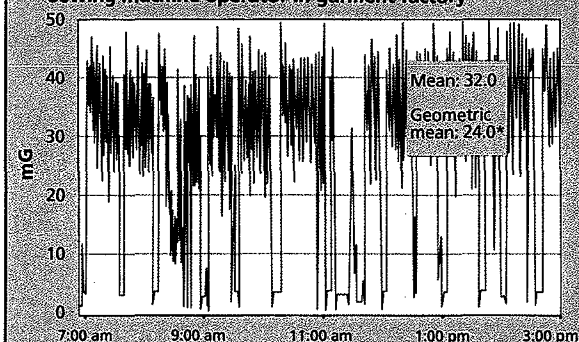
*These are typical EMFs at 1 m (3.3 ft) above ground for various distances from power lines in the Pacific Northwest. They are for general information. For information about a specific line, contact the utility that operates the line.
Source: Bonneville Power Administration, 1994.

Q What are possible EMF exposures in the workplace?

A The figures below are examples of magnetic field exposures determined with exposure meters worn by four workers in different occupations. These measurements demonstrate how EMF exposures vary among individual workers. They do not necessarily represent typical EMF exposures for workers in these occupations.

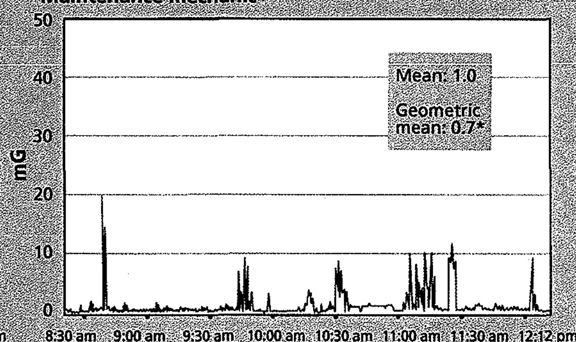
Magnetic Field Exposures of Workers (mG)

Sewing machine operator in garment factory



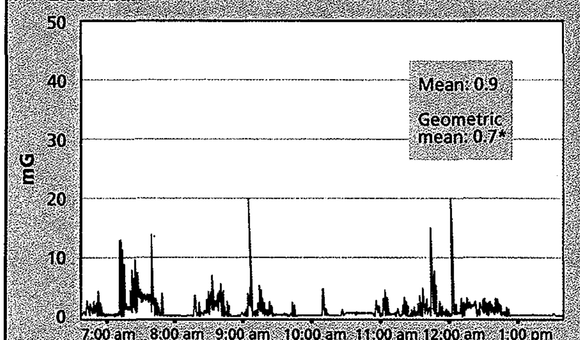
The sewing machine operator worked all day, took a 1-hour lunch break at 11:15 am, and took 10-minute breaks at 8:55 am and 2:55 pm.

Maintenance mechanic



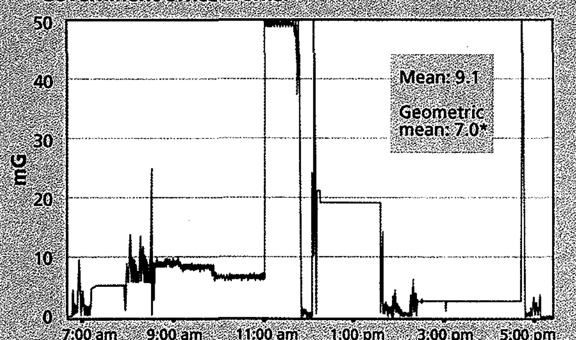
The mechanic repaired a compressor at 9:45 am and 11:10 am.

Electrician



The electrician repaired a large air-conditioning motor at 9:10 am and at 11:45 am.

Government office worker



The government worker was at the copy machine at 8:00 am, at the computer from 11:00 am to 1:00 pm and also from 2:30 pm to 4:30 pm.

*The geometric mean is calculated by squaring the values, adding the squares, and then taking the square root of the sum.
Source: National Institute for Occupational Safety and Health and U.S. Department of Energy

The tables below and on page 41 can give you a general idea about magnetic field levels for different jobs and around various kinds of electrical equipment. It is important to remember that EMF levels depend on the actual equipment used in

EMF Measurements During a Workday

Industry and occupation	ELF magnetic fields measured in mG: Median for occupation*	ELF magnetic fields measured in mG: Range for 90% of workers**
ELECTRICAL WORKERS IN VARIOUS INDUSTRIES		
Electrical engineers	1.7	0.5–12.0
Construction electricians	3.1	1.6–12.1
TV repairers	4.3	0.6–8.6
Welders	9.5	1.4–66.1
ELECTRIC UTILITIES		
Clerical workers without computers	0.5	0.2–2.0
Clerical workers with computers	1.2	0.5–4.5
Line workers	2.5	0.5–34.8
Electricians	5.4	0.8–34.0
Distribution substation operators	7.2	1.1–36.2
Workers off the job (home, travel, etc.)	0.9	0.3–3.7
TELECOMMUNICATIONS		
Install, maintenance, & repair technicians	1.5	0.7–3.2
Central office technicians	2.1	0.5–8.2
Cable splicers	3.2	0.7–15.0
AUTO TRANSMISSION MANUFACTURE		
Assemblers	0.7	0.2–4.9
Machinists	1.9	0.6–27.6
HOSPITALS		
Nurses	1.1	0.5–2.1
X-ray technicians	1.5	1.0–2.2
SELECTED OCCUPATIONS FROM ALL ECONOMIC SECTORS		
Construction machine operators	0.5	0.1–1.2
Motor vehicle drivers	1.1	0.4–2.7
School teachers	1.3	0.6–3.2
Auto mechanics	2.3	0.6–8.7
Retail sales	2.3	1.0–5.5
Sheet metal workers	3.9	0.3–48.4
Sewing machine operators	6.8	0.9–32.0
Forestry and logging jobs	7.6	0.6–95.5***

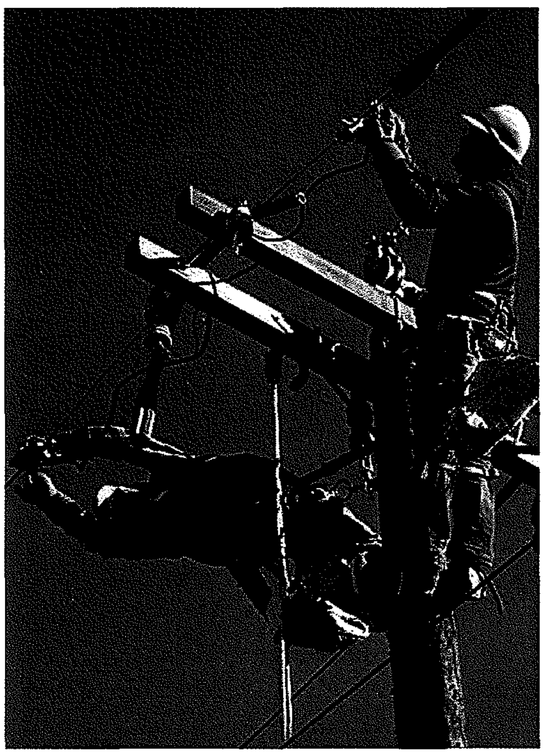
Source: National Institute for Occupational Safety and Health.
ELF (extremely low frequency)—frequencies 3–3,000 Hz.
* The median is the middle measurement in a sample arranged by size. These personal exposure measurements reflect the median magnitude of the magnetic field produced by the various EMF sources and the amount of time the worker spent in the fields.
** This range is between the 5th and 95th percentiles of the workday averages for an occupation.
*** Chain saw engines produce strong magnetic fields that are not pure 60-Hz fields.

the workplace. Different brands or models of the same type of equipment can have different magnetic field strengths. It is also important to keep in mind that the strength of a magnetic field decreases quickly with distance.

If you have questions or want more information about your EMF exposure at work, your plant safety officer, industrial hygienist, or other local safety official can be a good source of information. The National Institute for Occupational Safety and Health (NIOSH) is asked occasionally to conduct health hazard evaluations in workplaces where EMF is a suspected cause for concern. For further technical assistance contact NIOSH at 800-356-4674.

Q What are some typical sources of EMF in the workplace?

A Exposure assessment studies so far have shown that most people's EMF exposure at work comes from electrical appliances and tools and from the building's power supply. People who work near transformers, electrical closets, circuit boxes, or other high-current electrical equipment may have 60-Hz magnetic field exposures of hundreds of milligauss or more. In offices, magnetic field levels are often similar to those found at home, typically 0.5 to 4.0 mG. However, these levels can increase dramatically near certain types of equipment.



EMF Spot Measurements

Industry and sources	ELF magnetic fields (mG)	Other frequencies	Comments
ELECTRICAL EQUIPMENT USED IN MACHINE MANUFACTURING			
Electric resistance heater	6,000–14,000	VLF	
Induction heater	10–460	High VLF	
Hand-held grinder	3,000	–	Tool exposures measured at operator's chest.
Grinder	110	–	Tool exposures measured at operator's chest.
Lathe, drill press, etc.	1–4	–	Tool exposures measured at operator's chest.
ALUMINUM REFINING			
Aluminum pot rooms	3.4–30	Very high static field	Highly-rectified DC current (with an ELF ripple) refines aluminum.
Rectification room	300–3,300	High static field	
STEEL FOUNDRY			
Ladle refinery			
Furnace active	170–1,300	High ULF from the ladle's big magnetic stirrer	Highest ELF field was at the chair of control room operator.
Furnace inactive	0.6–3.7	High ULF from the ladle's big magnetic stirrer	Highest ELF field was at the chair of control room operator.
Electrogalvanizing unit	2–1,100	High VLF	
TELEVISION BROADCASTING			
Video cameras (studio and minicams)	7.2–24.0	VLF	
Video tape degaussers	160–3,300	–	Measured 1 ft away.
Light control centers	10–300	–	Walk-through survey.
Studio and newsrooms	2–5	–	Walk-through survey.
HOSPITALS			
Intensive care unit	0.1–220	VLF	Measured at nurse's chest.
Post-anesthesia care unit	0.1–24	VLF	
Magnetic resonance imaging (MRI)	0.5–280	Very high static field, VLF and RF	Measured at technician's work locations.
TRANSPORTATION			
Cars, minivans, and trucks	0.1–125	Most frequencies less than 60 Hz	Steel-belted tires are the principal ELF source for gas/diesel vehicles.
Bus (diesel powered)	0.5–146	Most frequencies less than 60 Hz	
Electric cars	0.1–81	Some elevated static fields	
Chargers for electric cars	4–63	–	Measured 2 ft from charger.
Electric buses	0.1–88	–	Measured at waist. Fields at ankles 2-5 times higher.
Electric train passenger cars	0.1–330	25 & 60 Hz power on U.S. trains	Measured at waist. Fields at ankles 2-5 times higher.
Airliner	0.8–24.2	400 Hz power on airliners	Measured at waist.
GOVERNMENT OFFICES			
Desk work locations	0.1–7	–	Peaks due to laser printers.
Desks near power center	18–50	–	
Power cables in floor	15–170	–	
Building power supplies	25–1,800	–	
Can opener	3,000	–	Appliance fields measured 6 in. away.
Desktop cooling fan	1,000	–	Appliance fields measured 6 in. away.
Other office appliances	10–200	–	

Source: National Institute for Occupational Safety and Health, 2001.
ULF (ultra low frequency)—frequencies above 0, below 3 Hz.
ELF (extremely low frequency)—frequencies 3–3,000 Hz.
VLF (very low frequency)—frequencies 3,000–30,000 Hz (3–30 kilohertz).

Q What EMF exposure occurs during travel?

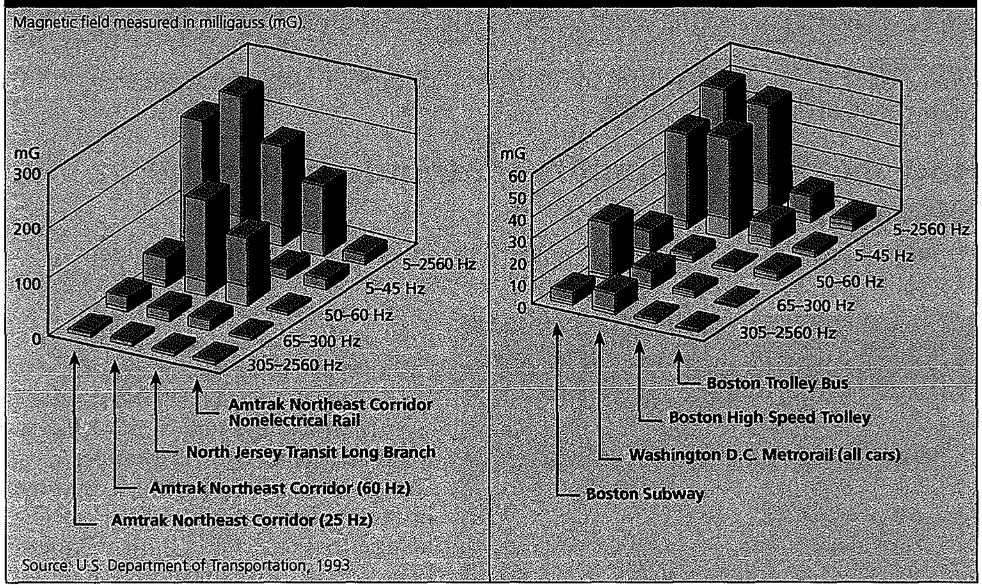
A Inside a car or bus, the main sources of magnetic field exposure are those you pass by (or under) as you drive, such as power lines. Car batteries involve direct current (DC) rather than alternating current (AC). Alternators can create EMF, but at frequencies other than 60 Hz. The rotation of steel-belted tires is also a source of EMF.

Most trains in the United States are diesel powered. Some electrically powered trains operate on AC, such as the passenger trains between Washington, D.C. and New Haven, Connecticut. Measurements taken on these trains using personal exposure monitors have suggested that average 60-Hz magnetic field exposures for passengers and conductors may exceed 50 mG. A U.S. government-sponsored exposure assessment study of electric rail systems found average 60-Hz magnetic field levels in train operator compartments that ranged from 0.4 mG (Boston high speed trolley) to 31.1 mG (North Jersey transit). The graph on the next page shows average and maximum magnetic field measurements in operator compartments of several electric rail systems. It illustrates that 60 Hz is one of several electromagnetic frequencies to which train operators are exposed.

Workers who maintain the tracks on electric rail lines, primarily in the northeastern United States, also have elevated magnetic field exposures at both 25 Hz and 60 Hz. Measurements taken by the National Institute for Occupational Safety and Health show that typical average daily exposures range from 3 to 18 mG, depending on how often trains pass the work site.

Rapid transit and light rail systems in the United States, such as the Washington D.C. Metro and the San Francisco Bay Area Rapid Transit, run on DC electricity. These DC-powered trains contain equipment that produces AC fields. For example, areas of strong AC magnetic fields have been measured on the Washington Metro close to the floor, during braking and acceleration, presumably near equipment located underneath the subway cars.

Magnetic Field Measurements in Train Operators' Compartments



These graphs illustrate that 60 Hz is one of several electromagnetic frequencies to which train operators are exposed. The maximum exposure is the top of the blue (upper) portion of the bar; the average exposure is the top of the red (lower) portion.

Q How can I find out how strong the EMF is where I live and work?

A The tables throughout this chapter can give you a general idea about magnetic field levels at home, for different jobs, and around various kinds of electrical equipment. For specific information about EMF from a particular power line, contact the utility that operates the line. Some will perform home EMF measurements.

You can take your own EMF measurements with a magnetic field meter. For a spot measurement to provide a useful estimate of your EMF exposure, it should be taken at a time of day and location when and where you are typically near the equipment. Keep in mind that the strength of a magnetic field drops off quickly with distance.

Independent technicians will conduct EMF measurements for a fee. Search the Internet under "EMF meters" or "EMF measurement." You should investigate the experience and qualifications of commercial firms, since governments do not standardize EMF measurements or certify measurement contractors.

At work, your plant safety officer, industrial hygienist, or other local safety official can be a good source of information. The National Institute for Occupational Safety and Health (NIOSH) sometimes conducts health hazard evaluations in workplaces where EMF is a suspected cause for concern. For further technical assistance, contact NIOSH at 800-356-4674.

Q How much do computers contribute to my EMF exposure?

A Personal computers themselves produce very little EMF. However, the video display terminal (VDT) or monitor provides some magnetic field exposure unless it is of the new flat-panel design. Conventional VDTs containing cathode ray tubes use magnetic fields to produce the image on the screen, and some emission of those magnetic fields is unavoidable. Unlike most other appliances which produce predominantly 60-Hz magnetic fields, VDTs emit magnetic fields in both the extremely low frequency (ELF) and very low frequency (VLF) frequency ranges (see page 8). Many newer VDTs have been designed to minimize magnetic field emissions, and those identified as "TCO'99 compliant" meet a standard for low emissions (see page 48).

Q What can be done to limit EMF exposure?

A Personal exposure to EMF depends on three things: the strength of the magnetic field sources in your environment, your distance from those sources, and the time you spend in the field.

If you are concerned about EMF exposure, your first step should be to find out where the major EMF sources are and move away from them or limit the time you spend near them. Magnetic fields from appliances decrease dramatically about an arm's length away from the source. In many cases, rearranging a bed, a chair, or a work area to increase your distance from an electrical panel or some other EMF source can reduce your EMF exposure.

Another way to reduce EMF exposure is to use equipment designed to have relatively low EMF emissions. Sometimes electrical wiring in a house or a building can be the source of strong magnetic field exposure. Incorrect wiring is a common source of higher-than-usual magnetic fields. Wiring problems are also worth correcting for safety reasons.

In its 1999 report to Congress, the National Institute of Environmental Health Sciences suggested that the power industry continue its current practice of siting power lines to reduce EMF exposures.

There are more costly actions, such as burying power lines, moving out of a home, or restricting the use of office space that may reduce exposures. Because scientists are still debating whether EMF is a hazard to health, it is not clear that the costs of such measures are warranted. Some EMF reduction measures may create other problems. For instance, compacting power lines reduces EMF but increases the danger of accidental electrocution for line workers.

We are not sure which aspects of the magnetic field exposure, if any, to reduce. Future research may reveal that EMF reduction measures based on today's limited understanding are inadequate or irrelevant. No action should be taken to reduce EMF exposure if it increases the risk of a known safety hazard.

5 EMF Exposure Standards

This chapter describes standards and guidelines established by state, national, and international safety organizations for some EMF sources and exposures.

Q Are there exposure standards for 60-Hz EMF?

A In the United States, there are no federal standards limiting occupational or residential exposure to 60-Hz EMF.

At least six states have set standards for transmission line electric fields; two of these also have standards for magnetic fields (see table below). In most cases, the maximum fields permitted by each state are the maximum fields that existing lines produce at maximum load-carrying conditions. Some states further limit electric field strength at road crossings to ensure that electric current induced into large metal objects such as trucks and buses does not represent an electric shock hazard.

State Transmission Line Standards and Guidelines

	Electric Field		Magnetic Field	
State	On R.O.W.*	Edge R.O.W.	On R.O.W.	Edge R.O.W.
Florida	8 kV/m[a] 10 kV/m[b]	2 kV/m	—	150 mG[a] (max. load) 200 mG[b] (max. load) 250 mG[c] (max. load)
Minnesota	8 kV/m	—	—	—
Montana	7 kV/m[d]	1 kV/m[e]		
New Jersey	—	3 kV/m		
New York	11.8 kV/m 11.0 kV/m[f] 7.0 kV/m[d]	1.6 kV/m	—	200 mG (max. load)
Oregon	9 kV/m	—	—	—

*R.O.W. = right-of-way (or in the Florida standard, certain additional areas adjoining the right-of-way). kV/m = kilovolt per meter. One kilovolt = 1,000 volts. [a]For lines of 69-230 kV. [b]For 500 kV lines. [c]For 500 kV lines on certain existing R.O.W. [d]Maximum for highway crossings. [e]May be waived by the landowner. [f]Maximum for private road crossings.

Two organizations have developed voluntary occupational exposure guidelines for EMF exposure. These guidelines are intended to prevent effects, such as induced currents in cells or nerve stimulation, which are known to occur at high magnitudes, much higher (more than 1,000 times higher) than EMF levels found typically in occupational and residential environments. These guidelines are summarized in the tables on the right.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) concluded that available data regarding potential long-term effects, such as increased risk of cancer, are insufficient to provide a basis for setting exposure restrictions.

The American Conference of Governmental Industrial Hygienists (ACGIH) publishes "Threshold Limit Values" (TLVs) for various physical agents. The TLVs for 60-Hz EMF shown in the table are identified as guides to control exposure; they are not intended to demarcate safe and dangerous levels.

ICNIRP Guidelines for EMF Exposure

Exposure (60 Hz)	Electric field	Magnetic field
Occupational	8.3 kV/m	4.2 G (4,200 mG)
General Public	4.2 kV/m	0.833 G (833 mG)

International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an organization of 15,000 scientists from 40 nations who specialize in radiation protection.
Source: ICNIRP, 1998.

ACGIH Occupational Threshold Limit Values for 60-Hz EMF

	Electric field	Magnetic field
Occupational exposure should not exceed	25 kV/m	10 G (10,000 mG)
Prudence dictates the use of protective clothing above	15 kV/m	–
Exposure of workers with cardiac pacemakers should not exceed	1 kV/m	1 G (1,000 mG)

American Conference of Governmental Industrial Hygienists (ACGIH) is a professional organization that facilitates the exchange of technical information about worker health protection. It is not a government regulatory agency.
Source: ACGIH, 2001.

Q Does EMF affect people with pacemakers or other medical devices?

A According to the U.S. Food and Drug Administration (FDA), interference from EMF can affect various medical devices including cardiac pacemakers and implantable defibrillators. Most current research in this area focuses on higher frequency sources such as cellular phones, citizens band radios, wireless computer links, microwave signals, radio and television transmitters, and paging transmitters.

Sources such as welding equipment, power lines at electric generating plants, and rail transportation equipment can produce lower frequency EMF strong enough to interfere with some models of pacemakers and defibrillators. The occupational exposure guidelines developed by ACGIH state that workers with cardiac pacemakers should not be exposed to a 60-Hz magnetic field greater than 1 gauss (1,000 mG) or a 60-Hz electric field greater than 1 kilovolt per meter (1,000 V/m) (see ACGIH guidelines above). Workers who are concerned about EMF exposure effects on pacemakers, implantable defibrillators, or other implanted electronic medical devices should consult their doctors or industrial hygienists.

Nonelectronic metallic medical implants (such as artificial joints, pins, nails, screws, and plates) can be affected by high magnetic fields such as those from magnetic resonance imaging (MRI) devices and aluminum refining equipment, but are generally unaffected by the lower fields from most other sources.

The FDA MedWatch program is collecting information about medical device problems thought to be associated with exposure to or interference from EMF. Anyone experiencing a problem that might be due to such interference is encouraged to call and report it (800-332-1088).

Q What about products advertised as producing low or reduced magnetic fields?

A Virtually all electrical appliances and devices emit electric and magnetic fields. The strengths of the fields vary appreciably both between types of devices and among manufacturers and models of the same type of device. Some appliance manufacturers are designing new models that, in general, have lower EMF than older models. As a result, the words "low field" or "reduced field" may be relative to older models and not necessarily relative to other manufacturers or devices. At this time, there are no domestic or international standards or guidelines limiting the EMF emissions of appliances.

The U.S. government has set no standards for magnetic fields from computer monitors or video display terminals (VDTs). The Swedish Confederation of Professional Employees (TCO) established in 1992 a standard recommending strict limits on the EMF emissions of computer monitors. The VDTs should produce magnetic fields of no more than 2 mG at a distance of 30 cm (about 1 ft) from the front surface of the monitor and 50 cm (about 1 ft 8 in) from the sides and back of the monitor. The TCO'92 standard has become a *de facto* standard in the VDT industry worldwide. A 1999 standard, promulgated by the Swedish TCO (known as the TCO'99 standard), provides for international and environmental labeling of personal computers. Many computer monitors marketed in the U.S. are certified as compliant with TCO'99 and are thereby assured to produce low magnetic fields.

Beware of advertisements claiming that the federal government has certified that the advertised equipment produces little or no EMF. The federal government has no such general certification program for the emissions of low-frequency EMF. The U.S. Food and Drug Administration's Center for Devices and Radiological Health (CDRH) does certify medical equipment and equipment producing high levels of ionizing radiation or microwave radiation. Information about certain devices as well as general information about EMF is available from the CDRH at 888-463-6332.

Q Are cellular telephones and towers sources of EMF exposure?

A Cellular telephones and towers involve radio-frequency and microwave-frequency electromagnetic fields (see page 8). These are in a much higher frequency range than are the power-frequency electric and magnetic fields associated with the transmission and use of electricity.

The U.S. Federal Communications Commission (FCC) licenses communications systems that use radio-frequency and microwave electromagnetic fields and ensures that licensed facilities comply with exposure standards. Public information on this topic is published on two FCC Internet sites: http://www.fcc.gov/oet/info/documents/bulletins/#56 and http://www.fcc.gov/oet/rfsafety/

The U.S. Food and Drug Administration also provides information about cellular telephones on its web site (http://www.fda.gov/cdrh/ocd/mobilphone.html).

6 National and International EMF Reviews

This chapter presents the findings and recommendations of major EMF research reviews, including the U.S. government's EMF RAPID Program.

Q What have national and international agencies concluded about the impact of EMF exposure on human health?

A Since 1995, two major U.S. reports have concluded that limited evidence exists for an association between EMF exposure and increased leukemia risk, but that when all the scientific evidence is considered, the link between EMF exposure and cancer is weak. The World Health Organization in 1997 reached a similar conclusion.

The two reports were the U.S. National Academy of Sciences report in 1996 and, in 1999, the National Institute of Environmental Health Sciences report to the U.S. Congress at the end of the U.S. EMF Research and Public Information Dissemination (RAPID) Program.

The U.S. EMF RAPID Program

EMF RAPID
Electric and Magnetic Fields Research and Public Information Dissemination Program

Initiated by the U.S. Congress and established by law in 1992, the U.S. EMF Research and Public Information Dissemination (EMF RAPID) Program set out to study whether exposure to electric and magnetic fields produced by the generation, transmission, or use of electric power posed a risk to human health. For more information about the EMF RAPID Program, visit the web site (http://www.niehs.nih.gov/emfrapid).

The U.S. Department of Energy (DOE) administered the overall EMF RAPID Program, but health effects research and risk assessment were supervised by the National Institute of Environmental Health Sciences (NIEHS), a branch of the U.S. National Institutes of Health (NIH). Together, DOE and NIEHS oversaw more than 100 cellular and animal studies, as well as engineering and exposure assessment studies. Although the EMF RAPID Program did not fund any additional epidemiological studies, an analysis of the many studies already conducted was an important part of its final report.

The electric power industry contributed about half, or $22.5 million, of the $45 million eventually spent on EMF research over the course of the EMF RAPID Program. The NIEHS received $30.1 million from this program for research, public outreach, administration, and the health assessment evaluation of extremely low frequency (ELF) EMF. The DOE received approximately $15 million from this program for engineering and EMF mitigation research. The NIEHS contributed an additional $14.5 million for support of extramural and intramural research including long-term toxicity and carcinogenicity studies conducted by the National Toxicology Program.

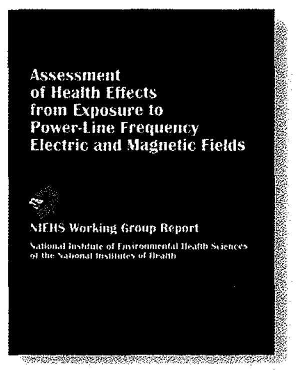
EMF RAPID Program Interagency Committee

- National Institute of Environmental Health Sciences
- Department of Energy
- Department of Defense
- Department of Transportation
- Environmental Protection Agency
- Federal Energy Regulatory Commission
- National Institute of Standards and Technology
- Occupational Safety and Health Administration
- Rural Electrification Administration

An interagency committee was established by the President of the United States to provide oversight and program management support for the EMF RAPID Program. The interagency committee included representatives from NIEHS, DOE, and seven other federal agencies with EMF-related responsibilities.

The EMF RAPID Program also received advice from a National EMF Advisory Committee (NEMFAC), which included representatives from citizen groups, labor, utilities, the National Academy of Sciences, and other groups. They met regularly with DOE and NIEHS staff to express their views. NEMFAC meetings were open to the public. The EMF RAPID Program sponsored citizen participation in some scientific meetings as well. A broad group of citizens reviewed all major public information materials produced for the program.

NIEHS Working Group Report 1998

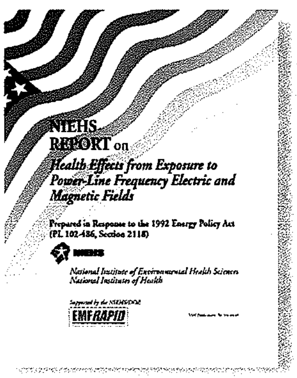


In preparation for the EMF RAPID Program's goal of reporting to the U.S. Congress on possible health effects from exposure to EMF from power lines, the NIEHS convened an expert working group in June 1998. Over 9 days, about 30 scientists conducted a complete review of EMF studies, including those sponsored by the EMF RAPID Program and others. Their conclusions offered guidance to the NIEHS as it prepared its report to Congress.

Using criteria developed by the International Agency for Research on Cancer, a majority of the members of the working group concluded that exposure to power-frequency EMF is a possible human carcinogen.

The majority called their opinion "a conservative public health decision based on limited evidence for an increased occurrence of childhood leukemias and an increased occurrence of chronic lymphocytic leukemia (CLL) in occupational settings." For these diseases, the working group reported that animal and cellular studies neither confirm nor deny the epidemiological studies' suggestion of a disease risk. This report is available on the NIEHS EMF RAPID web site (http://www.niehs.nih.gov/emfrapid).

NIEHS Report to Congress at Conclusion of EMF RAPID Program



In June 1999, the NIEHS reported to the U.S. Congress that scientific evidence for an EMF-cancer link is weak.

The following are excerpts from the 1999 NIEHS report:

> The NIEHS believes that the probability that ELF-EMF exposure is truly a health hazard is currently small. The weak epidemiological associations and lack of any laboratory support for these associations provide only marginal, scientific support that exposure to this agent is causing any degree of harm.
>
> The scientific evidence suggesting that extremely low frequency EMF exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults. While the support from individual studies is weak, the epidemiological studies demonstrate, for some methods of measuring exposure, a fairly consistent pattern of a small, increased risk with increasing exposure that is somewhat weaker for chronic lymphocytic leukemia than for childhood leukemia. In contrast, the mechanistic studies and the animal toxicology literature fail to demonstrate any consistent pattern across studies, although sporadic findings of biological effects (including increased cancers in animals) have been reported. No indication of increased leukemias in experimental animals has been observed.

The full report is available on the NIEHS EMF RAPID web site (http://www.niehs.nih.gov/emfrapid).

No regulatory action was recommended or taken based on the NIEHS report. The NIEHS director, Dr. Kenneth Olden, told the Congress that, in his opinion, the conclusion of the NIEHS report was not sufficient to warrant aggressive regulatory action.

The NIEHS did not recommend adopting EMF standards for electric appliances or burying electric power lines. Instead, it recommended providing public information about practical ways to reduce EMF exposure. The NIEHS also suggested that power companies and utilities "continue siting power lines to reduce exposures and . . . explore ways to reduce the creation of magnetic fields around transmission and distribution lines without creating new hazards." The NIEHS encouraged manufacturers to reduce magnetic fields at a minimal cost, but noted that the risks do not warrant expensive redesign of electrical appliances.

The NIEHS also encouraged individuals who are concerned about EMF in their homes to check to see if their homes are properly wired and grounded, since incorrect wiring or other code violations are a common source of higher-than-usual magnetic fields.

National Academy of Sciences Report

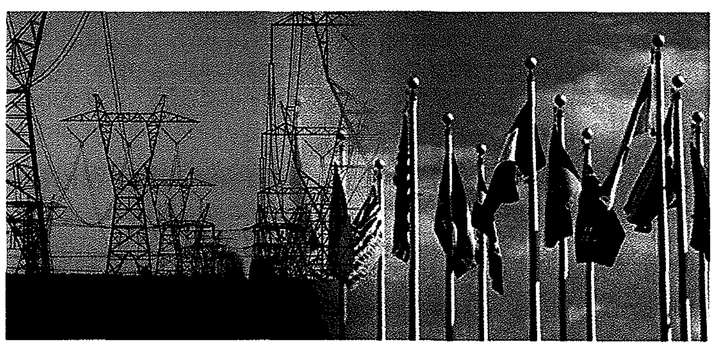
In October 1996, a National Research Council committee of the National Academy of Sciences (NAS) released its evaluation of research on potential associations between EMF exposure and cancer, reproduction, development, learning, and behavior. The report concluded:

> Based on a comprehensive evaluation of published studies relating to the effects of power-frequency electric and magnetic fields on cells, tissues, and organisms (including humans), the conclusion of the committee is that the current body of evidence does not show that exposure to these fields presents a human-health hazard. Specifically, no conclusive and consistent evidence shows that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects.

The NAS report focused primarily on the association of childhood leukemia with the proximity of the child's home to power lines. The NAS panel found that although a link between EMF exposure and increased risk for childhood leukemia was observed in studies that had estimated EMF exposure using the wire code method (distance of home from power line), such a link was not found in studies that had included actual measurements of magnetic fields at the time of the study. The panel called for more research to pinpoint the unexplained factors causing small increases in childhood leukemia in houses close to power lines.

World Health Organization International EMF Project

The World Health Organization (WHO) International EMF Project, with headquarters in Geneva, Switzerland, was launched at a 1996 meeting with representatives of 23 countries attending. It was intended to respond to growing concerns in many member states over possible EMF health effects and to address the conflict between such concerns and technological and economic progress. In its advisory role, the WHO International EMF Project is now reviewing laboratory and epidemiological evidence, identifying gaps in scientific knowledge, developing an agenda for future research, and developing risk communication booklets and other public information. The WHO International EMF Project is funded with contributions from governments and institutions and is expected to provide an overall EMF health risk assessment. Additional information about this program can be found on the WHO EMF web site (http://www.who.int/peh-emf).



As part of this project, in 1997 a working group of 45 scientists from around the world surveyed the evidence for adverse

EMF health effects. They reported that, "taken together, the findings of all published studies are suggestive of an association between childhood leukemia and estimates of ELF (extremely low frequency or power-frequency) magnetic fields."

Much like the 1996 U.S. NAS report, the WHO report noted that living in homes near power lines was associated with an approximate 1.5-fold excess risk of childhood leukemia. But unlike the NAS panel, WHO scientists had seen the results of the 1997 U.S. National Cancer Institute study of EMF and childhood leukemia (see page 17). This work showed even more strongly the inconsistency between results of studies that used a wire code to estimate EMF exposure and studies that actually measured magnetic fields.

Regarding health effects other than cancer, the WHO scientists reported that the epidemiological studies "do not provide sufficient evidence to support an association between extremely-low-frequency magnetic-field exposure and adult cancers, pregnancy outcome, or neurobehavioural disorders."

World Health Organization International Agency for Research on Cancer

The WHO International Agency for Research on Cancer (IARC) produces a monograph series that reviews the scientific evidence regarding potential carcinogenicity associated with exposure to environmental agents. An international scientific panel of 21 experts from 10 countries met in June 2001 to review the scientific evidence regarding the potential carcinogenicity of static and ELF (extremely low frequency or power-frequency) EMF. The panel categorized its conclusions for carcinogenicity based on the IARC classification system—a system that evaluates the strength of evidence from epidemiological, laboratory (human and cellular), and mechanistic studies. The panel classified power-frequency EMF as "possibly carcinogenic to humans" based on a fairly consistent statistical association between a doubling of risk of childhood leukemia and magnetic field exposure above 0.4 microtesla (0.4 μT, 4 milligauss or 4 mG).

In contrast, they found no consistent evidence that childhood EMF exposures are associated with other types of cancer or that adult EMF exposures are associated with increased risk for any kind of cancer. The IARC panel reported that no consistent carcinogenic effects of EMF exposure have been observed in experimental animals and that there is currently no scientific explanation for the observed association between childhood leukemia and EMF exposure. Further information can be obtained at the IARC web sites (http://www.iarc.fr and http://monographs.iarc.fr).

International Commission on Non-Ionizing Radiation Protection

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) issued exposure guidelines to guard against known adverse effects such as stimulation of nerves and muscles at very high EMF levels, as well as shocks and burns caused by touching objects that conduct electricity (see page 47). In April 1998, ICNIRP revised its exposure guidelines and characterized as "unconvincing" the evidence for an association between everyday power-frequency EMF and cancer.

European Union

In 1996, a European Union (EU) advisory panel provided an overview of the state of science and standards among EU countries. With respect to power-frequency EMF, the panel members said that there is no clear evidence that exposure to EMF results in an increased risk of cancer.

Australia—Radiation Advisory Committee Report to Parliament

In 1997, Australia's Radiation Advisory Committee briefly reviewed the EMF scientific literature and advised the Australian Parliament that, overall, there is insufficient evidence to come to a firm conclusion regarding possible health effects from exposure to power-frequency magnetic fields.

The committee also reported that "the weight of opinion as expressed in the U.S. National Academy of Sciences report, and the negative results from the National Cancer Institute study (Linet et al., 1997) would seem to shift the balance of probability more towards there being no identifiable health effects" (see pages 17 and 53).

Canada—Health Canada Report

In December 1998, a working group of public health officers at Health Canada, the federal agency that manages Canada's health care system, issued a review of the scientific literature regarding power-frequency EMF health effects. They found the evidence to be insufficient to conclude that EMF causes a risk of cancer.

The report concluded that while EMF effects may be observed in biological systems in a laboratory, no adverse health effects have been demonstrated at the levels to which humans and animals are typically exposed.

As for epidemiology, 25 years of study results are inconsistent and inconclusive, the panel said, and a plausible EMF-cancer mechanism is missing. Health Canada pledged to continue monitoring EMF research and to reassess this position as new information becomes available.

Germany—Ordinance 26

On January 1, 1997, Germany became the first nation to adopt a national rule on EMF exposure for the general public. Ordinance 26 applies only to facilities such as overhead and underground transmission and distribution lines, transformers, switchgear and overhead lines for electric-powered trains. Both electric (5 kV/m) and magnetic field exposure limits (1 Gauss) are high enough that they are unlikely to be encountered in ordinary daily life. The ordinance also requires that precautionary measures be taken on a case-by-case basis when electric facilities are sited or upgraded near homes, hospital, schools, day care centers, and playgrounds.

Great Britain—National Radiological Protection Board Report

The National Radiological Protection Board (NRPB) in Great Britain advises the government of the United Kingdom regarding standards of protection for exposure to non-ionizing radiation. The NRPB's advisory group on non-ionizing radiation periodically reviews new developments in EMF research and reports its findings. Results of the advisory group's latest review were published in 2001. The report reviewed residential and occupational epidemiological studies, as well as cellular, animal, and human volunteer studies that had been published.

The advisory group noted that there is "some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children." Specifically, the NRPB advisory group's analysis suggests "that relatively heavy average exposures of 0.4 μT [4 mG] or more are associated with a doubling of the risk of leukaemia in children under 15 years of age." The group pointed out, however, that laboratory experiments have provided "no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer."

Scandinavia—EMF Developments

In October 1995, a group of Swedish researchers and government officials published a report about EMF exposure in the workplace. This "Criteria Group" reviewed EMF scientific literature and, using the IARC classification system, ranked occupational EMF exposure as "possibly carcinogenic to humans." They also endorsed the Swedish government's 1994 policy statement that public exposure limits to EMFs were not needed, but that people might simply want to use caution with EMFs.

In 1996, five Swedish government agencies further explained their precautionary advice about EMF. EMF exposure should be reduced, they said, but only when practical, without great inconvenience or cost.

Health experts in Norway, Denmark, and Finland generally agreed in reviews published in the 1990s that if an EMF health risk exists, it is small. They acknowledged that a link between residential magnetic fields and childhood leukemia cannot be confirmed or denied. In 1994, several Norwegian government ministries also recommended increasing the distance between residences and electrical facilities, if it could be done at low cost and with little inconvenience.

Q What other U.S. organizations have reported on EMF?

A American Medical Association

In 1995, the American Medical Association advised physicians that no scientifically documented health risk had been associated with "usually occurring" EMF, based on a review of EMF epidemiological, laboratory studies, and major literature reviews.

American Cancer Society

In 1996, the American Cancer Society released a review of 20 years of EMF epidemiological research including occupational studies and residential studies of adult and childhood cancer. The society noted that some data support a possible relationship of magnetic field exposure with leukemia and brain cancer, but further research may not be justified if studies continue to find uncertain results. Of particular interest is the summary of results from eight studies of risk from use of household appliances with relatively high magnetic fields, such as electric blankets and electric razors. The summary suggested that there is no persuasive evidence for increased risk with more frequent or longer use of these appliances.

American Physical Society

The American Physical Society (APS) represents thousands of U.S. physicists. Responding to the NIEHS Working Group's conclusion that EMF is a possible human carcinogen, the APS executive board voted in 1998 to reaffirm its 1995 opinion that there is "no consistent, significant link between cancer and power line fields."

California's Department of Health Services

In 1996, California's Department of Health Services (DHS) began an ambitious five-year effort to assess possible EMF public health risk and offer guidance to school administrators and other decision-makers. The California Electric and Magnetic Fields (EMF) Program is a research, education, and technical assistance program concerned with the possible health effects of EMF from power lines, appliances, and other uses of electricity. The program's goal is to find a rational and fair approach to dealing with the potential risks, if any, of exposure to EMF. This is done through research, policy analysis, and education. The web site has educational materials on EMF and related health issues for individuals, schools, government agencies, and professional organizations (http://www.dhs.ca.gov/ps/deodc/ehib/emf).

Q What can we conclude about EMF at this time?

A Electricity is a beneficial part of our daily lives, but whenever electricity is generated, transmitted, or used, electric and magnetic fields are created. Over the past 25 years, research has addressed the question of whether exposure to power-frequency EMF might adversely affect human health. For most health outcomes, there is no evidence that EMF exposures have adverse effects. There is some evidence from epidemiology studies that exposure to power-frequency EMF is associated with an increased risk for childhood leukemia. This association is difficult to interpret in the absence of reproducible laboratory evidence or a scientific explanation that links magnetic fields with childhood leukemia.

EMF exposures are complex and come from multiple sources in the home and workplace in addition to power lines. Although scientists are still debating whether EMF is a hazard to health, the NIEHS recommends continued education on ways of reducing exposures. This booklet has identified some EMF sources and some simple steps you can take to limit your exposure. For your own safety, it is important that any steps you take to reduce your exposures do not increase other obvious hazards such as those from electrocution or fire. At the current time in the United States, there are no federal standards for occupational or residential exposure to 60-Hz EMF.

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