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EMF

Electric and Magnetic Fields
Associated with the
Use of Electric Power



Questions
&
Answers



prepared by the
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EMF RAPID
Electric and Magnetic Fields Research and Public Information Dissemination Program

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I ntroduction

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.

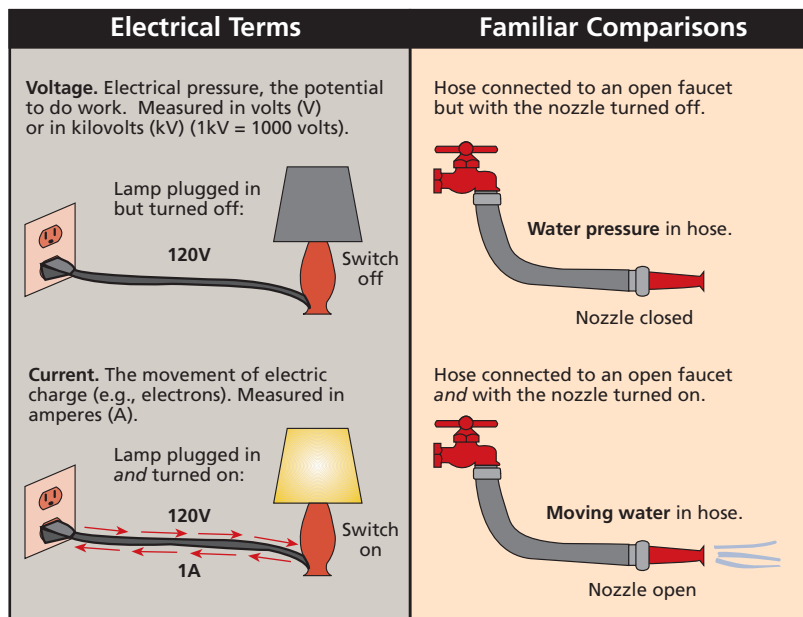
EMF exposures are complex and exist in the home and workplace as a result of all types of electrical equipment and building wiring as well as a result of nearby power lines. This booklet explains the basic principles of electric and magnetic fields, provides an overview of the results of major research 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.

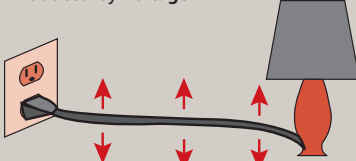
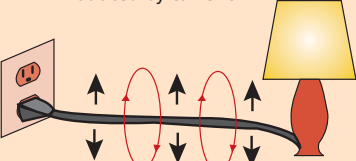
Electric fields are produced by voltage and increase in strength as the voltage increases. The electric field strength is measured in units of volts per meter (V/m). Magnetic fields result from the flow of current through wires or electrical devices and increase in strength as the current increases.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

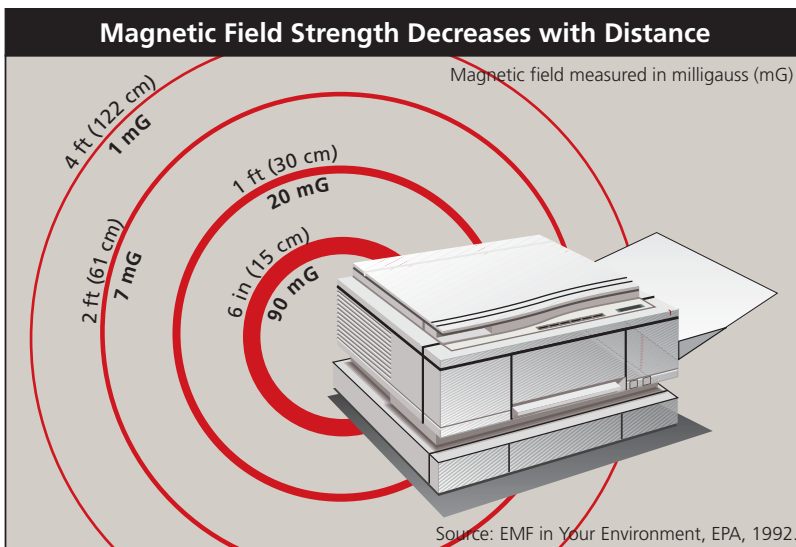
of EMF (sometimes called “transients”) can also occur when electrical devices are turned on or off.

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.

A Comparison of Electric and Magnetic Fields	
<p>Electric Fields</p> <ul style="list-style-type: none"> • Produced by voltage.  <p>Lamp plugged in but turned off. Voltage produces an electric field.</p> <ul style="list-style-type: none"> • Measured in volts per meter (V/m) or in kilovolts per meter (kV/m). • Easily shielded (weakened) by conducting objects such as trees and buildings. • Strength decreases rapidly with increasing distance from the source. 	<p>Magnetic Fields</p> <ul style="list-style-type: none"> • Produced by current.  <p>Lamp plugged in and turned on. Current now produces a magnetic field also.</p> <ul style="list-style-type: none"> • Measured in gauss (G) or tesla (T). • Not easily shielded (weakened) by most material. • Strength decreases rapidly with increasing distance from the source.

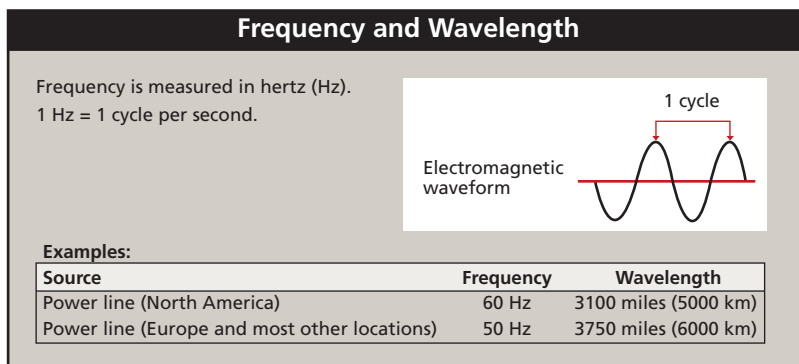
An appliance that is plugged in and therefore connected to a source of electricity has an electric field even when the appliance is turned off. To produce a magnetic field, the appliance must be plugged in and turned on so that the current is flowing.



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.



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 (μ T) 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 μ T

To convert a measurement from microtesla (μ T) to milligauss (mG), multiply by 10.

1 μ T = 10 mG; 0.1 μ T = 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?

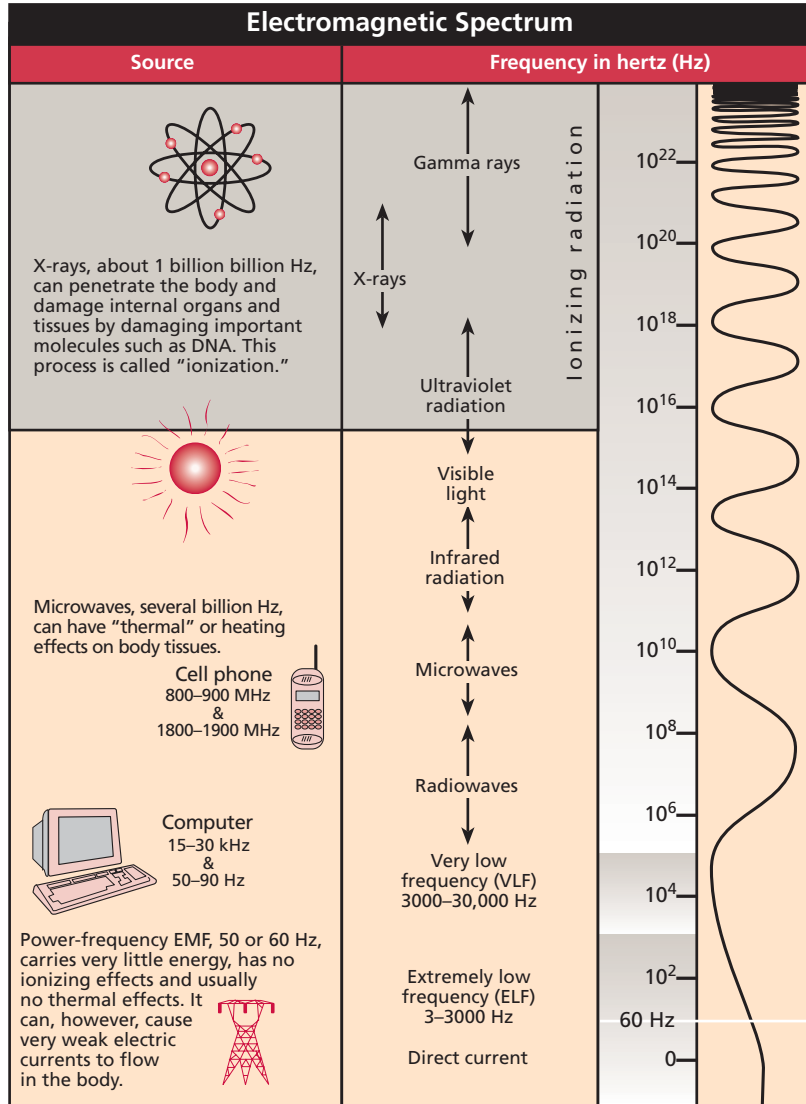
A X-rays, visible light, microwaves, radio waves, and EMF are all forms of electromagnetic energy. One property that distinguishes different forms of electromagnetic energy is the frequency, expressed in hertz (Hz). Power-frequency EMF, 50 or 60 Hz, carries very little energy, has no ionizing effects, 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 $10 \times 10 \times 10 \times 10$ 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.

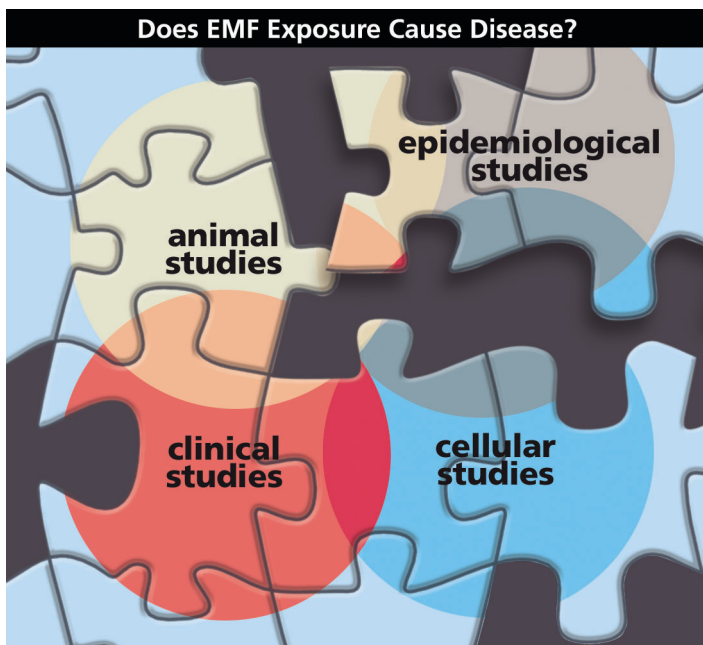
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Evaluating Potential Health Effects

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.

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.

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.

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

First author	Magnetic field category (mG)					
	>1 – ≤2 mG		>2 – ≤3 mG		>3 mG	
	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
Linnet	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
**United Kingdom	1 – <2 mG		2 – <4 mG		≥4 mG	
	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 (Linnet, 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?

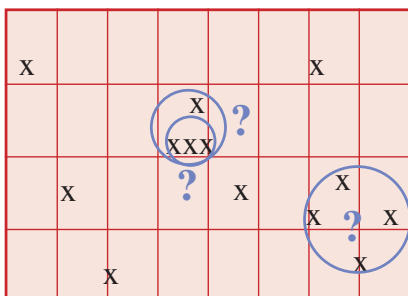
A The few studies that have been conducted to address EMF and adult cancer do not provide strong evidence for an association. Thus, a link has not been established between residential EMF exposure and adult cancers, including leukemia, brain cancer, and breast cancer (see table below).

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 μ T) 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 <i>In utero</i> 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 (μ T) = 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).

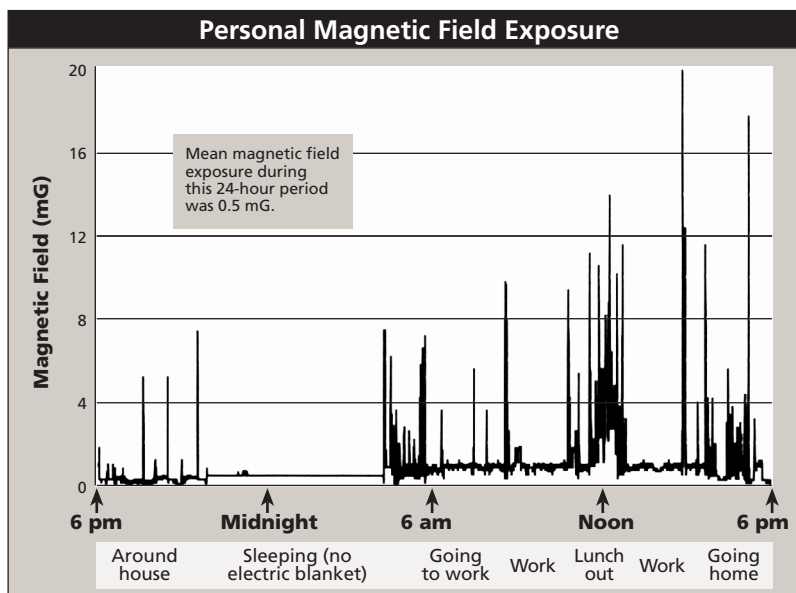
Q How is EMF exposure measured?

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