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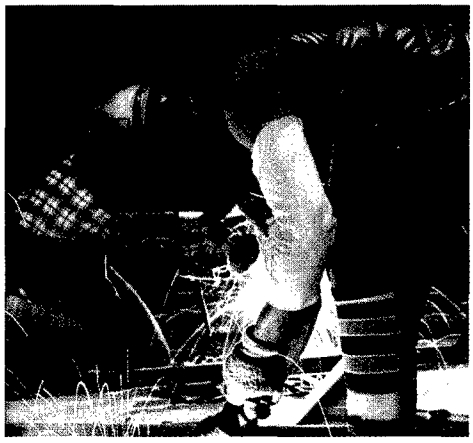
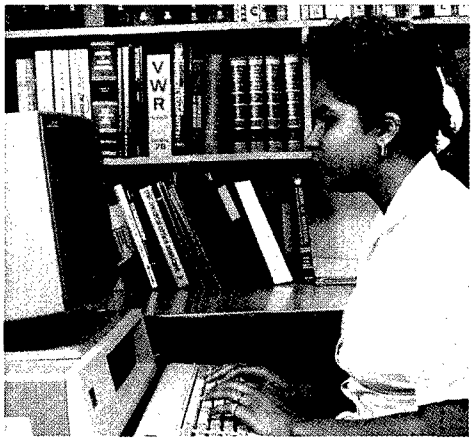
SEPTEMBER 1996

QUESTIONS AND ANSWERS

EMF IN THE WORKPLACE

ELECTRIC AND MAGNETIC FIELDS ASSOCIATED WITH THE USE OF ELECTRIC POWER





NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

NATIONAL INSTITUTE OF ENVIRONMENTAL HEALTH SCIENCES

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SEPTEMBER 1996

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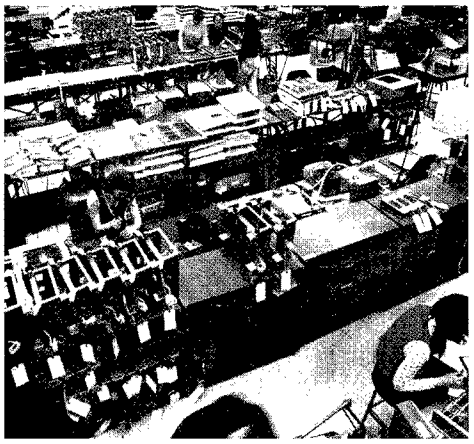
The booklet was written by staff members of the U.S. Department of Energy (DOE), the National Institute for Occupational Safety and Health (NIOSH), the National Institute of Environmental Health Sciences (NIEHS), and Oak Ridge National Laboratory. It was reviewed by experts from federal and state agencies, academic institutions, national laboratories, citizen groups, labor organizations, and industry.



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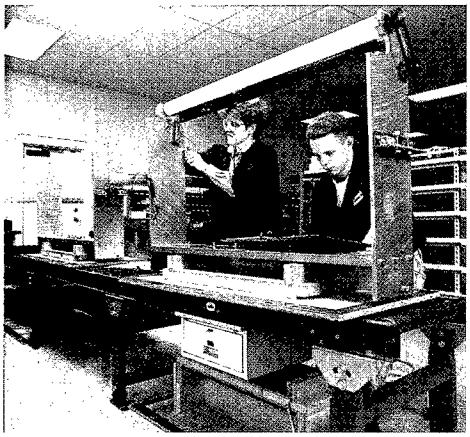
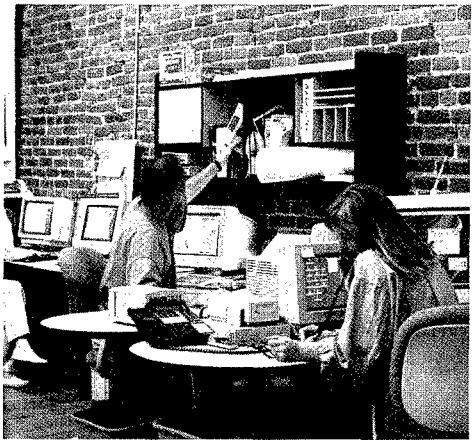


EMF In the Workplace is the second public information booklet produced by the EMF RAPID Program and focuses on occupational EMF exposure. Information about residential EMF exposure is provided in a previous booklet: *Questions and Answers About EMF,* available from the EMF Infoline: (800) 363-2383.

What's Inside

It is a modern fact of life that whether we are at work, at home, or at school, we are all exposed to EMFs—electric and magnetic fields produced by the generation, transmission, and use of electricity.

Some human health studies suggest that there may be a link between exposure to EMFs and certain types of cancer, primarily leukemia and brain cancer. Some scientists doubt that this apparent connection between EMF exposure and cancer is real, because it is difficult to explain biologically and because the research results are inconsistent. Most agree that more information is needed to resolve the issue about whether or not EMFs affect human health. The U.S. government has initiated a national EMF research effort and important study results are expected in the next few years.



The purpose of this booklet is to provide information about EMF exposure in the workplace. The booklet describes what researchers have learned (and have yet to learn) about EMFs and identifies some sources of EMFs in various industries.

At present, we do not have enough information to determine if EMF exposure causes adverse health effects. The information in this booklet should help workers and employers understand the scientific basis for the concerns and the uncertainties about EMF exposure.

Contents

EMF Basics

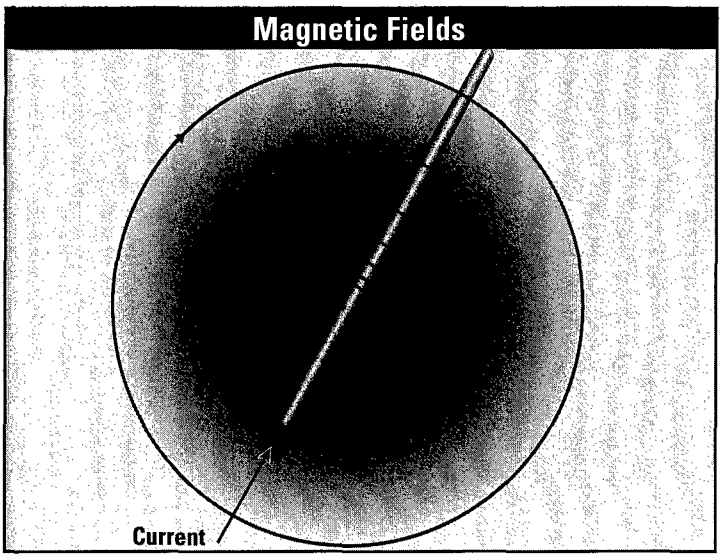
This chapter reviews basic terms needed to understand electric and magnetic fields, compares EMF with other forms of electromagnetic energy, and briefly discusses how such fields may affect us.

What are EMFs?

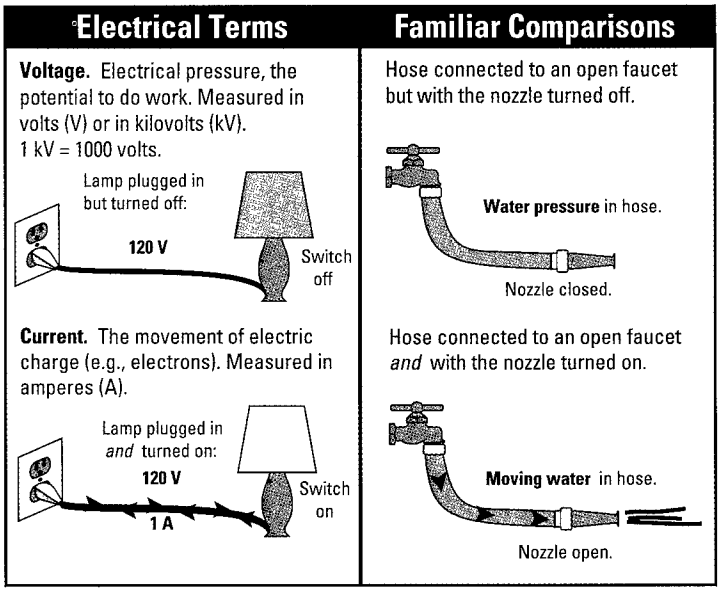
Electric and magnetic fields (EMFs) are produced by power lines, electrical wiring, and electrical equipment. There are many other sources of EMFs (see page 8). The focus of this booklet is on EMFs associated with the generation, transmission, and use of electric power. EMFs are invisible lines of force that surround any electrical device. 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, on the other hand, are present even when the equipment is switched off, as long as it remains connected to the source of electric power (see the following page).

Electric fields are shielded or weakened by materials that conduct electricity (including trees, buildings, and human skin). Magnetic fields, on the other hand, pass through most materials and are therefore more difficult to shield. Both electric and magnetic fields decrease as the distance from the source increases.

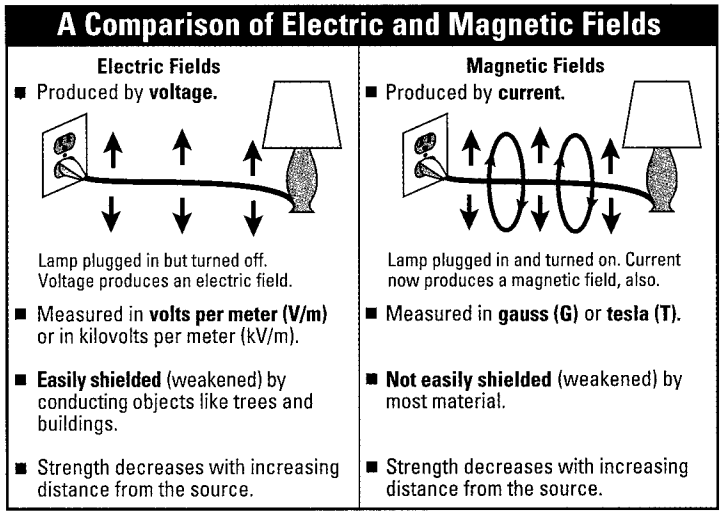
Even though both electric and magnetic fields are present around electrical equipment and power lines, most recent research has focused on potential health effects of magnetic fields. This is because some epidemiologic studies have reported an increased cancer risk associated with estimates of magnetic field exposure. (See the Human Health Studies section on page 11 for a summary of these studies.) No similar associations have been reported for electric fields.



Current flowing through a conductor creates magnetic fields, which form continuous loops around the current. Everything that carries electric power produces electric and magnetic fields. This includes power lines, wiring, and electrical equipment.



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



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, however, the appliance must not only be plugged in but also turned on, so that the current is flowing.

Measuring EMFs: 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 field intensity is 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. One tesla equals 10,000 gauss.

1 T = 10,000 G

Since most environmental EMF exposures involve magnetic field intensities which are only a fraction of a tesla or a gauss, these are commonly measured in units of **microteslas (μT)** or **milligauss (mG)**. A milligauss is 1/1000 of a gauss. A microtesla is 1/1,000,000 of a tesla.

1 G = 1000 mG 1 T = 1,000,000 μT

To convert a measurement from microteslas (μT) to milligauss (mG), multiply by 10.

1 μT = 10 mG 0.1 μT = 1 mG

Wavelength and frequency

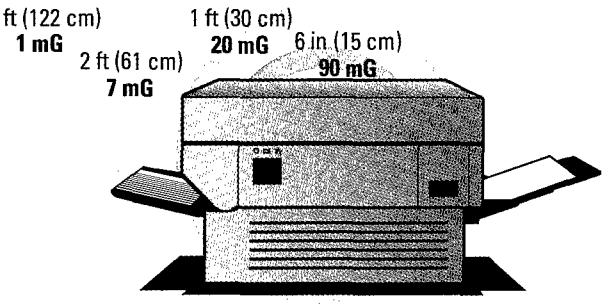
Electric and magnetic fields can be characterized by their wavelength, frequency, and amplitude (or field intensity). Wavelength describes the distance between one peak on the wave and the next peak. The frequency, measured in **hertz (Hz)**, describes how many wave peaks pass by in 1 second of time. Electricity in North America alternates 60 times each second and thus has a frequency of 60 cycles per second, or 60 Hz. In many other parts of the world, the frequency for electric power is 50 Hz.

How is the term EMF used in this booklet?

When you hear about EMFs in the news, the term 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 the Electromagnetic Spectrum on the next page). When we use EMF in this booklet, we mean power-frequency EMFs which are in the extremely low frequency (ELF) range as illustrated on the next page. In the ELF range, electric and magnetic fields are not coupled or interrelated in the the same way that they are at higher frequencies. One of the consequences is that ELF fields do not radiate as do higher frequency fields. So, it is actually more accurate 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.

What Does a Magnetic Field Look Like?

Magnetic field measured in milligauss (mG)



Source: EMF in Your Environment, EPA, 1992

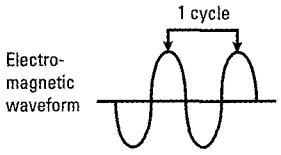
You cannot see a magnetic field, but this illustration represents how the strength of the magnetic field—measured in milligauss—can diminish just 1 to 2 feet (30 to 61 centimeters) from the source. This magnetic field is a 60-Hz power-frequency field.

Frequency and Wavelength

Frequency is shown in **Hertz (Hz).** 1 Hz = 1 cycle per second.

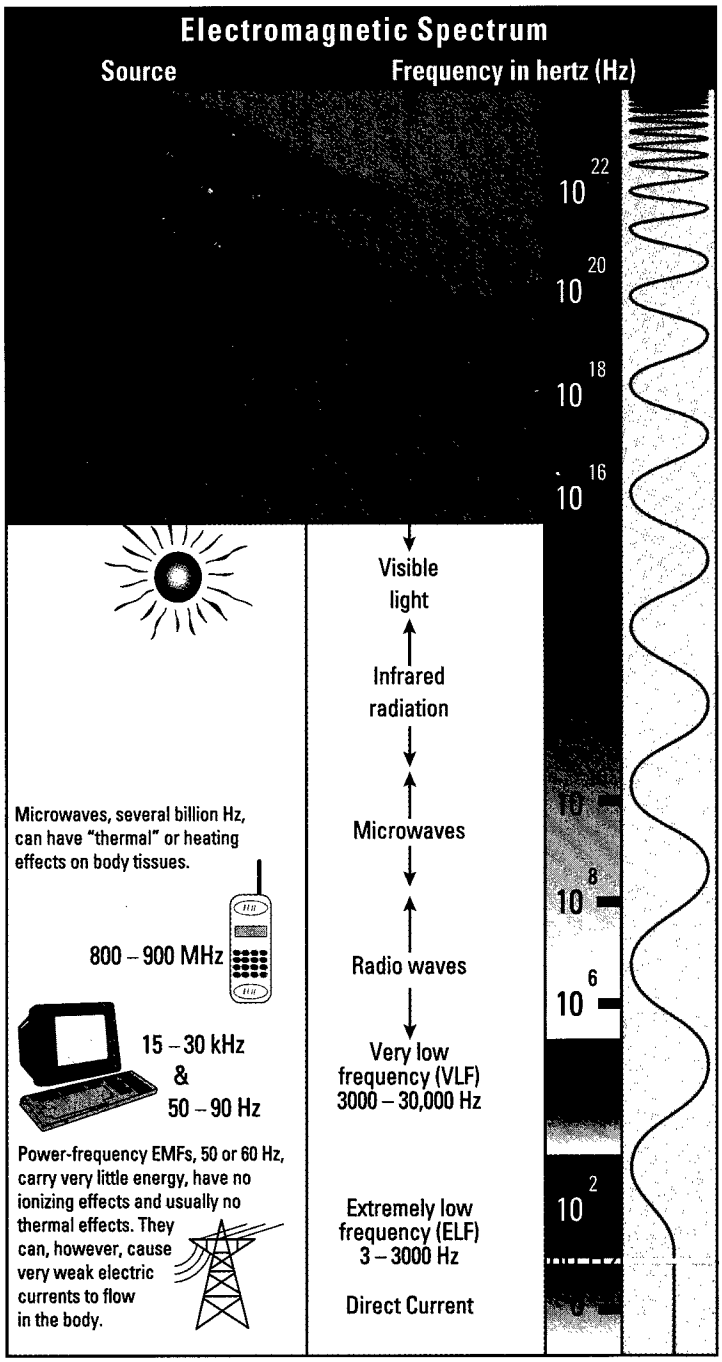
kHz = kilohertz = 1000 Hz

MHz = megahertz = 1,000,000 Hz



Examples:

Source	Frequency	Wavelength
Power line	60 Hz	3100 miles (5000 km)
Microwave oven (inside)	2450 MHz	4.8 inches (12.2 cm)



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 all 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.

How are EMFs different from other types of electromagnetic energy?

X-rays, visible light, microwaves, radio waves, and EMFs are all forms of electromagnetic energy. One property that distinguishes different forms of electromagnetic energy is the frequency, expressed in hertz (Hz).

Just as various chemicals affect our bodies in different ways, various forms of electromagnetic energy can have very different biological effects (see the Biological Studies section on page 22).

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 range, in addition to power-frequency EMFs. 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 Hz). We are shielded from the higher frequency fields by the casing of the oven, but we are not shielded from the 60-Hz fields.

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

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

Some equipment can run on either alternating current (AC) or direct current (DC). 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 Hz (in most parts of the United States). If the equipment uses batteries, then electric current flows in one direction only, from the batteries to the equipment. This 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 their normal operation. AC electric power produces magnetic fields that can generate weak electric currents in humans. These are called induced currents. Much of the research on how EMFs may affect human health has focused on AC-induced currents. It should be noted, however, that very strong DC magnetic fields are present in some industrial environments and may be of concern for other reasons, such as potential effects on implanted medical devices. (See page 40 for more information about effects of magnetic fields on pacemakers and other medical devices.) DC electric power does not induce electric currents in humans in most practical situations. Induced currents from AC fields have been a focus for research on how EMFs could affect human health.

Doesn't the earth produce EMFs?

The earth produces EMFs, mainly in the form of static fields, like the fields generated by DC electricity. Electric fields are produced by thunderstorms and other atmospheric activity. Magnetic fields of around 500 mG are 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 the same way that fields associated with alternating current do. Therefore, concerns about power-frequency sources of EMFs (which involve alternating fields), cannot simply be dismissed by the argument that much stronger magnetic fields already exist in nature.

What happens when I am exposed to EMFs?

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 only occur at close range because electric fields are easily shielded or weakened by buildings, trees, and other objects that conduct electricity.

Magnetic fields

Alternating magnetic fields produced by AC electricity can induce weak electric current flow in the body. However, these currents are typically much smaller than those produced naturally by the brain, nerves, and heart.

How do we define EMF exposure?

No one knows which aspect of EMF exposure, if any, affects human health. Many questions must be asked when gathering information about EMF exposures:

How strong is the EMF?

Field strength (or magnitude) may be an important aspect of EMF exposure to consider, but it may not be the only one.

How long does the exposure last?

Does the EMF source operate continuously? How long are you near that source?

When does the EMF exposure occur?

The time of day, point in a person's sleep/wake cycle, or even stage of life may be important.

What is the frequency?

The frequency measured in hertz (Hz) tells us how many times the current changes direction or cycles in 1 second. A mixture of different electromagnetic frequencies is often present in work environments.

How consistent is the exposure?

It may be important to measure the intermittency of the exposure—how often or how much your exposure changes over time. Our bodies adapt to continued exposure but may need a certain amount of time at a steady exposure to respond or adjust.

Are there any short bursts or spikes in the field?

During our workday, most of us experience very brief bursts of EMF exposure when electrical equipment is turned on or off (see page 32). Research is under way to see if such transient exposures are important.

What is the average field strength?

With cancer-causing chemicals, a person's average exposure over many years can be a good way to predict their chances of getting the disease. So, in occupational EMF studies, the information reported most often has been a worker's EMF exposure averaged over time. This may not, however, be the only or the most important aspect of EMF exposure to consider (see page 30).

There are different ways to calculate average magnetic field exposures. One method for determining an individual's average exposure involves having the person wear a small monitor that takes many measurements over a shift, a day, or longer. Then the average of those measurements is calculated. Sometimes averages are calculated for people with the same occupation, working in similar environments, or using several brands of the same type of equipment.

Means and Medians

One way to determine a value that represents a group of measurements is to add all measurements in a sample and divide by the number of measurements taken. This is called the **arithmetic mean.** Another common way to find a representative value for a series of measurements is to select the **median**—the middle measurement in a sample arranged by size. Half of the measurements are higher than the median and half are lower. Sometimes EMF studies report the **geometric mean,** which involves squaring the values, adding the squares, and then taking the square root of the sum. This procedure is often used to calculate an average when there are a few very large measurements in a sample.

Human Health Studies

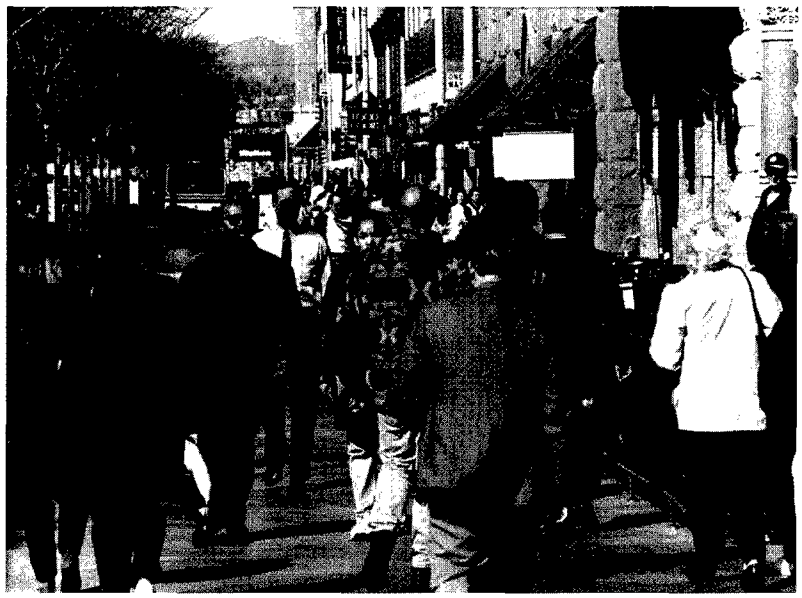
This chapter gives some background information about epidemiology and summarizes results of major occupational EMF studies.

How do researchers study the possible effects of EMFs on people?

Although animal experiments, cell culture studies, and computer models provide useful information, most researchers agree that one of the most valuable tools to help identify human health risks associated with exposure to a particular agent is to study a human population that has actually experienced the exposure. This type of research is called epidemiology—the study of patterns and possible causes of diseases in human populations.

Epidemiologic 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" (see box on this page). The epidemiologist does not create the exposure and cannot control for all the factors that might cause the disease in the way that a laboratory researcher, working with animals, generally can. However, laboratory studies may not be able to re-create the complex environment of humans, and the results of animal studies cannot always be extrapolated to humans.

Epidemiologists have been able to identify important risk factors for cancer, including cigarette smoke and benzene. However, in the case of EMF exposure, the evidence for an association with disease has been inconsistent. Some scientists who have studied the issue say that if a relationship exists at all between EMFs and certain cancers, the risks must be very small. When the risk is small, or if there is no risk, epidemiologic studies can be difficult to interpret. However, even a small cancer risk from EMFs, if demonstrated consistently and convincingly, would be looked at seriously. Because vast numbers of people are exposed to EMFs, even a small risk could add up to a substantial number of additional cancers nationwide.



WARREN GRETZ, NREL/PIX 04098

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

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 the suspicion that the exposure increases the risk of the disease.

Studies mentioned in this booklet are referenced in the page-by-page listing beginning on page 44. References are also listed alphabetically beginning on page 55.

How do we evaluate the results of various epidemiologic studies of EMF?

Something that is associated statistically with increased incidence of a certain disease may not always turn out to be an actual cause of the disease. To judge whether the association reported in a study is causal, epidemiologists consider several criteria, including the following:

Strength of association

The stronger the association, 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—10 times the normal risk. In the studies that suggest a relationship between EMFs and certain rare cancers, the association is weaker than this. For example, see the meta-analysis discussion following and the description of utility worker studies on page 14.

Consistency

Consistency requires that an association found in one study appear in other studies involving different study populations and methods. Consistently found associations are more likely to be causal. With regard to EMFs, study results disagree in important ways, such as the type of cancer associated with EMF exposure, so scientists cannot be sure whether the increased risks are due to EMFs or other factors.

Dose-response

The epidemiological data are more convincing if increasing exposure levels correspond to higher disease rates. Such dose-response relationships have appeared in only a few EMF studies.

Biological plausibility

When associations are weak in an epidemiological study, results of laboratory studies are more heavily relied upon to support the association. Some scientists will remain skeptical about an association between EMFs and cancer until a plausible biological explanation is found. Experiments with laboratory animals and cells are currently under way to provide information about possible biological effects of EMF exposure.

Reliability of exposure information

Another important consideration with EMF epidemiologic studies is the quality of the exposure information on which they are based. Early studies estimated EMF exposure based on job titles alone; no actual measurements were conducted. More recent studies have included measurements of magnetic field exposure. However, measurements conducted today can only give approximate estimates of previous exposure, and no one knows for sure which aspects of EMF exposure are most important to measure. A lack of precise exposure information does not explain away a positive association. Poor exposure information can result in an underestimation, rather than an overestimation, of the significance of an association, if the association is real.

Meta-analysis

Various groups and individuals have tried to evaluate the results of epidemiologic studies of EMF exposure in the workplace and draw conclusions about the possible health risk. One way to do this is to conduct a "meta-analysis," which combines many studies to explore their differences and if appropriate, calculate a summary risk estimate. A recent meta-analysis of occupational EMF exposure and brain cancer (Kheifets et al., 1995) found that, compared with other workers, workers in electrical occupations had a 10% to 20% higher risk (1.1 to 1.2 times the risk) of developing brain cancer. In their conclusion, however, the authors stated that "... because of the lack of adequate exposure information and a clear dose-response pattern, it is not possible to conclude that EMF is causally associated with the observed excess of brain cancer in workers employed in electrical occupations."

What have studies shown about "electrical workers" and cancer?

Since 1982, several epidemiologic surveys and studies of cancers have reported a higher than expected number of leukemia cases among people who worked in certain "electrical" occupations compared with people who work in other occupations. In these studies, the category "electrical worker" included electrical engineers, phone line workers, TV and radio repairers, power station operators, electricians, and welders. Other studies have reported associations between brain cancer incidence or mortality and working in these same occupations. No association with total cancer incidence has been reported in these studies.

The first of these studies was completed in 1982 by Dr. Samuel Milham. Dr. Milham conducted what is known as a "proportional mortality ratio" study, which examined the causes of death among deceased men in various occupations in the state of Washington. He designated several occupations as "electrical workers," based on his judgment that people who worked at these jobs would have higher than typical exposure to electromagnetic energy. His definition of EMFs included power frequency (60 Hz) as well as radio frequencies and direct current (see the Electromagnetic Spectrum on page 8). Dr. Milham reported that among electrical workers, the proportion of deaths due to leukemia versus other causes was higher than expected. The conclusion was based on the proportion of deaths from leukemia compared with all causes of death in the white male population of Washington State. Exposure to EMFs was proposed as a possible explanation.

At that time, very little information was available about the types or ranges of EMF exposure experienced by workers in different jobs. Using the occupation listed on the death certificate as a surrogate for EMF exposure allows epidemiologists to

What Is Cancer?

Cancer

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

The incidence of cancer in adults in the United States is 382 per 100,000 per year. The causes of most cases are not known, and the factors that influence risk differ among the forms of cancer. Each of the known risk factors such as smoking, alcohol, and diet, contributes to specific types of cancer.

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. (Leukemia is the most common form of cancer found in children, however.) 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 adult 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 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 six 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.

Source: National Cancer Institute, 1995

obtain information for a large number of people quickly and relatively inexpensively. Epidemiologists in other states and in other countries reported similar findings for leukemia, and others found an association with brain cancer. Some studies of similar design found no associations between these rare cancers and "electrical" occupations. When associations were reported, they tended to be weak. Taken together, the results showed some puzzling inconsistencies. For example, as noted by a government advisory committee in Great Britain, no increased leukemia has been reported overall in studies of welders, yet they are among the occupations with the highest EMF exposures.

In 1990, Drs. Loomis and Savitz gathered data from 16 states to study the causes of death in U.S. workers. As in the earlier studies, they took no measurements but estimated exposure based on job title. They found that, compared to other workers, people categorized as "electrical workers" had a higher incidence of brain cancer, but not leukemia. In their summary, the authors concluded that to resolve questions about EMF exposure and disease, researchers would have to go beyond the use of job titles alone as a surrogate measure of exposure.

> *"... no number of replications using a basic design relying on job titles as surrogate measure of exposure will resolve questions of etiology [cause of disease] or public health importance."*

To get a more precise answer to the question of how magnetic fields might be linked with leukemia or brain cancer would require researching the work histories of thousands of workers and obtaining actual measures of magnetic field exposures for individual workers at typical job tasks.

What have studies of electric utility workers shown?

In recent years, researchers in California, North Carolina, Canada, and France have reported the results from three major studies of electric utility workers. These studies are considered to be among the best EMF epidemiological studies conducted, mainly because they included large numbers of workers and because the researchers estimated the workers' magnetic field exposures based on measurements made in the workplace, rather than solely on job titles. Here is what they found.

California study

The California researchers, led by Dr. Jack Sahl at Southern California Edison Company (1993), studied 36,000 electric utility workers and reported no strong, consistent evidence of an association between magnetic fields and any type of cancer. Because there were relatively few cases of leukemia and lymphoma, the study was not capable of detecting very small risks, if present.

Canada/France study

The Canadian and French researchers, led by Dr. Gilles Thériault at McGill University in Montreal (1994), conducted a study of 223,292 workers at two large utilities in Canada and the national utility in France. They reported that workers with acute myeloid leukemia were about three times more likely to be in the half of the workforce with higher cumulative exposure to magnetic fields. In the analysis of median cumulative magnetic field exposure, no significant elevated risks were found for the other 29 types of cancer studied.

There were inconsistencies in the results from the three individual utilities involved in this study and no clear sign that the risk of cancer increased as the level of exposure increased. Based on their results, the researchers concluded that the study did not provide clear-cut evidence that magnetic fields caused the elevated risks found for leukemia and brain cancer. However, they observed as "noteworthy" the fact that the leukemia and brain cancer results did agree with results from certain previous studies. In a later analysis, the authors reported an association between exposure to short bursts or spikes in the magnetic field that were not in the ELF power-frequency range and increased risk of lung cancer. No other data support this finding, however, and the researchers are uncertain about the exposure data on which it is based.

North Carolina study

In another major study involving more than 138,000 utility workers at five electric utilities in the United States (Savitz et al., 1995), the authors concluded that the results "do not support an association between occupational magnetic field exposure and leukemia, but do suggest a link to brain cancer."

Three major studies of electric utility workers in recent years have examined the possible association between EMF exposure and cancer.

Do electrical workers have higher EMF exposures than other workers?

It is 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. The early studies did not include actual measurements of EMF exposure on the job. Instead, they used job titles as an estimate of assumed EMF exposure among electrical workers. Recent studies, however, have included extensive EMF exposure assessments.

A report published in 1994 by Dr. Stephanie London and colleagues provided some information about estimated EMF exposures of workers in a number of electrical jobs in electric utilities and other industries. The study showed that in Los Angeles, electrical workers did have higher EMF exposures than workers in other jobs. 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.

EMF Exposures of Workers in Los Angeles

Job Type	Electric Field*	Magnetic Field*
Electrical	19.0 V/m	9.6 mG
Nonelectrical	5.5 V/m	1.7 mG

**The table displays the* mean *measurements (the sum of all measurements in a sample divided by the number of measurements taken).*

Source: London et al., 1994

The study showed that in Los Angeles, electrical workers had higher EMF exposures than workers in other jobs.

Have studies suggested a link between EMFs and cancer in other industries?

One of the largest studies to report an association between cancer and magnetic field exposure in a broad range of industries was conducted by Dr. Birgitta Floderus, a researcher at the Swedish National Institute of Working Life. The study included an assessment of EMF exposure in 1015 different workplaces in Sweden and involved over 1600 people in 169 different occupations. Floderus reported an association between estimated EMF exposure and increased risk for chronic lymphocytic leukemia. An increased risk for brain tumors was reported for men under the age of 40 whose work involved an average magnetic field exposure of more than 2 mG.

Another Swedish study by Alfredsson and colleagues (1996) found an excess risk of lymphocytic leukemia among railway engine drivers and conductors. The *total* cancer incidence (all tumors included) among these workers was lower than in the general Swedish population. In 1994, Floderus reported a similar finding in a study of Swedish railway workers. However, a 1994 study of Norwegian railway workers found no evidence for an association between EMF exposure and leukemia or brain cancer. Preliminary studies in Europe and the United States suggest that railway workers are exposed to comparatively strong magnetic fields at work. (See page 38 regarding exposure assessment studies of transportation workers.)

PHOTODISK, INC./PIXCD7-201

No increased leukemia has been reported overall in studies of welders, yet they are among the workers with the highest EMF exposures.

Is there evidence that EMF exposure increases the risk of breast cancer?

Breast cancer in men

The first epidemiologic evidence for an association between EMF exposure and breast cancer was for male breast cancer. In 1991, Dr. Genevieve Matanoski of Johns Hopkins University reported finding two cases of breast cancer among 900 men who worked in a central switching station of a New York telephone company. Since male breast cancer is a very rare disease (one in 100,000 men per year in the United States develop breast cancer), finding two cases in a group this small was unusual.

Norwegian researchers (Tynes and Andersen, 1990) reported that breast cancer occurred more frequently among men who worked in electrical occupations in Norway. The number of cases was small (12) but more than might be expected by chance alone. Other studies of breast cancer and electrical work have provided conflicting results. A subsequent study of men who had breast cancer (Demers et al., 1991) reported that they were more likely than a comparison group without breast cancer to have had jobs in "electrical" occupations.

In 1992, Dr. Dana Loomis at the University of North Carolina, reported that after studying death records of men in 24 states he found, in general, no excess number of deaths from breast cancer among those who had worked in electrical occupations. However, a higher than expected proportion of these breast cancer cases among electrical workers involved men who were less than 65 years old at death. In a 1993 study of cancer incidence among Danish workers, Dr. Pascal Guénel reported that in occupations with presumed intermittent or continuous EMF exposure, breast cancer developed more frequently than expected in men, but less frequently than expected in women. The results of these studies are limited because they

include no workplace measurements and the investigators were unable to assess the role of known risk factors, such as family history of breast cancer, that can confound the analysis.

The three major studies of electric utility workers (described on page 14) estimated the workers' occupational exposures to EMF during the course of their careers with the electric companies. None of these studies reported an association between male breast cancer and jobs involving exposure to magnetic fields.

Breast cancer in women

Although breast cancer in men is rare, in women it is unfortunately common. The incidence rate for female breast cancer in the United States per year is more than one in 1000 (110 in 100,000).

A 1994 study by researchers at the University of North Carolina examined death records of female workers in the United States and found that women employed in electrical occupations were slightly more likely to have died of breast cancer than were other working women. However, this study did not control for confounding factors such as age at birth of first child, diet, fertility, and family history, all of which are known to affect breast cancer risk. Without this background information about the women in the study, it is impossible to know whether the apparent association with EMF exposure is being "confounded" with another risk factor that may also be common among women in electrical occupations.

In the study of Danish workers mentioned earlier, Guénel and colleagues estimated the exposure of all working women in the country by grouping jobs into high and low categories of EMF exposure. Women whose jobs were ranked in the highest exposure category did not have more breast cancer than did women who had jobs in the lowest exposure category.

Several large-scale studies are now under way in the United States and in other countries to see if women living in homes with higher EMF exposures have an increased risk of developing breast cancer. Biological studies are under way as well, examining the potential role of EMFs and melatonin in the development and suppression of breast cancer (see page 23).

Could EMF be linked to other illnesses?

Since 1979, researchers in England, Sweden, and Canada have looked at the overall health of high-voltage workers at electrical utilities. In Sweden, long-term workers who had been exposed to power frequency fields in substations did not report any unusual health problems. In England, power distribution and transmission line workers were surveyed for health problems. Workers exposed to EMFs did not report more headaches or fatigue than did other workers.

A Swedish researcher has evaluated the effect of short-term exposures to power line fields on performance, behavior, mood, and self-reported symptoms in workers at an electrical utility. He compared the same workers after a day working under exposed conditions to another day under unexposed conditions. No differences were found in stress, reaction time, or other measures of performance and health.

Later studies of people living near transmission lines looked at self-reported symptoms that are considered in identifying depression. There is no clear indication that these symptoms were higher among residents closer to a transmission line.

A study published in 1995 reported that among workers studied in Finland and in California, those with higher than typical exposures to EMF (primarily seamstresses, dressmakers, and tailors in this study) had about three times the risk of developing Alzheimer's disease as did other workers. This was the first study to examine the possible association between

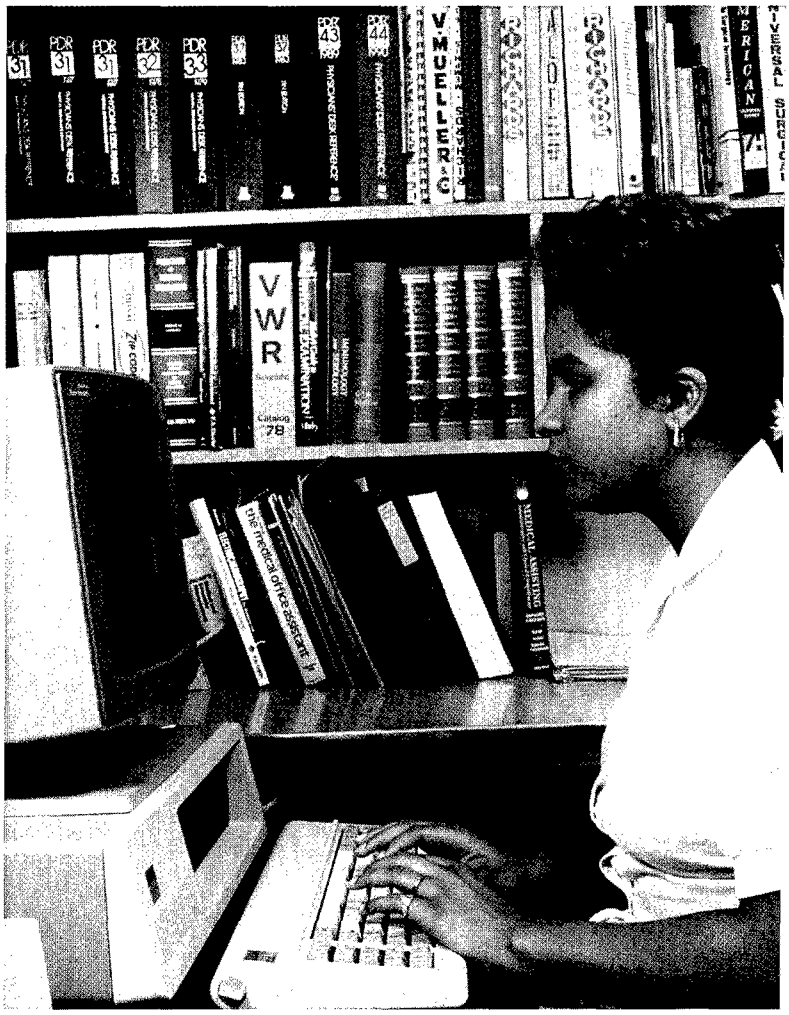
EMF exposure and Alzheimer's disease. According to the authors, further studies are needed to confirm their findings.

Scientists have looked into the possibility that some workers may be "electrosensitive" and experience a reaction of some kind to EMFs. The question arose because some workers, primarily in Scandinavian countries, reported skin problems or other symptoms when working with computers. Swedish researchers have reported that their preliminary experiments have not shown a link between a person's symptoms and exposure to electric or magnetic fields. The actual cause of these problems is still unknown. It may reflect a variety of factors, including temperature and humidity of the room and job stress.

Does working with video display terminals (VDTs) increase the risk of miscarriage or birth defects?

In the late 1970s, as the use of video display terminals (VDTs) in the workplace became increasingly common, questions arose concerning the potential effects on pregnancy outcomes of working with these terminals. Clusters of miscarriages and birth defects were reported at several workplaces in the United States and Canada (see page 21 for a discussion of clusters).

Various VDT exposures and emissions have been measured: X-rays, ultraviolet radiation, visible light, infrared radiation, radio frequency fields, power-frequency EMFs, chemicals (PCBs), air ions, and static fields. Workers' exposures to these emissions are very low. However, unlike other office equipment, VDTs emit pulsed electromagnetic fields in the very low frequency (VLF) range, specifically 15,000 to 30,000 Hz (see the Electromagnetic Spectrum on page 8). In 1982, a laboratory in Spain reported that malformations occurred in chicken embryos exposed to pulsed magnetic fields at low frequencies. Although these results could not be repeated by the Spanish researchers or



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Most epidemiologic studies have reported that work with computer monitors did not increase the risk of miscarriage or birth defects.

others, epidemiologic studies of workers were started to find out if miscarriages or birth defects occur more among VDT users.

In the following decade, more than 10 epidemiologic studies were completed in the United States, Canada, Sweden, Finland, Norway, and Denmark. Most of the studies reported that work with VDTs did not affect the risk of miscarriage or birth defects (Ericson and Kallen, 1986; Bryant and Love, 1989; Nielsen and Brandt, 1990). However, in only three studies were VDT exposures measured.

Standards

The U.S. government has no exposure or emission standards for magnetic fields from video display terminals (VDTs). The Swedish government issued guidelines recommending that VDTs purchased by the government produce extremely low frequency (ELF) magnetic fields of no more than 2 mG at a distance of 30 centimeters (11.8 inches) from the VDT surface. The standard is based on what is technologically achievable, not on medical or epidemiological research, according to the Swedish Board for Technical Accreditation (SWEDAC) which issued the standard.

In 1991, researchers at the National Institute for Occupational Safety and Health (NIOSH) studied two groups of telephone operators. One group used VDT displays; the other did not. The levels of power-frequency magnetic fields (60 Hz) measured at the operators' locations were similar for the two groups. This study reported that miscarriages happened no more often among full-time VDT users than among those workers not using VDTs. The study also reported that there appeared to be no relationship between the amount of time a woman used a VDT and her chance of having a miscarriage.

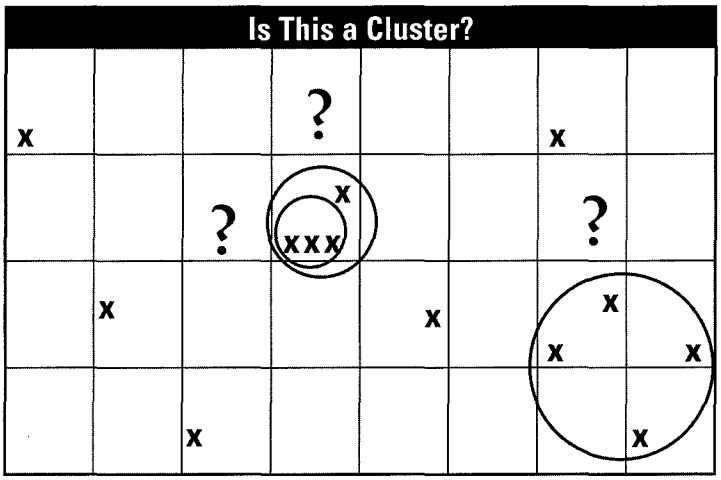
A study from Finland (Lindbohm et al., 1992) reported that women who miscarried at one of three companies were more likely to have used models of VDTs that could produce 50-Hz magnetic fields above 3 mG. Finnish investigators did not find an overall link between miscarriage or birth defects and VDT use, nor was there a relationship between increased incidence of miscarriages with increasing VLF field strength.

Recently, a large study at Yale focused on the effects of EMF exposure on the growth rate of the unborn child (Bracken et al., 1995). These researchers obtained information about power frequency magnetic field exposure from power line and home sources. VDT use over 20 hours a week was not found to affect the weight or growth rate of the baby, nor did the mother's exposure to higher magnetic fields or to "high" field sources such as electrically heated beds.

In 1994, the National Radiological Protection Board (NRPB) of Great Britain invited an advisory group of scientists to review studies of possible health effects related to the use of VDTs. They concluded that there was "no good reason to suppose" that exposure to low frequency electromagnetic fields from the use of VDTs harms the unborn child.

Have clusters of cancer or other adverse health effects in certain workplaces been linked to EMF exposure?

An unusually large number of cancers, miscarriages, or other adverse health effects, which occur in one area or over one period of time is called a "cluster." Sometimes clusters are an early warning sign of a health hazard. But most of the time the reason for the cluster is not known. Depending on how it has been defined, a cluster may or may not be unusual. Sometimes, for example, further study shows that the cluster may involve several different types of cancer or other health effects. There have been no proven instances of cancer clusters linked with EMF exposure, although several clusters have been studied carefully.



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?

Biological Studies

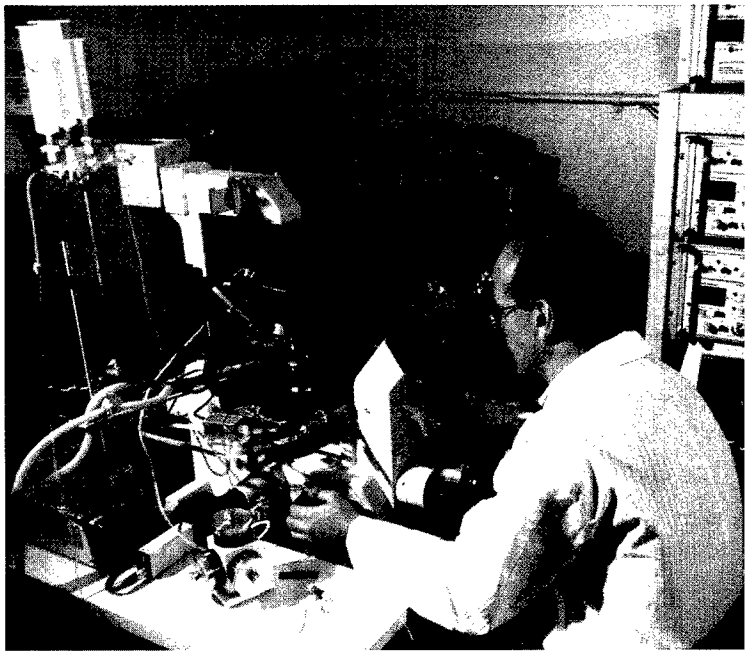
This chapter describes biological studies that examine effects of EMF on animals and individual cells.

What effects of EMFs have been reported in laboratory studies?

Some laboratory studies have reported that EMF exposure can produce biological effects, including changes in functions of cells and tissues and changes in human brain activity and heart rate. A biological effect is a measurable change in some biological response that may or may not have an adverse health effect.

We do not know whether the biological effects observed in the laboratory would have any impact on human health. Some of these effects are within the normal range of variation. A biological response to a particular stimulus does not have to be harmful. For example, the pupils of our eyes constrict when exposed to bright light and our eardrums vibrate with sound.

Very specific laboratory conditions are needed for researchers to be able to detect EMF effects. In most cases, it is not clear how EMFs actually produce these effects.



OAK RIDGE NATIONAL LABORATORY/PIX 04099

At Oak Ridge National Laboratory, a researcher prepares to expose cells to EMFs.

Studies mentioned in this booklet are referenced in the page-by-page listing beginning on page 44. References are also listed alphabetically beginning on page 55.

How might EMFs cause these biological effects?

Much of the debate about EMFs centers on this question. Researchers are trying to determine the biophysical mechanisms by which EMFs could cause the biological effects reported in some experiments. One such mechanism may be the weak electric currents generated in the body by oscillating electric and magnetic fields. However, some scientists argue that because these currents are much smaller than natural body currents, they are unlikely to have any effect on health. Others propose that currents from EMF exposure can have a steady frequency and a regular wave shape that is very different from the body's own electricity and that cells may somehow "sense" these currents, even though they are small.

Laboratory studies have not shown that EMFs cause the gene mutations that *initiate* the cancer process. Some studies suggest, however, that EMFs may *promote* cancerous activity in cells that are already precancerous.

Several recent studies have tried to find out whether exposure to EMFs can contribute to the promotion of cancer. In these studies, researchers first exposed a group of laboratory animals to chemicals that initiate skin or breast cancers. Then, they exposed some of the animals in the group to magnetic fields or to magnetic fields plus another chemical known to promote tumors. Several studies report no evidence for tumor promotion. However, some research has indicated that under certain circumstances EMF exposure may promote tumor development in animals.

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 come up with similar results. The U.S. government is currently sponsoring research that attempts to replicate some of these animal studies.

What about effects of EMFs on the hormone melatonin?

Melatonin is a hormone secreted mainly at night by the pineal gland, a small gland attached to the brain. Scientists have reported results of laboratory experiments showing that melatonin can slow the growth of some cancer cells, including breast cancer cells. If melatonin helps prevent cancer growth and if EMFs decrease melatonin, then this might help explain the results of studies showing increased cancer risk with EMF exposure.

The Midwest Research Institute (MRI) in Kansas City, Missouri, has studied the effect of EMF exposure on human melatonin levels in men. In 1993, MRI reported that although subjects showed no effect on the average, those individuals with naturally lower levels of melatonin did show a small additional decrease when exposed intermittently to 60-Hz magnetic fields of 200 mG. However, in 1994, MRI reported that a second study, designed to produce the same results as the earlier study, found no such effect. In 1995, MRI evaluated the effects of continuous exposure to magnetic fields at the same intensity; again, no effects on melatonin were found.

Some laboratory experiments have reported that EMF exposure alters melatonin levels in hamsters and rats. Results of the experiments have not been replicated consistently, however.

Summaries and Opinions

This chapter gives a sampling of opinions from individuals who have studied the EMF issue and from various organizations. Not everyone reaches the same conclusion.

What do EMF researchers have to say about possible health effects of occupational EMF exposure?

After nearly 20 years of research, experts are still unable to tell us for sure whether EMF exposure is safe or unsafe. Although opinions vary regarding the possible risk, most agree that more research is needed. Here is what several prominent scientists have concluded so far about the possibility that workplace EMF exposure may affect our health.

"The possibility of a risk exists, but it cannot be regarded as established, and it is not biologically plausible."

Sir Richard Doll
Oxford University
May 22, 1995

"There are sufficient data for there to be real concern. The concern is not imaginary, (but) there's a lot to be done to understand whether certain types of exposure are more important than other types. Until we have a handle on the exposure metric and the significant exposures, we will be very much in the dark about the possible effects."

Dr. David Bates
University of British Columbia
July 25, 1995

"If EMF effects are occurring, they are likely to be very weak or to require special or unusual conditions. With weak effects, the body is almost always able to compensate, making them very hard to study. Nevertheless, they may be important for certain groups of people whose normal compensating processes do not function properly. The new research tools being developed to address these difficult questions will add to our overall understanding of biology, and may ultimately lead to advances in medicine."

Dr. Paul Gailey
Oak Ridge National Laboratory
March 1, 1996

"On the one hand, a number of studies suggest a weak effect. On the other hand, most of the studies are very limited in exposure assessment and the data are inconsistent with regard to which specific type of cancer is associated and what aspect of the field is important. Thus, it is impossible to say that the association is likely to be one of cause and effect. The data are really not sufficient to warrant more than very simple and inexpensive avoidance measures."

Dr. Stephanie London
University of Southern California
(currently with the National Institute of Environmental Health Sciences)
April 12, 1996

"I would say there are two key points. First, the research is mixed with regard to whether there is any health risk associated with occupational EMF exposure. And second, in light of that uncertainty, my suggestion would be that only the easiest, most convenient, and least disruptive mitigation efforts should be considered."

Dr. David Savitz
University of North Carolina
October 13, 1995

"Epidemiological studies have shown weak statistical associations between magnetic field exposures and cancer, but such studies cannot prove causality. It is not unlikely, however, that ELF MF [magnetic field] exposures can interact with, for example, the human endocrine system."

Dr. Birgitta Floderus
Swedish National Institute for Working Life
June 3, 1996

"It does not look like there is a health impact from work around energized equipment. If fields are hazardous, the risk would be small. A very serious international research effort has not been able to find consistent results."

Dr. Jack Sahl
Southern California Edison Company
June 30, 1995

What have officials in the United States and in other countries concluded about EMFs and cancer?

Most reviews have concluded that existing evidence does not prove that EMFs cause cancer. These include national reviews by the U.S. Committee on Interagency Radiation Research and Policy Coordination, the Australian Ministry of Health, the National Radiological Protection Board of the United Kingdom, the Danish Ministry of Health, and the French National Institute of Health and Medical Research. The U.S. Environmental Protection Agency (EPA) developed a draft report in 1990 which was reviewed by the EPA's Science Advisory Board, but no final report was published. The U.S. government is now conducting a major interagency EMF research effort which will produce a report to Congress in 1998. (See description of the EMF RAPID Program on page 27). Several U.S. states have sponsored EMF research reviews including California, Texas, Connecticut, Illinois, Maryland, Colorado, and Virginia. Reference information for these reports is provided on page 51.

According to a 1992 report by the National Radiological Protection Board of the United Kingdom: "The epidemiologic findings that have been reviewed provide no firm evidence of the existence of a carcinogenic hazard from exposure [to EMFs]." In 1993, after reviewing results of three additional occupational studies (from Denmark, Norway, and Sweden) the NRPB reported, "The three new occupational studies ... strengthened the evidence for believing that some groups of workers in industries where exposure to electromagnetic fields may have been elevated have an increased risk of leukaemia, but not of brain cancers. No increase in the risk of leukaemia has, however, been seen in workers exposed to high levels of electromagnetic fields. The conclusion remains that whether the hazard, if one exists, is due to exposure to electromagnetic fields or to some chemical associated with the work is impossible to decide at the present."

The Swedish National Institute of Occupational Health (now the National Institute of Working Life) issued a public information document in May 1994 that states, "We suspect that magnetic fields may pose certain risks to health, but we cannot be certain." According to the Swedish report, "current knowledge is not sufficient for us to tell how magnetic fields affect us. So we do not have a basis on which to set [exposure] limits." While research is under way, the report continues, "... there is good reason to exercise a certain amount of caution." The Swedish government recommends against locating new homes and schools near existing electricity-generating plants and proposes that high magnetic fields in homes, schools, and workplaces be limited.

The state of California has initiated a statewide research and education program to inform decision makers about EMFs. Meanwhile, California electric utilities are taking no-cost and low-cost steps to reduce magnetic fields from new facilities.

What have nongovernmental organizations concluded about EMFs and cancer?

A number of organizations have issued public statements about the possibility of an association between EMF exposure and cancer.

The Harvard Center for Risk Analysis, in an April 1995 analysis, assessed current research findings linking occupational EMF exposure and cancer. About leukemia, the report found that while the data are too inconsistent to establish a cause-and-effect relationship, "there is enough evidence of association to raise concern." Evidence on EMFs and brain cancer was "sketchy," but the report noted that "the results of the Savitz study are likely to fuel greater interest in the hypothesis that EMFs can cause brain cancer."

The American Physical Society, an association of physicists, issued a statement in April 1995 on the overall scientific evidence relating to EMFs and public health. The statement read in part: "The scientific literature and the reports of reviews by other panels show no consistent, significant link between cancer and power line fields ... From this standpoint, the conjectures relating cancer to power line fields have not been scientifically substantiated."

The American Medical Association (AMA) issued a report in December 1994 stating that "no scientifically documented health risk has been associated with the usually occurring levels of electromagnetic fields." The AMA recommends "continued investigation of basic effects ... studies of people's average exposures, and the developing of national exposure standards, if such are recommended by an authoritative advisory panel." Until more is known, the AMA suggests: "Physicians may advise that patients themselves can control some of their exposures to electric and magnetic fields."

In a 1993 position statement on EMF, the American Industrial Hygiene Association (AIHA) said the following: "At present, the AIHA finds that the lack of replicated studies, an accepted interaction mechanism in the laboratory studies, and an absence of significant associations with measured fields in the epidemiological studies, make it impossible to come to a definite decision regarding the magnitude of health effects associated with exposure to extremely low frequencies. Good industrial hygiene and public health practice suggests that when there are conflicting data ... a cautious approach is recommended. The AIHA also supports the need for more research to close the current knowledge gaps."

Ongoing Research

Most authorities agree that more research is needed before we will have solid answers about whether EMF exposure affects our health. This chapter summarizes the current U.S. government EMF research effort.

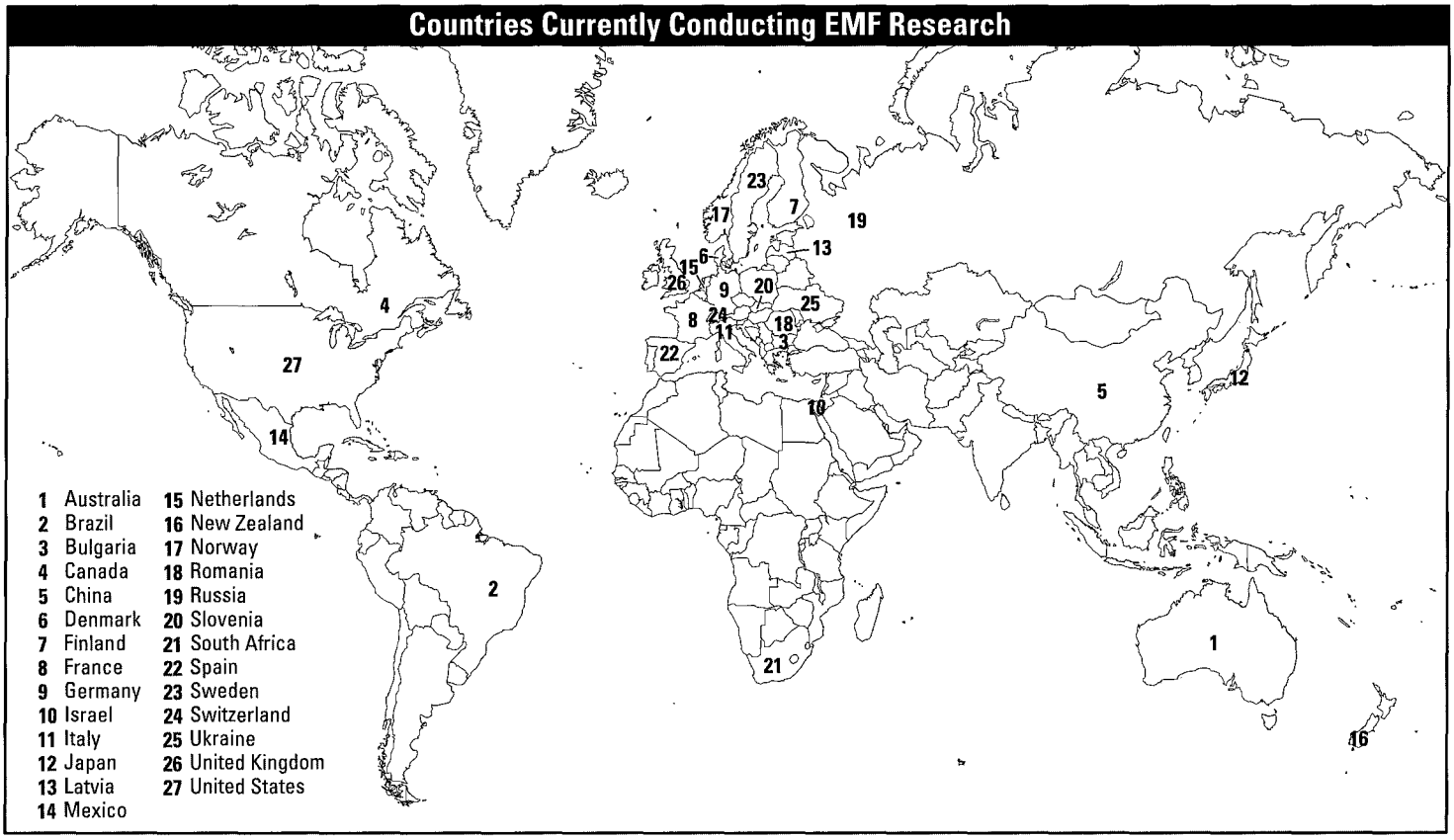
Are more EMF studies being done?

Yes. Worldwide, about 200 studies are under way or planned involving EMFs. These include epidemiologic, laboratory, environmental, and engineering studies. Many of these involve some aspect of cancer development.

EMF RAPID Program

In the United States, the federal Energy Policy Act established a 5-year program (begun in 1994) to expand ongoing EMF research and to provide accurate public information about EMFs. The EMF Research and Public Information Dissemination Program, known as the EMF RAPID Program, is being managed by the U.S. Department of Energy and the National Institute of Environmental Health Sciences. The EMF RAPID Program is supported by federal and nonfederal funds.

Laboratory research is being conducted to explore the potential relevance of EMF exposure to possible health effects, including cancer and effects on reproduction and the nervous system. Work is also under way on exposure assessment and on risk assessment. This booklet is a product of the public information component of the EMF RAPID Program.



EMF research is under way in at least 27 countries.

The following federal government agencies are represented on an interagency committee which provides guidance for the EMF RAPID Program:

- U.S. Department of Energy
- National Institute of Environmental Health Sciences
- U.S. Environmental Protection Agency
- U.S. Department of Defense
- Occupational Safety and Health Administration
- National Institute of Standards and Technology
- U.S. Department of Transportation
- Rural Utilities Service
- Federal Energy Regulatory Commission
- U.S. Department of the Interior (ad hoc member).

The program also is guided by the National EMF Advisory Committee, which includes representatives of public interest groups, organized labor, state health agencies, scientific organizations, and industry.

Nonfederal contributors include member companies of the following organizations:

- Edison Electric Institute
- American Public Power Association
- National Rural Electric Cooperatives Association
- National Electrical Manufacturers Association
- National Associations of Realtors
- Empire States Electric Energy Research Company
- Electric Power Research Institute.

These contributors are prohibited by law from influencing the program direction.

Additional U.S.-Sponsored Research

In addition to work sponsored by the EMF RAPID Program, the following federal agencies are conducting research on electric and magnetic fields or have done so in the past.

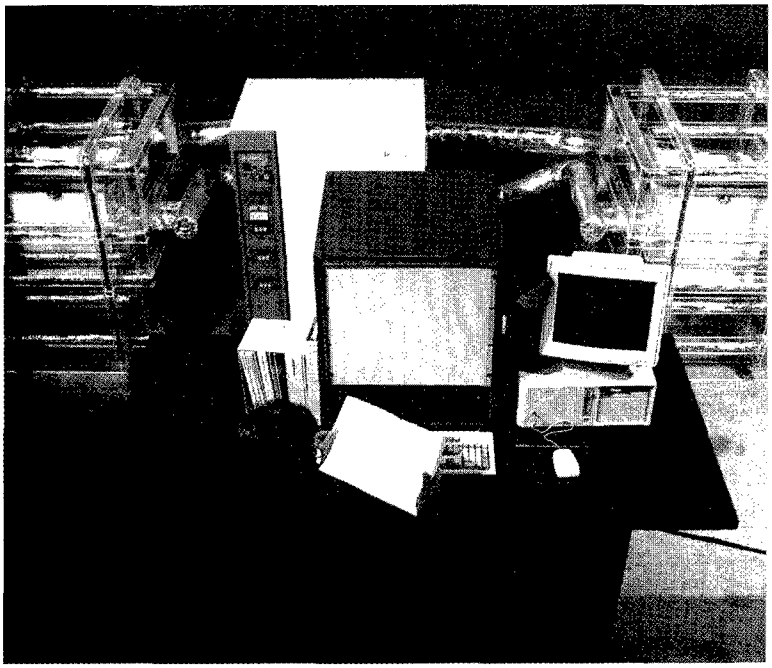
- **National Institute of Environmental Health Sciences**—Health effects and hazard identification/risk assessment, animal toxicology studies.
- **National Institute for Occupational Safety and Health**—Workplace sources and exposures, computer monitors and industrial equipment, radio frequency heating devices, police radar, two-way radios. Regional EMF exposure facility.
- **U.S. Food and Drug Administration**—Cellular phones, electric blankets, medical equipment. Regional EMF exposure facility.
- **National Cancer Institute**—Epidemiologic studies of breast cancer and childhood leukemia.
- **U.S. Department of Defense**—Radio frequency, breast cancer studies.
- **U.S. Department of Energy**—Biological mechanisms, exposure assessment.
- **U.S. Department of Transportation**—Studies of high-speed and magnetic levitation trains, electric rail transportation systems, and airway facilities.
- **U.S. Environmental Protection Agency**—Formerly conducted power-frequency and radio-frequency research and research reviews. No current research is being conducted.

In 1995, special magnetic field exposure equipment was installed in four federal facilities (Oak Ridge National Laboratory, Pacific Northwest Laboratory, the Food and Drug Administration, and the National Institute for Occupational Safety and Health) to enable EMF researchers to attempt to reproduce critical published experiments in identical exposure settings.

Other EMF Research

EMF research in the United States is also being conducted by the following organizations:

- **Electric Power Research Institute**—Epidemiology, biological mechanisms, exposure assessment
- **California Department of Health Services**—Epidemiology, exposure assessment
- **Empire State Electric Energy Research Corporation**—Health research, exposure assessment, field management.



PACIFIC NORTHWEST NATIONAL LABORATORY/PIX 01417

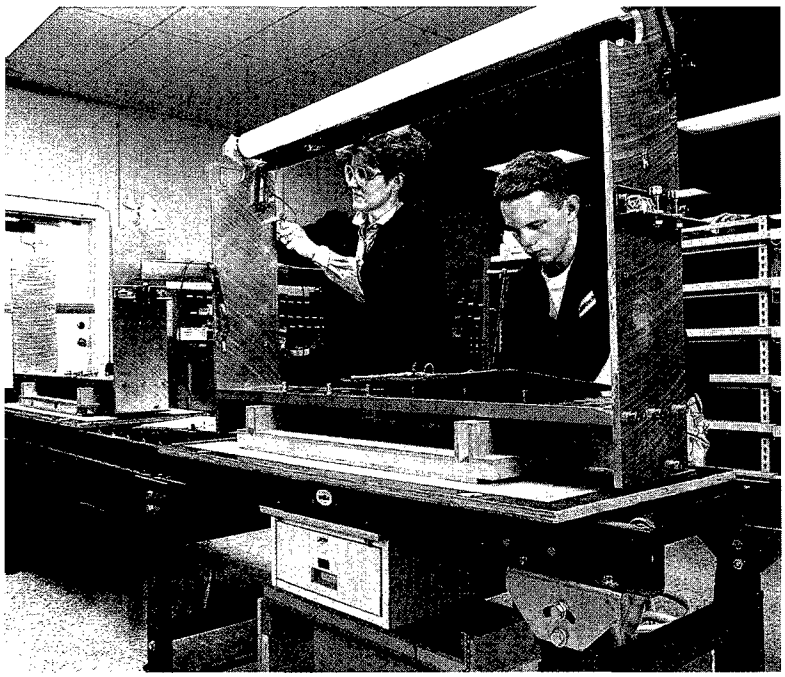
The U.S. government has set up magnetic field exposure facilities to enable EMF researchers to attempt to reproduce critical published experiments in identical exposure settings.

Who is paying for all the EMF research?

In the United States, public and private funds support EMF research. The federal government has conducted EMF studies for almost 20 years. The state governments of New York and California have sponsored EMF-related epidemiologic research, and several other states have commissioned EMF research summaries. Major financial support for EMF research has also come from the electric power industry. Worldwide, at least 27 countries support EMF research.

Your EMF Environment

This chapter discusses typical EMF exposures in various work environments, identifies EMF sources, and suggests ways to reduce exposure.



©JIM YOST/PIX 04042

Many industries with potentially high EMF exposures have not yet been studied. Exposure assessment studies are now under way in various U.S. industries, including steel manufacturing, auto manufacturing, pulp and paper production, and glass manufacturing.

Potentially Important Aspects of EMF Exposure

- Field strength (magnitude)
- Frequency
- Length of time of exposure
- Time of day exposure occurs
- Transients—brief bursts or spikes of EMF exposure that occur when equipment is turned on and off
- Intermittency—how often or how much the exposure changes over time
- Harmonics—multiples of the basic frequency that occur when the waveform is distorted (common with motors, electronics that control power supply)

What are some typical EMF exposures?

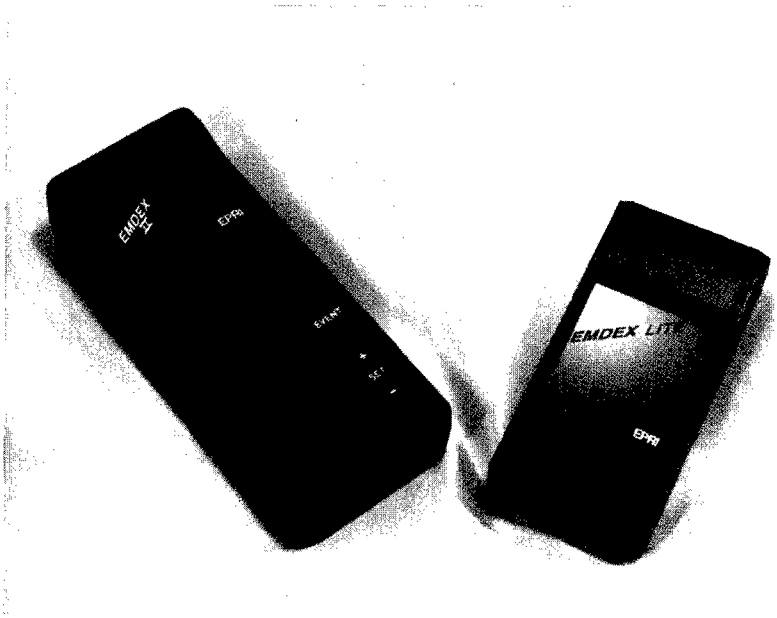
A magnetic field exposure that averages 1 or 2 milligauss (mG) or less over a day is typical in homes and in many workplaces, based on the information we have so far. The 1993 occupational study conducted by Dr. Birgitta Floderus and coworkers (see a discussion of the study on page 16) found that 50% of male employees had a workday mean magnetic field exposure of at least 1.7 mG and a workday median of at least 1.1 mG. The Electric Power Research Institute sponsored a study of nearly 1000 randomly selected U.S. homes (Zaffanella et al., 1993). Researchers calculated the average of measurements from all the rooms and found the median for all the homes to be 0.6 mG. Although 1 or 2 mG magnetic field exposure is typical for many work environments, some can involve exposure to magnetic fields of far greater magnitude.

Average magnetic field exposures have been measured in many occupations, and some of those values are summarized in the tables on pages 35 and 37. Most EMF health studies have assumed that the time-averaged magnetic field measurement is the most relevant measure for health effects (see discussion on page 10). However, laboratory experiments have shown that other aspects of magnetic field exposure can produce biological responses. It may be that the more critical measure of exposure is something other than the average, such as the amount of time spent in fields that are above a certain value, or rapid changes in the magnetic field, or the frequency content of the field. Some research suggests that the earth's static magnetic field, acting in conjunction with an AC field, may have some biological significance. Exposure assessment studies now under way are gathering information on these aspects of the magnetic field to provide a more complete picture of the EMF environment in which we work.

How is EMF exposure measured?

Small measurement devices—called gaussmeters or power-frequency magnetic field meters—can be carried or worn by a person to record magnetic field exposures automatically during the course of a work shift or day. To determine a worker's personal EMF exposure, the measurement device is usually either worn at the waist, or placed so that its probe is as close as possible to the worker. When the worker is stationed a sufficient distance away from the source, the person's actual exposure may be low, even if a particular workplace contains a powerful EMF source.

To locate prominent EMF sources, spot measurements are sometimes taken. Such measurements do not necessarily reflect a worker's personal EMF exposure because they are not always taken at a distance from the source that approximates the worker's location, they generally don't account for the amount of time the worker is actually there, and exposure may be different at other times during the day. Spot measurements also fail to capture the temporal variations of the field, which can be large.



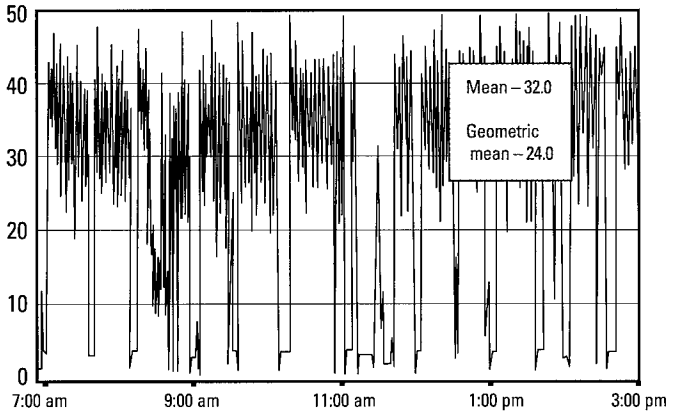
EPRI/ENERTECH CONSULTANTS/PIX 04100

Portable power-frequency magnetic field meters such as these can be carried or worn to record magnetic field exposures. These meters are one example of many brands of meters available on the market.

EMF Exposure Plots of Workers

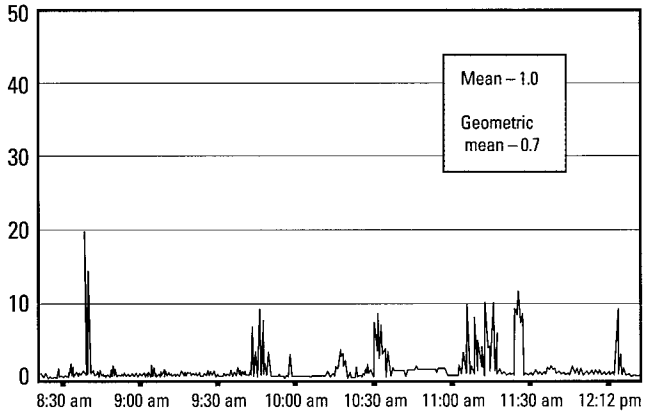
Measurements in milligauss (mG)

Sewing machine operator in garment factory



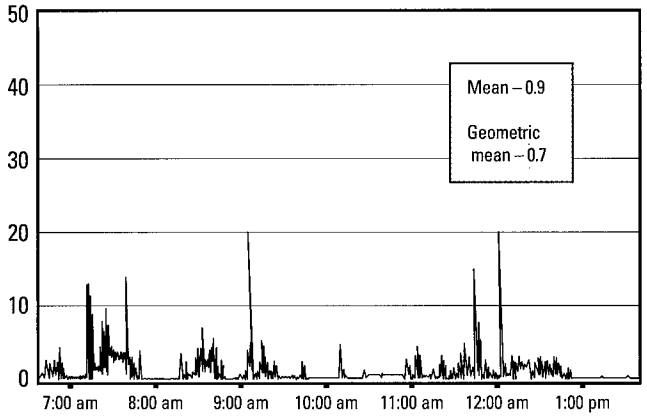
The sewing machine operator worked all day, took a 1-hour lunch break at 11:15 am, and took 10-minute breaks at 8:55 am and 2:55 pm.

Maintenance mechanic



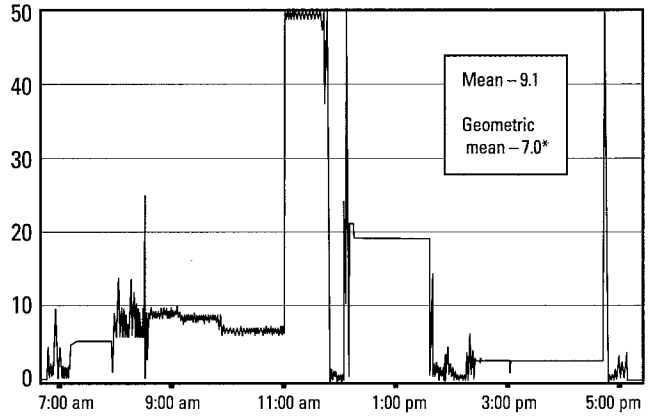
The mechanic repaired a compressor at 9:45 am and 11:10 am.

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.

**See "Means and Medians" on page 10 for an explanation of mean and geometric mean.*
Source: NIOSH, DOE

The figures above are examples of magnetic field exposures determined with exposure meters worn by four workers in different occupations. These measurements demonstrate how surprising and varied an individual worker's EMF exposure can be. These exposure plots do not necessarily represent typical EMF exposures for workers in these occupations.

Is there something significant about the 2-mG magnetic field level?

A typical U.S. home has a background magnetic field level (away from any appliances and averaged over time) that ranges from 0.5 mG to 4 mG, with an average value of 0.6 mG. This estimate is based on the Electric Power Research Institute study (see related discussion on page 30; Zaffanella et al., 1993). Most ordinary electrical equipment produces higher magnetic fields close to the source. (See figure on page 36 for examples of fields from various EMF sources.)

Following standard epidemiologic practices, several EMF human health studies have used average exposures of 2 or 3 mG as an arbitrary cutoff point to define broad categories of exposure. Below this level, subjects were considered "unexposed," and above this level, they were considered "exposed." In some studies, a higher cancer risk was found within the exposed group. Two milligauss was significant in one influential Swedish study in that it was used as the boundary to define the exposed group, not because it identified a safety threshold. Laboratory experiments with cells have reported effects at field levels as low as 12 mG, but there is no peer-reviewed research reporting effects at 2 mG during an in vitro (test tube) study.

To conclude from current research results that 2 mG constitutes a safety threshold is to read far too much into the data. Several expert review panels, as well as the Swedish government, have so far concluded that current knowledge does not provide sufficient basis for setting exposure limits to magnetic fields of such low intensity.

How can I find out how strong the EMFs are where I work?

The tables on the following pages 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 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 drops off quickly with distance. A spot measurement is most useful in estimating a worker's personal exposure if it is taken at a location that approximates the worker's location and at a time when the exposure is typical of the workday. When spot readings are taken, they should be noted on paper along with notes showing the meter location, time, and what equipment is operating.

Some electric utilities will conduct EMF measurements for customers at no charge. You can make your own measurements if you have a magnetic field meter. Different meter models are now available, and many are advertised in the EMF periodicals listed on page 43.

A booklet that describes and rates currently available meters can be purchased from the Electrical Power Research Center in Ames, Iowa for $25 by calling (515) 294-8057. Independent environmental firms can also be hired to conduct EMF measurements. In some cities they are listed in the yellow pages of the telephone book under headings such as "Engineers, Environmental;" "Environmental Services;" and "Industrial Hygiene Consultants." You should investigate the experience and qualifications of commercial firms, since governments do not standardize EMF measurements or certify measurement contractors.

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.

This table shows the range of magnetic field exposures averaged over a workday for workers in selected occupations. These personal exposure measurements reflect the average magnitude of the magnetic field produced by the various EMF sources and the amount of time the worker spent in the fields. Measurements were also obtained in nonoccupational locations and situations, for the purpose of comparison. The data summarized in this table came from various studies, all of which are listed in the Reference section on page 53.

Studies are now being conducted as part of the U.S. EMF RAPID Program to find out more about EMF exposures in various occupational environments including schools, shopping malls, grocery stores, and hospitals. (For a description of the program, see page 27.)

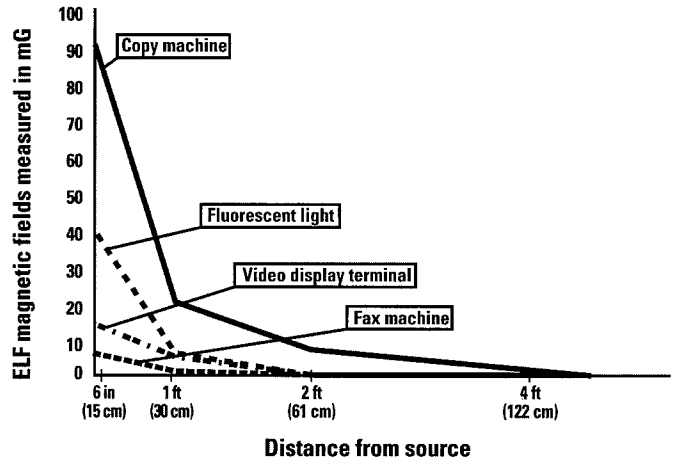
EMF Measurements Averaged Over a Workday

Industry and Occupation	ELF magnetic fields measured in mG Median for occupation	Range for 90% of workers*
Employed men in Sweden		
Construction machine operators	0.4	0.2 – 0.6
Motor vehicle drivers	0.8	0.3 – 1.9
Teachers in theoretical subjects	1.2	0.4 – 3.1
Machine repair and assembly	1.7	0.3 – 3.7
Retail sales	2.7	0.8 – 4.4
Electrical workers in various industries		
Electrical engineers	1.7	0.5 – 12.0
Construction electricians	3.1	1.6 – 12.0
TV repairers	4.3	0.6 – 8.6
Welders	8.2	1.7 – 96.0
Electric utilities		
Clerical workers without computers	0.5	0.5 – 1.6
Clerical workers with computers	1.2	0.3 – 6.3
Line workers	2.5	0.5 – 35.0
Electricians	5.4	0.8 – 34.0
Distribution substation operators	7.2	1.1 – 34.0
Workers off the job (home, travel, etc.)	0.9	0.3 – 3.7
Telecommunications		
Install, maintenance, & repair technicians	1.6	0.9 – 3.1
Central office technicians	2.1	0.5 – 8.2
Cable splicer	3.2	0.7 – 15.0
Auto transmission manufacturing		
Assemblers	0.7	0.2 – 4.9
Machinists	1.9	0.6 – 28.0
Hospitals		
Nurses	1.1	0.5 – 2.1
X-ray technicians	1.5	1.0 – 2.2
Garment industry workers in Finland		
Sewing machine operator	22.0	10.0 – 40.0
Other factory workers	3.0	1.0 – 6.0

**This range is between the 5th and 95th percentiles of daily average measurements for an occupation.*

Source: Data compiled by NIOSH. See the References section.

EMF Spot Measurements Taken at Various Distances



Source: EMF in Your Environment, 1992

As the graph illustrates, EMF strength diminishes quickly as distance from the source increases.

Ranges for Low-Frequency EMFs

These ranges show the frequencies used in the table at right.

Range	Frequencies
Static	0 hertz (Hz)
ULF Ultra low frequencies	above 0, below 3 Hz
ELF Extremely low frequencies	3–3000 Hz
VLF Very low frequencies	3000–30,000 Hz (3–30 kilohertz)
RF Radio frequencies	10,000–1 billion Hz (1 gigahertz or 1 GHz)

What are some typical sources of EMF in the workplace?

Exposure assessment studies so far have shown that electrical appliances and tools and the power supply for the building are the main sources of magnetic field exposure that most people receive at work. People who work near transformers, electrical closets, circuit boxes, or other high-current electrical equipment may have 60-hertz (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.

The table on the next page gives examples of magnetic field levels based on spot measurements of electrical equipment used in various occupations. Many people are surprised when they compare measurement data from one piece of equipment to another and see that the magnetic field does not depend on how large, complex, powerful, or noisy the equipment is. Instead, magnetic field magnitude is determined by the product's internal wiring and by the amount of the current it uses. It is common for a small piece of equipment, such as a desktop fan, to be a strong, localized magnetic field source at a workstation for those individuals working within 2 feet (61 centimeters) of the equipment. Generally, the intensity of the EMFs decrease rapidly with distance from these sources.

These measurements were taken primarily from hazard evaluations conducted by the National Institute for Occupational Safety and Health (NIOSH) in various industries. The measurements were taken in one of three ways. Unless the table specifies otherwise, the measurement was taken at the worker's location. Some measurements were conducted at a fixed distance from the source (if several sources were being compared). In the case of "walk-through surveys," the investigator took a series of measurements at different locations in a room.

The data summarized in this table came from various studies, all of which are listed in the References section on page 53.

Industry and Sources	ELF magnetic fields measured in mG	Comments	Other frequencies
Mechanical equipment used in manufacturing			
Electric resistance heater	6000 – 14,000		VLF
Induction heater	10 – 460		High VLF
Hand-held grinder	3000	Tool exposures measured at operator's chest	
Grinder	110		
Lathe, drill press, etc.	1 – 4		
Electrogalvanizing			
Rectification room	2000 – 4600	Rectified DC current (with an ELF ripple) galvanizes metal parts	High static fields
Outdoor electric line and substation	100 – 1700		
Aluminum refining			
Aluminum pot rooms	3.4 – 30	Highly-rectified DC current (with an ELF ripple) refines aluminum	Very high static field
Rectification room	300 – 3300		High static field
Steel foundry			
Ladle refinery		Highest ELF field was at the chair of control room operator	High ULF from the ladle's big magnetic stirrer
ladle electrodes active	170 – 1300		
electrodes inactive	0.6 – 3.7		
Electrogalvinizing unit	2 – 1100		High VLF
Television broadcasting			
Video cameras (studio and minicams)	7.2 – 24		VLF
Video tape degaussers	160 – 3300	Measured 1 ft. away	
Light control centers	10 – 300	Walk-through survey	
Studios and newsrooms	2 – 5		
Telecommunications			
Relay switching racks	1.5 – 32	Measured 2 in. – 3 in. from relays	Static fields and ULF-ELF transients
Switching rooms (relay & electronic switches	0.1 – 1300	Walk-through survey	Static fields and ULF-ELF transients
Underground phone vault	3 – 5	Walk-through survey	
Hospitals			
Intensive care unit	0.1 – 220	Measured at nurse's chest	VLF
Post-anesthesia care unit	0.1 – 24		VLF
Magnetic resonance imaging (MRI)	0.5 – 280	Measured at technician's work locations	Very high static field, VLF and RF
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		
Computer center	0.4 – 6.6		
Can opener	3000	Appliance fields measured 6 in. away	
Desktop cooling fan	1000		
Other office appliances	10 – 200		
Building power supplies	25 – 1800		

Information about the magnitude of other frequencies measured can be found in the original reports from which data for this table were drawn. They are listed in the References section on page 53.

What EMF exposure occurs during travel?

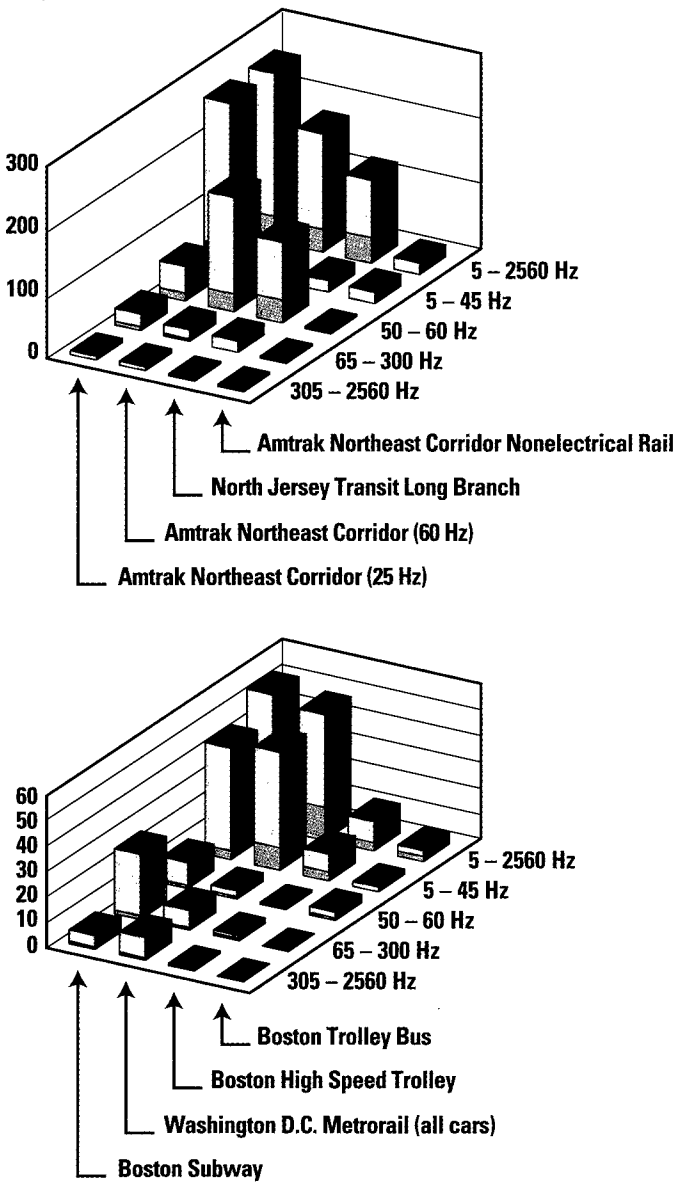
Inside a car or bus, the main sources of magnetic field exposure are those you pass by (or under) as you drive, such as power lines. Car batteries involve direct current (DC) rather than alternating current (AC). Alternators can create EMFs, but at frequencies other than 60 Hz.

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 electrified 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 right shows average and maximum magnetic field measurements in operator compartments of several electrified 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 electrified 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 (NIOSH) 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.

EMF Measurements in Train Operators' Compartments



Source: U.S. Department of Transportation, 1993

These graphs illustrate that 60 Hz is one of several electromagnetic frequencies to which train operators are exposed. The maximum exposure is the bar top; the average exposure is the horizontal line.

Are there any standards for occupational exposure to EMFs?

In the United States, presently there are no federal standards limiting occupational exposure to EMFs. Two organizations have developed voluntary occupational exposure guidelines for EMF exposure. These guidelines are intended to prevent effects, such as induced current in cells or nerve stimulation, which are known to occur at high magnitudes, much higher (over 1000 times higher) than EMF levels found typically in occupational and residential environments.

Guidelines for EMF Exposure

International Commission on Non-Ionizing Radiation Protection

Exposure—50/60 Hz	Electric field	Magnetic field
Occupational		
Whole working day	10 kV/m	5 G (5,000 mG)
Short term*	30 kV/m	50 G (50,000 mG)
Limbs	–	250 G (250,000 mG)
General Public		
Up to 24 hours per day	5 kV/m	1 G (1,000 mG)
Few hours per day	10 kV/m	10 G (10,000 mG)

**For electric fields of 10–30 kV/m, field strength (kV/m) multiplied by hours of exposure should not exceed 80 for the whole working day. Whole-body exposure to magnetic fields up to 2 hours per day should not exceed 50 G.*

Source: ICNIRP 1994

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

Guidelines for EMF Exposure

Threshold Limit Values for EMF Exposure
American Conference of Governmental Industrial Hygienists

Exposure—60 Hz	Electric field	Magnetic field
Occupational		
Levels should not exceed	25 kV/m* (from 0 to 100 Hz)	10 G (10,000 mG)
Workers with cardiac pacemakers	1 kV/m or below	1 G (1,000 mG)

**Prudence dictates the use of protective devices (e.g. suits, gloves, insulation) in fields above 15 kV/m.*

Source: ACGIH 1996

The 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.

Do EMFs affect people with pacemakers or other medical devices?

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

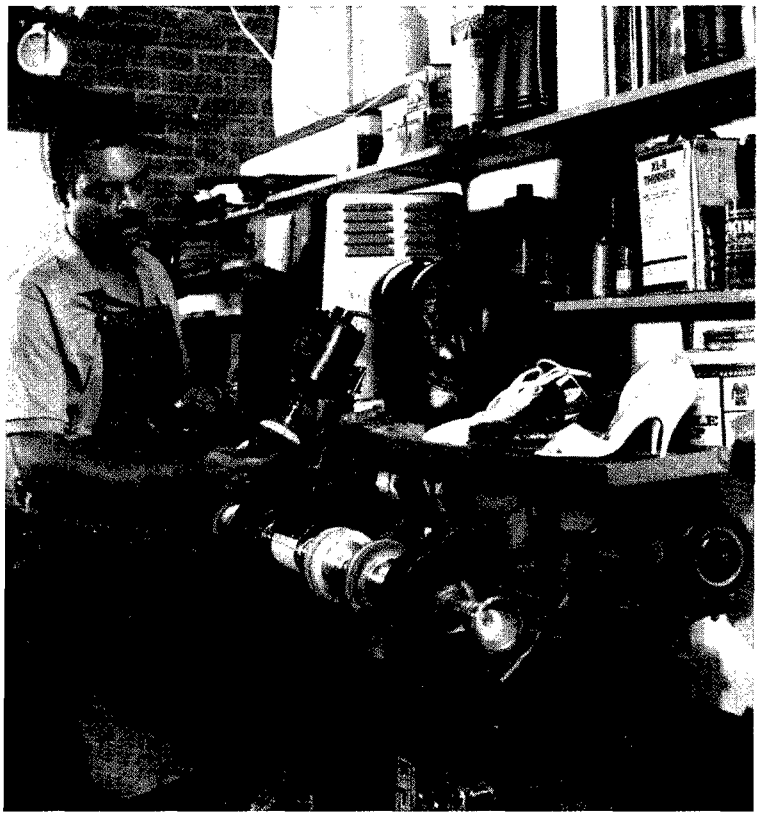
However, sources such as welding equipment, power lines at electricity generating plants, and rail transport equipment can produce lower-frequency EMFs strong enough to create interference in various medical devices. Some research suggests that metal equipment located near a magnetic field source can greatly enhance the intensity of the field from that source (Hansen, 1990). Some metallic medical implants (such as pins, nails, screws, and plates) can be affected by high static magnetic fields from magnetic resonance imaging (MRI) equipment and aluminum refining processes.

The occupational threshold limit values for EMF developed by the American Conference of Governmental Industrial Hygienists state that workers with cardiac pacemakers should not be exposed to a 60-Hz magnetic field greater than 1 gauss (1000 mG) or an electric field greater than 1 kilovolt (1000 volts) per meter (see table on page 39). Workers with pacemakers or implantable defibrillators should consult their doctors and their industrial hygienists if they think their workplace contains sources of high electric or magnetic fields.

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

What about products that are advertised as producing or emitting low or reduced magnetic fields?

This question must be answered product by product, depending on the claims of the manufacturer. Beware of advertisements claiming the federal government has certified that the advertised equipment produces little or no EMF. The federal government has no such certification program, guidelines or standards. The U.S. Food and Drug Administration (FDA) Center for Devices and Radiological Health is responsible for protecting the public from radiation generated by electronic products. If you have questions about a specific product, contact the FDA at (301) 443-3840.



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Your EMF exposure depends on the strength of the source, your distance from the source, and the amount of time you spend in the magnetic field.

If workers and employers want to reduce EMF exposure at work, what can they do?

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

If you are concerned about EMF exposure at work, your first step should be to find out where the major EMF sources are in your work area and move away from them or limit the time you spend near them. Magnetic fields often drop off dramatically about an arm's length away from the source (see page 31 for information on measuring EMFs). Another way to reduce EMF exposure is to use equipment designed to have relatively low EMF emissions. Sometimes electrical wiring in a building can be the source of strong magnetic field exposure. Rearranging the work area to increase your distance from the electrical panel or wiring can reduce your EMF exposure in some cases.

We are not sure which aspect of the magnetic field exposure, if any, to reduce. (See discussion on page 10 of the complexity of EMF exposure.) 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 health or safety hazard, such as electrocution.

While research continues, concerned workers and employers might consider the following simple, inexpensive measures for reducing EMF exposures:

- Provide information to employers and employees about the possibility of risk from EMF exposure.
- Find out where major EMF sources are in your work area.
- Increase the distance between the worker and the EMF source.
- Reduce the time spent near EMF sources.
- Use equipment designed to have low EMF emissions, if available.

For More Information

This section lists sources of additional information including toll-free telephone hotlines, an Internet listing, and publications written for a general audience.

Telephone Hotlines

EMF InfoLine (800) 363-2383
or (703) 442-8934 in the Washington, D.C. area

The EMF InfoLine is managed by the U.S. Environmental Protection Agency (EPA) and responds to public inquiries about 60-Hz EMFs and radio frequency radiation. It is jointly supported by the EPA and the EMF Research and Public Information Dissemination (RAPID) Program.

ENVIRO-HEALTH Hotline (800) 643-4794

The National Institute of Environmental Health Sciences operates a hotline to answer questions about various environmental health issues, including EMFs.

Information on Workplace Hazards Hotline (800) 35 NIOSH (356-4674)

Run by the National Institute for Occupational Safety and Health (NIOSH), this hotline answers questions about safety and health in the workplace.

On the Internet

EMFRAPID Home Page
http://www.niehs.nih.gov/emfrapid/home.htm

Information about the federal government's EMF research effort, including public information materials developed by the EMF RAPID Program, can be accessed through this Internet site. The EMF RAPID Home Page is maintained by the National Institute of Environmental Health Sciences and is funded by the EMF Research and Public Information Dissemination (EMF RAPID) Program.

Canadian Centre for Occupational Health and Safety Home Page
http://www.ccohs.ca

A tripartite (labour, employer, government) organization dedicated to Workplace Health and Safety. The Inquiries Service of the Centre provides free information. Hamilton, Ontario, L8N 1H6, Canada. (800) 263-8466.

Federal Government Publications

Questions and Answers About EMF: Electric and Magnetic Fields Associated with Electric Power, U.S. Department of Energy and the National Institute of Environmental Health Sciences, January 1995. Single copies available free from any of the three telephone hotlines listed in the previous column. Also available in Spanish.

NIOSH Facts: EMFs In the Workplace, 1995. A fact sheet from the National Institute for Occupational Safety and Health. Free from the NIOSH hotline (800) 356-4674.

NIOSH Publications on Video Display Terminals, National Institute for Occupational Safety and Health, June 1991. Free from the NIOSH hotline (800) 356-4674.

Progress Report on the Electric and Magnetic Fields (EMF) Research and Public Information Dissemination (RAPID) Program, EMF RAPID Program Interagency Committee, December 1995. Describes agenda and progress through 1995 of 5-year national research and risk assessment program on EMFs. Write the U.S. Department of Energy Public Inquiries Center, 1000 Independence Avenue, Washington, D.C. 20585, and request publication number DOE/EE-0021. Free.

EMF Periodicals

Mention of the following publications does not imply endorsement. The authors of this booklet do not bear responsibility for the accuracy of information presented in these publications.

Between the Lines and *EMF Keeptrack,* Center for Energy Information, Winthrop, ME. Call (800) 947-8765.

EMF Health and Safety Digest, Robert S. Banks Associates, Inc., Minneapolis, MN. Call (612) 623-4600.

EMF Health Report, Information Ventures, Inc., Philadelphia, PA. Call (215) 732-9083.

EMF News, Edison Electric Institute, Washington, D.C. Call (202) 508-5656.

Microwave News, New York. Call 212-517-2800. To receive a current list of gaussmeter manufacturers, send $1.00 and a self-addressed, stamped envelope to Microwave News, P.O. Box 1799, Grand Central Station, New York, NY 10163.

Public Information on EMF from Nonfederal Sources

Answers to Frequently Asked Questions about Electric and Magnetic Fields (EMFs) Produced by 60-hertz (Hz) Electric Power, Massachusetts Department of Public Health, 1995. Call (617) 727-7170. Free.

Electric and Magnetic Field Fundamentals: An EMF Health Effects Research Paper, Electric Power Research Institute, March 1994. Call (510) 934-4212 and ask for publication number BR-103745. Free.

Extremely Low Frequency (ELF) Electric and Magnetic Fields, American Industrial Hygiene Association, 1995. Call (703) 849-8888. $32.00 per copy.

"Workers, EMFs and Cancer," (Vol. 3, Number 2) of *Risk in Perspective*, Harvard Center for Risk Analysis, April 1995. For a free copy of the article, contact Melissa Rocha by phone (617) 432-4497, fax (617) 432-0190, or e-mail *mrocha@sph.harvard.edu.*

The following booklets are available from Carnegie Mellon University:

Fields from Electric Power, 1995. $6.50 per copy.

Measuring Power-Frequency Fields, 1992. $2.50 each copy, $2.25 each for 10 or more copies.

What Can We Conclude from Measurements of Power-Frequency Fields? 1992. $3.00 each or $2.25 each for 10 or more copies.

To order, send a prepaid written request to: Department of Engineering and Public Policy, Attention: EMF Brochure, Carnegie Mellon University, Pittsburgh, PA 15213. (412) 268-2670.

References

Studies mentioned in this document are listed twice: according to the page on which they appear in the booklet, and again, alphabetically.

Page-by-Page Listing

page 12

See studies listed for pages 13–16.

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Sahl, J.D.; Kelsh, M.A.; Greenland, S. **Cohort and Nested Case-Control Studies of Hematopoietic Cancers and Brain Cancer Among Electric Utility Workers.** *Epidemiology.* 1993; 4: pp. 104–114.

Savitz, D.A.; Loomis, D.P. **Magnetic Field Exposure in Relation to Leukemia and Brain Cancer Mortality Among Electric Utility Workers.** *American Journal of Epidemiology.* 1995; 141: pp. 123–134.

Thériault, G.; Goldberg, M.; Miller, A.B.; Armstrong, B.; Guénel, P.; Deadman, J.; Imbernon, E.; To, T.; Chevalier, A.; Cyr, D.; Wall, C. **Cancer Risks Associated with Occupational Exposure to Magnetic Fields Among Electric Utility Workers in Ontario and Québec, Canada, and France: 1970–1989.** *American Journal of Epidemiology.* 1994; 139: pp. 550–572. Authors corrections to data. **Erratum.** *American Journal of Epidemiology.* 1994; 139: p. 1053.

Summary of Laboratory EMF Studies

Reviews of Animal and Cell Studies

Anderson, L.E. *Investigation of Exposure to Extremely Low Frequency (ELF) Magnetic and Electric Fields: Ongoing Animal Studies.* PNL-SA-23995. Richland, WA: Pacific Northwest Laboratory; 1994.

Blank, M., ed. *Electricity and Magnetism in Biology and Medicine: Review and Research Papers Presented at the First World Congress for Electricity and Magnetism in Biology and Medicine.* San Francisco, CA: San Francisco Press, 1993.

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Löscher, W.; Mevissen, M. **Mini-review: Animal Studies on the Role of 50/60-Hertz Magnetic Fields in Carcinogenesis.** *Life Sciences.* 1994; 54(21): pp. 1531–1543.

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