EMF AND YOUR HEALTH

2015 Update

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Electric and magnetic fields (EMF) are present whenever and wherever electricity is generated, transmitted and used. Electricity has a unique and growing role in modern life: to light our homes, refrigerate our food, heat and cool our homes, power the equipment and technologies that diagnose and treat illnesses, as well as entertain us and allow instantaneous communication regardless of distance. Given EMF's constant presence in our lives, we must also ask: Is EMF safe?

To address this question, thousands of scientific studies have been carried out around the world over the last 35-plus years. Conducted at universities and research institutions, these studies have used a variety of approaches to explore the potential health effects of EMF. Some have looked at patterns of disease in human populations, some have exposed laboratory animals to EMF, and still others have exposed isolated cells to explore mechanisms that might plausibly link EMF to various effects. The World Health Organization (WHO) has weighed the full body of evidence from all these studies and concluded that, "[d]espite extensive research, to date there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health."

This brochure is intended to explain the issues surrounding EMF. It covers the physical nature of EMF, our everyday exposures to EMF, the health research and its findings, and the conclusions reached by expert scientific panels and government agencies. It provides key updates to the review of the science that the National Institute of Environmental Health Sciences (NIEHS) published in 2002 in a booklet entitled, "EMF: Electric and Magnetic Fields Associated with the Use of Electric Power – Questions & Answers." The 2002 booklet contains very useful information that remains current, and that the reader of this brochure may find of value.

This brochure was produced by the Electric Power Research Institute (EPRI), a non-profit institution that has been involved in research on the health effects of EMF for more than 35 years. EPRI's EMF program continues to fund research by independent investigators at universities and other research institutions, all of whom publish their findings in peer-reviewed scientific journals.

What Are Electric and Magnetic Fields (EMF)?

The Electromagnetic Spectrum

Electric and magnetic fields (EMF), are often described as invisible lines of force. They are present as a part of both the natural environment and environments produced by human activity. As shown in Figure 1, these fields are part of the electromagnetic spectrum which is arranged in order of increasing frequency left-to-right. Frequency is the number of times every second that a field completes a full cycle (or oscillates), and is expressed in units of Hertz (Hz).

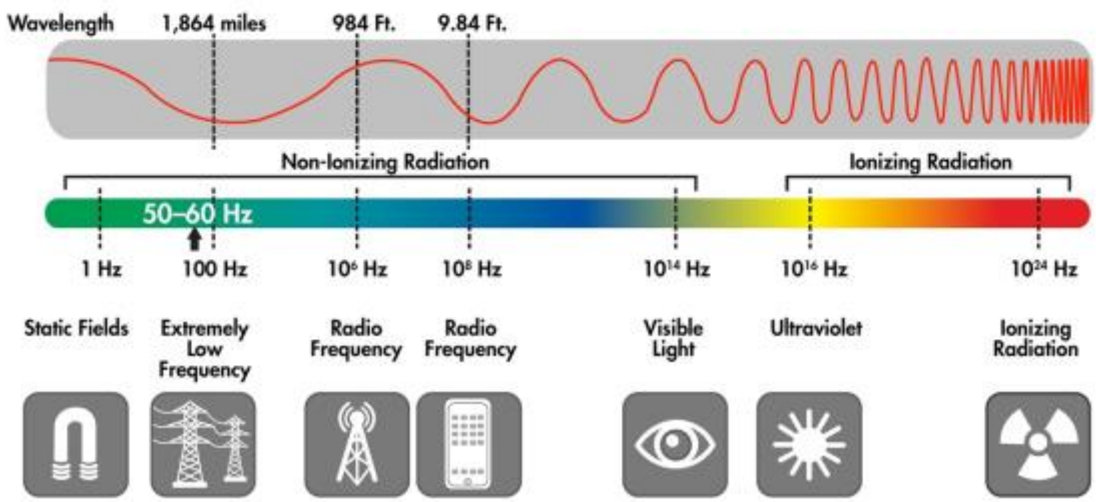

Figure 1 – The electromagnetic spectrum. The electric power system operates at 60 Hz in North America and 50 Hz in Europe (see transmission line tower symbol, second from left).

The high end of the spectrum comprises ionizing radiation, such as x-rays and gamma rays, with frequencies in the range of a billion-billion cycles per second. Ionizing radiation has enough energy to damage cells, and its use in medicine and nuclear energy is carefully managed. In the middle of the electromagnetic spectrum (millions to billions of cycles per second), are the radio-frequency (RF) fields we use every day for television, radio, microwave ovens, walkie-talkies, and cellular (including smart) phones. RF fields are non-ionizing but at sufficiently high levels are able to heat tissues in the body. Various organizations, including most prominently, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute for Electrical and Electronic Engineers (IEEE) issue guidelines and standards recommending exposure limits that protect against such effects. As described later, they also publish recommendations for EMF.

Our electric power systems operate and produce EMF near the low end of the spectrum, 50 Hz in Europe and 60 Hz in North America (note the transmission line tower symbol in Figure 1). These frequencies are also referred to as 'power frequencies'. EMF exposures at power frequencies neither directly damage cells nor produce tissue heating. This brochure focuses on the health research addressing exposure to 50 and 60 Hz EMF, with a greater emphasis on magnetic than electric fields. Although of comparatively greater concern from the 1970s through the mid-80s, the research into potential biological effects from exposure to electric fields did not reveal apparent health risks. The health issue and the associated scientific questions concerning the electrical power system evolved since that period to deal mainly with magnetic fields.

Basic Electricity and EMF

But first, what are voltage and current? Voltage may be visualized as electric ‘pressure’ similar to the pressure in a water hose. Current is the movement or flow of electricity like the flow of water in a hose. Electric fields are created by the voltage applied to an electrical cable or piece of equipment, whether or not current is flowing. A magnetic field is created by current, and disappears upon interruption of the current. Electric fields are readily shielded by objects and materials, such as houses, trees, wood, metal, animals and people. Magnetic fields, on the other hand, are not shielded and pass freely through most objects (and people).

The unit of measure for electric fields is volts per meter (V/m), and directly beneath transmission lines where the field is typically in the thousands of V/m, kilovolts per meter (kV/m) is the unit most commonly used. In the U.S., the unit of measure for the magnetic field is the gauss (abbreviated as G), with exposure expressed often in milligauss or mG (1/1000th of a gauss). The international unit for magnetic field is the Tesla, with exposures usually expressed in units of microtesla (μT); one μT is equal to 10 mG. Most of the fields experienced in daily life are anywhere from 1 to 10 mG, but can be up to 1,000 mG near electrical appliances and equipment. By way of reference, and as described later, ICNIRP recommends a 50/60 Hz magnetic field exposure limit for the general public of 2.0 G (2,000 mG) and IEEE recommends 9.1 G (9,100 mG).

Exposure to Magnetic Fields

Exposure to magnetic fields from electric power sources occurs during daily activities at home, and virtually everywhere we go, including our places of work or school, at retail and business establishments, recreational facilities and hospitals. Sources of exposure include any electrical device (e.g., electric shaver), appliance (e.g., food blender) or piece of equipment (e.g., power tool) during its operation, in addition to building wiring and nearby power lines.

Power Lines

Figure 2 illustrates the route electrical power takes from its origin at a generating station to its end use in our homes. The substation “steps down” the voltage from incoming transmission lines to voltages carried on distribution lines that bring electrical power into our communities for use in our homes. Electricity is transported on transmission lines of varying voltage classifications, line configuration and tower design depending on numerous factors, including the required capacity (the maximum amount of power a line’s design allows), available space on the right-of-way (ROW), state and local requirements, and other factors. In North America, transmission lines are energized at voltages that vary from about 115 kilovolts (kV) to 765 kV (other countries use different standard voltages of about 100 to 400 kV). On the downstream side of the substation, distribution lines may be energized anywhere from 4 kV (older lines) to 35 kV, and are also built with a variety of pole designs (or nowadays, often underground) depending on local conditions and requirements.

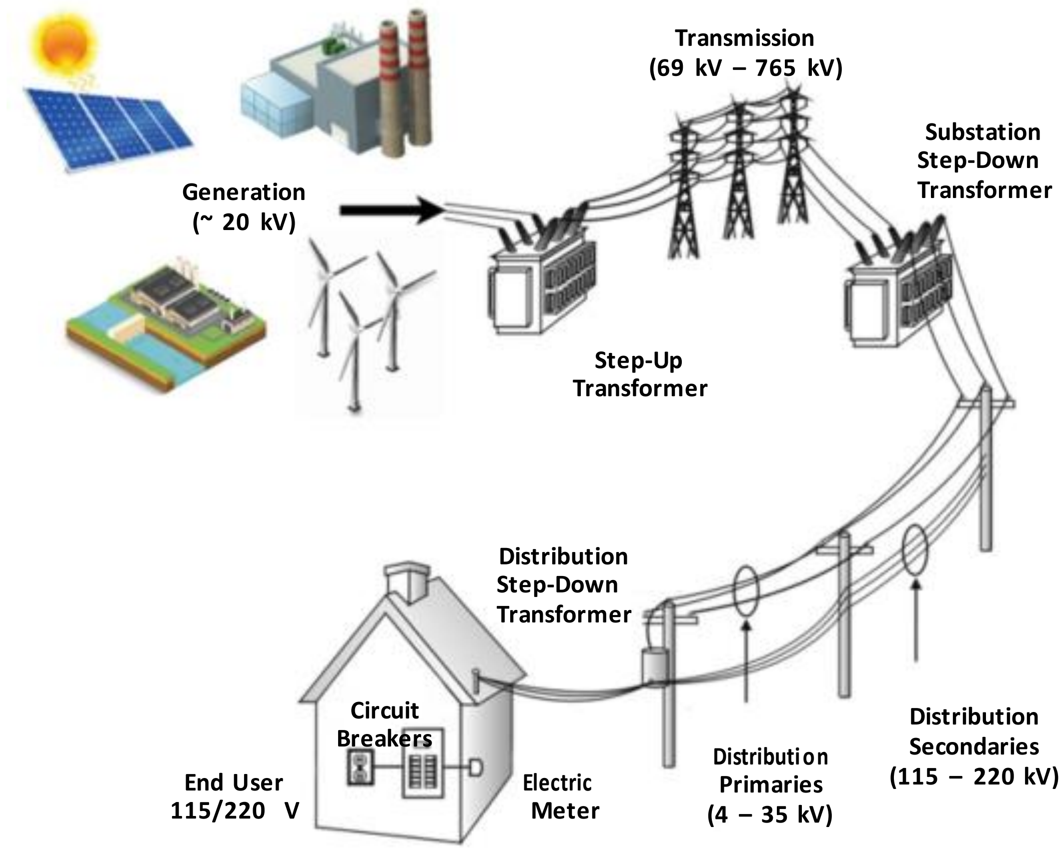

Figure 2 – Transport of electrical power from generating station to a home.

Some may ask, why do transmission lines have such high voltages? The answer has two facets. First when electrical current flows on a conductor, some of its energy is lost as heat, meaning a portion of its energy never reaches its intended user. Second, electrical power carried on a line scales directly with the line's voltage multiplied by its current. The higher the voltage the less the current required for the same amount of power. Therefore, the voltage is 'stepped up' at a transformer at the generation station for long distance transport over transmission lines. Stepping up the voltage lowers the current and far less energy is lost. The voltage is 'stepped down' at the local substation transformer such that distribution lines can serve our neighborhoods. The voltage on the distribution system is stepped down again to house voltage (about 115 volts) by a transformer located usually on a nearby pole in the street, or in a metal cabinet on the ground.

Cross-sections of representative tower and pole configurations used in the U.S. are shown in Figure 3 to provide a flavor for the variability of line types that are in operation. (Not shown are "sub-transmission lines" rated between about 40 and 70 kV and underground high voltage transmission lines, which are prevalent in heavily urbanized areas.)

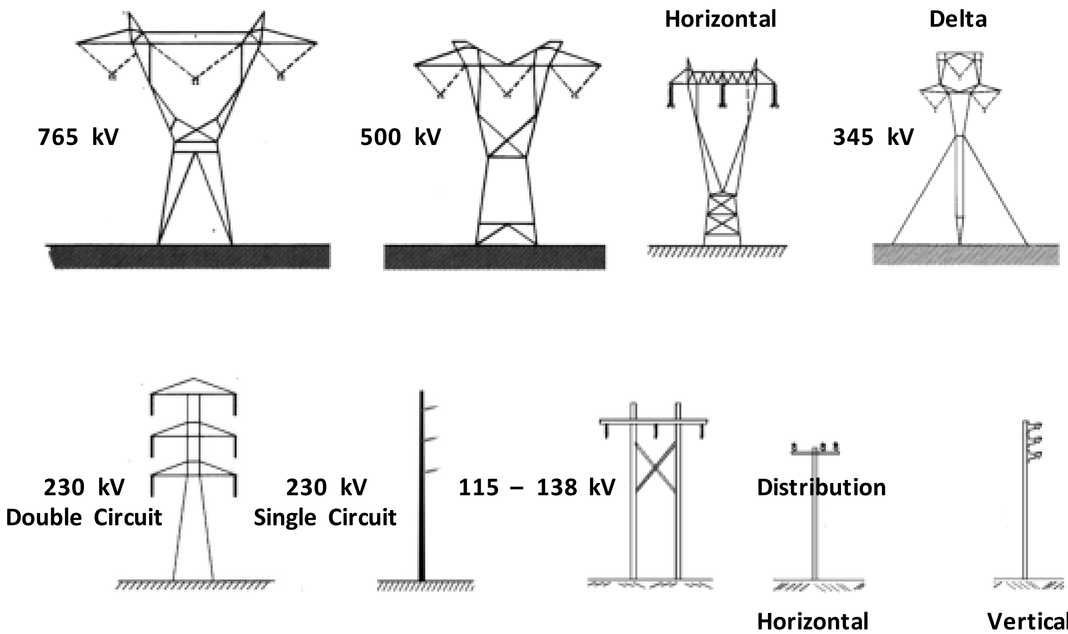

Figure 3 – Cross sections of representative transmission towers of different voltage and distribution poles. (Not shown are "sub-transmission lines" rated between about 40 and 70 kV and underground high voltage transmission lines, which are prevalent in heavily urbanized areas.)

Figure 4 illustrates the magnetic field profiles with distance from the lines that would occur with typical (or greater) current loads for the voltage classifications shown. As a general rule the fields decrease with the inverse square of distance as you move away, meaning if you double your distance from a line, the field decreases to one fourth ($1/2^2$) of the field's value at the closer distance; tripling the distance would decrease the field to ($1/3^2$), or one-ninth of the field at the closer distance. Despite this general rule, the specific magnetic field values associated with overhead power lines are highly variable. However, the magnetic field may exceed 100 mG directly beneath the center of a 765-kV line, with fields generally decreasing at progressively lower line voltages; up to 30 mG may be found beneath heavily-loaded distribution lines.

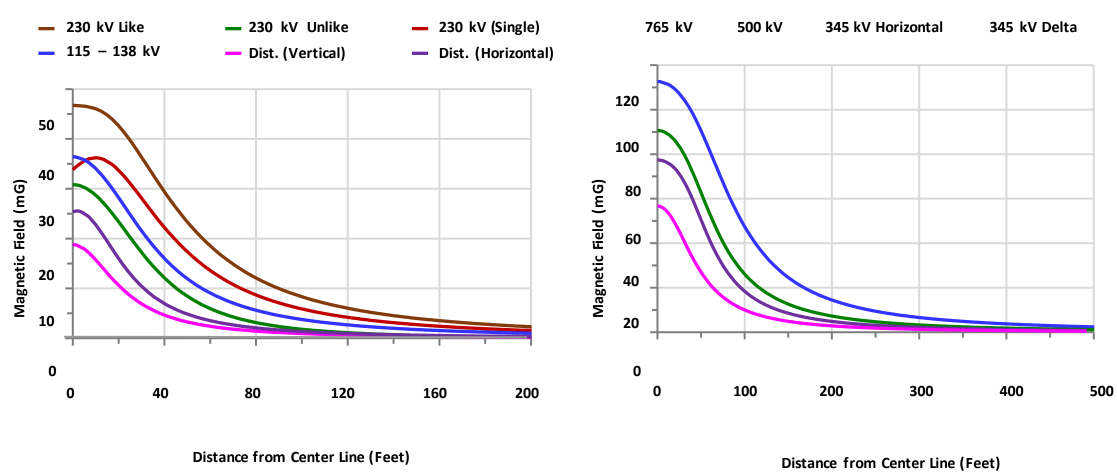

Figure 4 – Magnetic fi profi from transmission lines representing the range of voltages in the U.S. and from distribution lines. (Note: For 230 kV lines, "Like" and "Unlike" refer to the lines' phasing arrangements, as explained further below in connection with Figure 8. Unlike phasing produces lower magnetic fi

For underground lines, the general public's magnetic field exposure level is at its maximum value at walkway or street level directly above the line, with its value depending on load, the depth at which the line is buried, and other design factors. The field may exceed 50 mG or more in certain cases, decreasing with the inverse square of distance (as above for overhead lines). In many cases, the line may be buried beneath a thoroughfare, and exposure from these sources could occur while driving along the road or crossing as a pedestrian.

Typical Levels and Exposures

As indicated earlier, a household appliance (and its wiring) produces an electric field whenever it is plugged in, whether operating or not. On the other hand an appliance produces a magnetic field only when it is turned on. Within a few feet of an appliance, both types of fields fall to background levels. As shown in Table 1, some of the appliances that are used close to the body can produce magnetic fields that are quite high. For example, at the head, the exposure levels from some hairdryers can be as high as 700 mG. Fields from computer monitors and TVs are quite low overall.

Table 1 – Typical Magnetic Fields from Appliances (at 1 foot away and at the distance from the appliance during typical use)

	Appliance	Appliance	Appliance	Appliance
Magnetic Field (mG)	AC Adapter	Baby Monitor	Dimmer Switch	Compact Flourescent Blub
At 1 foot	0 – .75	0 – 2	0 – 0.8	0 – 0.1
	0 – 0.8	0 – 15	0 – 0.8	0 – 0.6
	Portable Heater	Electric Stove	Hairdryer	Gaming Console
At 1 foot	1 – 40	1 – 5	0 – 70	0 – 0.5
	5 – 150	0 – 20	0 –700	0 – 0.6
	Laptop Computer	Digital Clock	Microwave	Plasma LCD
At 1 foot	0	0 – 8	1 – 200	1.4 – 2.2 0 – 2.5
	0 – 0.1	0 – 8	0 – 300	0 – 0.1 0 – 0.6

The level of magnetic field exposure a person receives depends on various factors including the location of their residence relative to nearby transmission and distribution lines; their behavior and activities within the residence as they may relate to local sources, such as appliances, electronic devices, and the wiring within the home associated with electrical service; and the field sources present in locations away from home (e.g., your workplace, stores frequented, or recreational facilities) all factored in to the amount of time spent in these locations. Thus, magnetic field exposure fluctuates constantly over time, with an example of an individual's 24-hour exposure record shown in Figure 5.

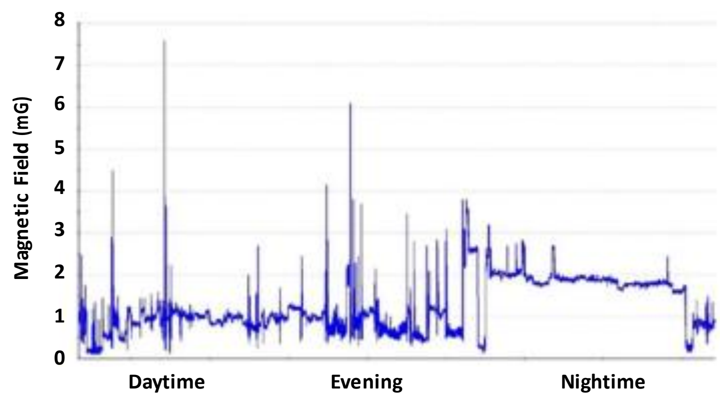

Figure 5 – Exposure recorded by a magnetic fi data logger over a day.

The 'Thousand Person Study', sponsored by the U.S. Department of Energy (DOE), was designed to capture personal exposures to magnetic fields representing the demographic cross-section of the U.S. For example, Figure 6 shows that the top 5% of people in the country were exposed to an average of at least 3 to 4 mG in the home, whether or not in bed, while the top 1% of the population experienced higher exposures (5 to 10 mG) while at home. The highest average exposures away from home (red and yellow bars) were generally lower than those at home. Though completed more than 15 years ago, the results are still considered generally representative of contemporary exposure patterns.

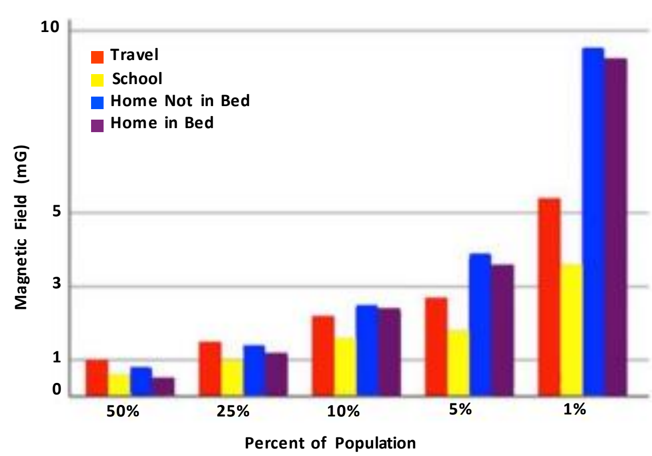

Figure 6 – Population-wide magnetic fi exposures in the U.S. (U.S. DOE 1,000 Person Study, 1998)

Evaluating Environmental Exposures

Overall Process

Like hundreds of other environmental agents, EMF has undergone extensive expert review with respect to potential health risks associated with exposure. These evaluations use a 'weight-of-evidence' methodology in which a panel of multi-disciplinary scientific experts considers the full body of research according to the general process flow shown in Figure 7. By its very name this process must await the accumulation over years of a critical volume of research that permits a balanced and objective evaluation according to established criteria.

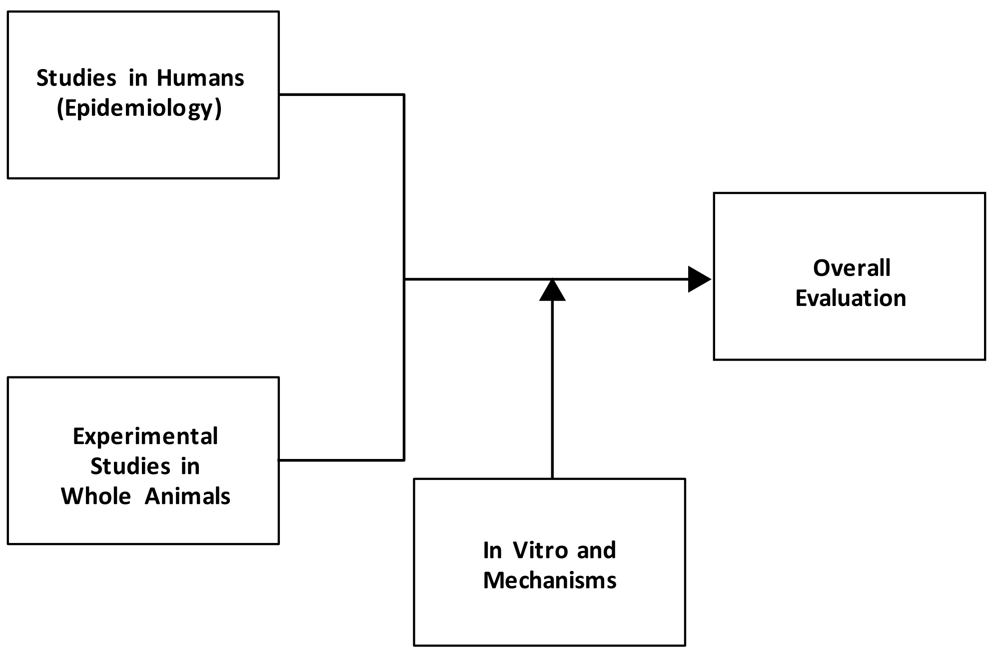

Figure 7 – General process used by health agencies to evaluate potential risks from environmental agents.

Epidemiology

Epidemiology, represented in the upper left box in Figure 7, is the study of patterns and determinants of disease within human populations. Its most important advantage is that data are obtained about real people under actual exposure conditions. A disadvantage is that sampling and studying people is not a neat and clean process like separating cells into exposed and unexposed culture dishes in a laboratory.

The most commonly used study design in EMF epidemiology involves the selection of individuals from a defined geographic region, within a given age bracket, diagnosed with the disease or outcome of interest within a defined interval of calendar time; we can call this group the 'cases'. A second group, referred to as 'controls', consists of subjects representing the very same demographic, but who are disease-free. Each individual from both groups is assigned an exposure score by any of various methodologies (which will not be described here).

RELATIVE RISK

At its core, risk simply means the probability, or chance, of a specific outcome usually under a given set of circumstances. The outcome is most often related to health or safety, for example, the risk of an accident while driving and texting, or the risk of infection from a medical procedure. In epidemiologic studies, results are usually expressed as a comparison of risk within one group exposed to an environmental agent compared to that of another unexposed group. This comparison is called 'relative risk' and is calculated as the occurrence of disease among the exposed population divided by its occurrence among the unexposed population. In EMF epidemiology, the study designs are such that the relative risk is very often expressed as an 'odds ratio', but it essentially means relative risk. Let's say that over a very large sample of the population, 4% of people exposed to factor X (for example, airline travel) during a given year developed disease Y (for example, influenza), while only 2% of the unexposed population (non-flyers) developed the same disease. The relative risk would be 4% divided by 2% or 2. We would then say that the data support a 'positive association' of influenza with air travel, but we still would not know whether air travel or some other factor is the direct cause. On the other hand, if the outcome occurred in about the same percentage in both groups, the relative risk would be close to one, or the 'null', as epidemiologists may call it. In this case, the results would not support a positive association of X with Y. Epidemiologists apply sophisticated statistical techniques that control for extraneous factors (as well as possible) to determine if a result convincingly points towards an association. If, over many studies, the association is consistently null, then it becomes highly unlikely that the exposure studied is a risk factor for the disease under investigation. When positive associations are consistently reported, then further investigation into the root cause (or causes) of those observations is frequently warranted.

The analytical objective is to compare the EMF exposure profiles of the two groups, that is, how EMF exposure is distributed across both groups. If statistical analyses indicate that the profiles of the two are about equal, then one concludes that the disease was not associated with EMF. On the other hand, if the exposure profile for the cases is clearly greater than for the controls, then the analysis could suggest that the disease and exposure are 'positively associated' with one another. Epidemiology results are most often reported as 'relative risks' (often abbreviated as RR), which is a value that reflects the occurrence of disease in an exposed population compared to that disease's occurrence in a population with comparatively low exposures (often referred to for simplicity as an 'unexposed' population). The sidebar on relative risk provides further information.

It is important to note that a positive association means that the exposure is correlated or somehow related to the disease, not necessarily its direct cause. For example, a positive association could also represent an artifact due to the manner in which the study population was sampled. Sampling human populations and soliciting their participation in a study such that the two groups of subjects are demographically equivalent is burdened with challenges. Thus, unequal sampling could skew the data to produce an impression of an association when one does not actually exist. Alternatively, the exposure under study may be masking the effect of another, yet unidentified, environmental factor with which it is highly correlated. This is why drawing broad conclusions about an exposure's risk or lack of risk cannot be based on a single or small handful of studies, but requires judgments based on a sufficiently large body of evidence.

As an example, a few early EMF epidemiology studies suggested a possible link of residential magnetic fields with brain cancer in children. With time additional studies of brain cancer were completed that were not supportive of the early findings. Finally, in 2010, an analysis was conducted pooling the childhood brain cancer data from all 10 available studies. The investigators concluded, "Taken as a whole, our results provide little evidence for an association between ELF-MF [extremely-low-frequency magnetic fields] exposure and childhood brain tumors." We cannot say for sure what the entire basis was for this series of observations; possibly, the quality of studies improved over time that minimized artefacts present in the earlier studies. In either case, the data accumulated to a point that a positive association between magnetic fields and childhood brain cancer, suggested by the earlier studies, was no longer apparent.

Studies in Whole Animals

The second major stream of evidence comes from studies of whole animals (usually mice and/or rats). With respect to cancer outcomes, the experiments are long-term, with many lasting for most or all of the animals' lifespan; such studies are often referred to as 'bioassays'. The animals are split into exposure groups, with one group remaining unexposed to serve as a control group. In the magnetic field bioassays that were conducted, the exposures were many times the levels typically experienced by humans, extending up to 10 G (our typical exposures are at least 100 times lower).

One may question the applicability of experiments in rodents to humans, but two factors should be borne in mind. Despite their external appearance, rats and mice are genetically very similar to humans. Secondly, rodent bioassays have an excellent track record in identifying exposures carcinogenic to humans. The International Agency for Research on Cancer (IARC, discussed later) has evaluated nearly 1,000 exposures for their carcinogenic potential and published its results over the past three decades in a series of detailed reports, called monographs. In the latest version of its preamble to its monographs (2006), IARC states that: "All known human carcinogens that have been studied adequately for carcinogenicity in experimental animals have produced positive results in one or more animal species." Many bioassays of animals exposed to magnetic fields have by now been conducted with a uniform lack of effects on cancer development (including leukemia), which strongly suggests a lack of carcinogenicity in humans.

In vitro Studies and Mechanisms

The third element of a risk evaluation includes (1) in vitro studies, meaning studies of cells and tissue placed in a culture dish and exposed to the agent of interest in a culture dish and (2) theoretical assessments of possible mechanisms of action, that is exploring how an agent such as a magnetic field may trigger a biological effect. These approaches are most useful when specific and validated effects have already been observed either in whole animals or in epidemiology studies. In a practical sense, without consistent or corroborating evidence in human and animal studies, it is not possible to get clues of effects that may occur in people or animals based only on observations in isolated cells or from theoretical analyses. For EMF, this third line of evidence has been unable to contribute research information or insights that would alter the conclusions based on epidemiologic and whole animal studies.

Thus, a risk evaluation relies on streams of evidence from different research disciplines and methodologies blended together and judged against criteria that determine whether exposure to an environmental agent has the necessary and sufficient qualities to be considered a health risk.

EMF Health Research

Background

Over the past 40 years, a great many studies have addressed questions about potential health risks associated with exposures to power frequency EMF. A broad range of health outcomes has been studied including cancers of various types in children and adults, pregnancy outcome including miscarriage and birth defects, neurodegenerative diseases that include Alzheimer's disease, amyotrophic lateral sclerosis (ALS, also known as Lou Gehrig's disease) and Parkinson's disease, cardiovascular function and disease, behavioral responses and others.

In the mid to late 1980s the emphasis of health-related research shifted away from electric fields to magnetic fields. A major reason for the shift was that a large body of research supported by the U.S. Department of Energy (DOE) and EPRI, among others, did not uncover hazards associated with electric field exposure from typical levels up to those present beneath transmission lines. However, in the same time period epidemiologic studies increased the public's concern regarding the relationship of childhood cancer particularly leukemia with residential magnetic fields.

The RAPID Program in the U.S.

In 1993, the U.S. federal government, under the 1992 Energy Policy Act, launched the RAPID program (Research And Public Information Dissemination), with the purpose of "providing scientific evidence to determine whether exposure to power-frequency EMF involves a potential risk to human health." (quoted from NIEHS 2002 Q&A booklet) The program, administered by the National Institute of Environmental Health Sciences (NIEHS) with engineering support from the U.S. Department of Energy (DOE), consisted of a broad range of laboratory and exposure characterization studies. It ended in 1999 with NIEHS' submission of its final report to the U.S. Congress. That report, based on an extensive review by a multi-disciplinary scientific panel stated (see sidebar on panel appointments):

> The ultimate goal of any risk assessment is to estimate the probability of disease in an exposed population. …The NIEHS believes that the probability that ELF-EMF exposure is truly a health hazard is currently small. The weak epidemiological associations and lack of any laboratory support for these associations provide only marginal, scientific support that exposure to this agent is causing any degree of harm.

Evaluations by Government Agencies and Expert Panels

NIEHS, 2002: In 2002, after the RAPID program was complete, the NIEHS published its "Questions & Answers" booklet for the public that covered the topics relevant to a general understanding of EMF and the research to that point in time. The NIEHS stated in its conclusion:

> Electricity is a beneficial part of our daily lives, but whenever electricity is generated, transmitted, or used, electric and magnetic fields are created. Over the past 25 years, research has addressed the question of whether exposure to power-frequency EMF might adversely affect human health.

> For most health outcomes, there is no evidence that EMF exposures have adverse effects. There is some evidence from epidemiology studies that exposure to power-frequency EMF is associated with an increased risk for childhood leukemia. This association is difficult to interpret in the absence of reproducible laboratory evidence or a scientific explanation that links magnetic fields with childhood leukemia.

This conclusion was based on NIEHS' report to Congress, as well as by an evaluation conducted in 2001 by the International Agency for Research on Cancer (IARC), located in Lyon, France. IARC was established in 1965 as a part of the World Health Organization to "…provide governments with expert, independent, scientific opinion on environmental carcinogenesis." It is also important to note that IARC is not a policy setting organization and it publishes its evaluations for use "by national and international authorities to make risk assessments, formulate decisions concerning preventive measures, provide effective cancer control programmes and decide among alternative options for public health decisions… [and] no recommendation is given [by IARC] with regard to regulation or legislation, which are the responsibility of individual governments or other international organizations."

For about 40 years, IARC has issued carcinogen evaluations in reports called 'monographs' for nearly one thousand exposures, including chemicals, physical factors, medications, foods and additives, industrial processes, and various occupations. Each exposure evaluated also receives a classification with respect to its carcinogenicity to humans (see sidebar "IARC Classifications").

IARC appointed an expert panel that convened in 2001 to evaluate power frequency EMF, and published its final report in 2002. The panel examined a wealth of whole animal experiments (many of them lifetime exposures) and did not find evidence to support magnetic fields as carcinogenic for any cancer studied (including leukemia). The panel was also unable to identify a mechanism through which magnetic fields at everyday levels interact with living bodies to produce biological effects.

APPOINTING AN EXPERT SCIENTIFIC PANEL

Without the confidence and trust of the public, the scientific community, and policy-makers, an expert panel's evaluation of potential risks from exposure to an environmental agent is unlikely to be viewed as entirely credible. Therefore, governmental agencies and risk assessment organizations adopt processes to provide assurance that their appointed panels successfully serve their intended purpose. As an example, the National Academy of Sciences (NAS) in the U.S. has described the principles to follow to appoint an effective and credible panel (*http://www.nationalacademies.org/site_assets/groups/nasite/documents/webpage/na_069618.pdf*). First, the panel must include an "appropriate range of expertise," that is cover the disciplines required to conduct a full weight-of-evidence evaluation. For EMF, this requirement calls for credentials in engineering, exposure assessment, epidemiology, laboratory experimental sciences (both whole animals and isolated cells and tissues), and physics. Second, an appointed group must include a "balance of perspectives…to ensure that the committee [i.e., panel] can carry out its charge objectively and credibly." Looking at an issue exclusively from one side is likely to culminate in a one-sided evaluation. Finally, panel members must be screened for conflict of interest, which is present when one's position on the science is dictated strictly by one's affiliation. The panels referenced under the heading, "EMF Health Research" were convened under a process similar to that laid out by the NAS. There are also cases of self-appointed groups who have reviewed the EMF science who lack one or more of these qualities. Consequently, their reviews run the risk of not evaluating the full weight of evidence as objectivity and independence requires. Such groups are prone to rely on selected studies that support a pre-determined point of view.

LEUKEMIA

Childhood leukemia has been an important focus of EMF health research. On page 18 of its Q&A booklet, NIEHS provided a brief synopsis of key facts: "Leukemia describes a variety of cancers that arise in the bone marrow where blood cells are formed. The leukemias represent less than 4% of all cancer cases in adults but are the most common form of cancer in children. For children age 4 and under, the incidence of childhood leukemia is approximately 6 per 100,000 per year, and it decreases with age to about 2 per 100,000 per year for children 10 and older. In the United States, the incidence of adult leukemia is about 10 cases per 100,000 people per year. Little is known about what causes leukemia, although genetic factors play a role. The only known causes are ionizing radiation, benzene, and other chemicals and drugs that suppress bone marrow function, and a human T-cell leukemia virus."

Despite our lack of knowledge about causes of childhood leukemia, medical progress in successfully treating the disease has been dramatic. In 1964, an article in Scientific American characterized leukemia as "almost invariably fatal." Today, the most common form of childhood leukemia – acute lymphocytic leukemia (ALL) – has survival rates of 90% for children under 10, and about 80% for children between 10 and 15 years of age.

When examining the epidemiologic literature, the panel determined that for all childhood and adult cancers with one exception, there was inadequate evidence with which to conclude that power frequency magnetic fields are carcinogenic. That exception was childhood leukemia for which there was "limited" evidence that the reported association with power frequency magnetic fields represented a cause-and-effect relationship. On this basis, IARC classified power frequency magnetic fields into Group 2B, or an exposure 'Possibly carcinogenic to humans'. The Group 2B designation reflects the panel's conclusion that uncertainties remain, but does not assert that evidence of an adverse health effect has been identified at a high level of confidence.

The IARC panel also determined that there was no adequate evidence with which to conclude that power frequency electric fields are carcinogenic in children or adults.

In addition, IARC reviewed the pregnancy outcome literature concluding: "Taken as a whole, the results of human studies do not establish an association of adverse reproductive outcomes with exposure to ELF electric and magnetic fields." Also, "[p]renatal exposure to ELF [extremely-low-frequency] magnetic fields generally does not result in adverse effects on reproduction and development in mammals."

Since the NIEHS Q&A booklet was published in 2002 other governmental agencies and risk assessment organizations around the world have reviewed the EMF health literature:

WHO, 2007: In 2005 the World Health Organization (WHO) followed up IARC's review of EMF and cancer with a review of all health outcomes, convening an expert scientific panel at WHO headquarters in Geneva, Switzerland. In 2007, WHO published its report as part of its ongoing series of Environmental Health Criteria. The WHO report agreed with IARC that the epidemiologic evidence for childhood leukemia was 'limited', concluding:

> …the epidemiological evidence [regarding childhood leukemia] is weakened by methodological problems, such as potential selection bias. In addition, there are no accepted biophysical mechanisms that would suggest

> that low-level exposures are involved in cancer development. Thus, if there were any effects from exposures to these low-level fields, it would have to be through a biological mechanism that is as yet unknown. Additionally, animal studies have been largely negative. Thus, on balance, the evidence related to childhood leukaemia [British spelling of leukemia] is not strong enough to be considered causal.
>
> A number of other adverse health effects have been studied for possible association with ELF magnetic field exposure. These include other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioural effects and neurodegenerative disease. The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukaemia. In some instances (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them.

Health Canada, 2012: Quoting its website, "Health Canada is the Federal department responsible for helping Canadians maintain and improve their health, while respecting individual choices and circumstances." In 2012 Health Canada updated its website that provides the public with information on EMF, stating:

> The results of some studies of human populations have suggested that there may be an increase in risk of childhood leukaemia at higher than usual magnetic field exposures in homes, some of which are near to large power lines. Studies have also looked at whether exposure is linked to the risk of other illnesses such as Alzheimer's disease. Although there have been some results suggesting a link, the overall balance of evidence is towards no effect and much weaker than that for childhood leukaemia.

IARC CLASSIFICATIONS

In its classification hierarchy, IARC places an agent with 'sufficient' epidemiologic evidence of carcinogenicity (with or without evidence in animals) into Group 1, 'Carcinogenic to humans', meaning there is little to no doubt about the ability of such agents to cause cancer in humans; such exposures include ionizing radiation (e.g., x-rays), asbestos, smoking. Agents with 'sufficient' evidence in whole animals, but limited or inadequate epidemiologic evidence are place in Group 2A, 'Probably carcinogenic to humans'. This group includes many organic chemicals, some pharmaceuticals, and some specific circumstances, such as occupation as a hairdresser or barber, and shift work (which can disrupt waking-sleep cycles). Power frequency magnetic fields were classified in Group 2B (Possibly carcinogenic to humans), a classification that includes for the most part various types of chemicals, but also some familiar exposures, such as coffee, pickled vegetables, and gasoline fumes. Group 3 consists of agents that have inadequate evidence with which to classify them as Group 1, 2A or 2B. A fourth group (Group 4), consists of one substance of the nearly one thousand agents classified. This group is designated as "Probably not carcinogenic to humans."

> The types of studies that investigate these risks face many difficulties, including the possibility of chance, bias and the presence of confounding factors that may confuse the findings. Importantly there is no known mechanism or clear experimental evidence to explain how these effects might happen.
>
> Health Canada does not consider that any precautionary measures are needed regarding daily exposures to EMFs at ELFs. There is no conclusive evidence of any harm caused by exposures at levels found in Canadian homes and schools, including those located just outside the boundaries of power line corridors.

EFHRAN (2012): The European Commission funded EFHRAN (European Health Risk Assessment Network on Electromagnetic Fields Exposure) with the "specific aim of establishing a wide-ranging network of recognised experts in relevant disciplines that interact and cooperate to perform a health risk assessment of exposure to EMF across the frequency spectrum." EFHRAN released a report in 2012 that reviewed a full range of health outcomes across the spectrum. EFHRAN was consistent with the preceding reviews regarding childhood leukemia. For all other outcomes the report stated:

> There is inadequate evidence for Alzheimer's disease, childhood brain tumours, and amyotrophic lateral sclerosis…further studies on these outcomes would be useful. For all other cancers, other neurodegenerative diseases and for non-specific symptoms, evidence is also inadequate, but there appears to be no justification to conduct further studies. There is evidence suggesting a lack of effect for breast cancer, cardiovascular disease and for EHS [electromagnetic hypersensitivity].

PHE: Public Health England (formerly the Health Protection Agency) provides information on all matters related to health and wellness to the citizens of the United Kingdom. PHE's responsibilities include, "making the public healthier by encouraging discussions, advising government and supporting action by local government, the NHS [National Health Service] and other people and organisations," and "researching, collecting and analysing data to improve our understanding of health and come up with answers to public health problems."

With reference to EMF, PHE states:

> The results of some studies of human populations have suggested that there may be an increase in risk of childhood leukaemia at higher than usual magnetic field exposures in homes, some of which are near to large power lines. Studies have also looked at whether exposure is linked to the risk of other illnesses such as Alzheimer's disease. Although there have been some results suggesting a link, the overall balance of evidence is towards no effect and much weaker than that for childhood leukaemia.
>
> The types of studies that investigate these risks face many difficulties, including the possibility of chance, bias and the presence of confounding factors that may confuse the findings. Importantly there is no known mechanism or clear experimental evidence to explain how these effects might happen.

PHE offers the following three reasons for why evidence weighs against magnetic fields as a cause of leukemia:

- "Magnetic fields don't have sufficient energy to damage cells and thereby cause cancer.
- At present there is no clear biological explanation for the possible increase in childhood leukaemia from exposure to magnetic fields.
- The evidence that exposure to magnetic fields causes any other type of illness in children or adults is far weaker."

SCENIHR, 2015: The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) serves the European Commission and "deals with questions related to emerging or newly identified health and environmental risks." Similar to two other committees that serve the commission, SCENIHR provides it "with the scientific advice it needs when preparing policy and proposals relating to consumer safety, public health and the environment." In 2014 this committee prepared an update to its previous 2007 and 2009 reports on EMF, entitled "Opinion on Potential Health Effects of Exposure to Electromagnetic Fields (EMF)." The report concluded,

> The new epidemiological studies are consistent with earlier findings of an increased risk of childhood leukaemia with estimated daily average exposures above 0.3 to 0.4 μT [3 to 4 mG]. As stated in the previous opinions, no mechanisms have been identified and no support is existing from experimental studies that could explain these findings, which, together with shortcomings of the epidemiological studies prevent a causal interpretation.
>
> Epidemiological studies do not provide convincing evidence of an increased risk of neurodegenerative diseases, including dementia, related to ELF MF exposure. Furthermore, they show no evidence for adverse pregnancy outcomes in relation to ELF MF. The studies concerning childhood health outcomes in relation to maternal residential ELF MF exposure during pregnancy involve some methodological issues that need to be addressed. They suggest implausible effects and need to be replicated independently before they can be used for risk assessment.
>
> Recent results do not show that ELF fields have any effect on the reproductive function in humans.

Update on Childhood Leukemia Research

The preceding review of expert scientific opinion since the NIEHS Q&A booklet was published in 2002 condensed the panels' and agencies' conclusions regarding the many health outcomes that have been the subject of EMF health research. It was evident that, repeatedly, mainstream expert opinion has found no evidence that everyday exposure levels of magnetic fields cause effects on such varied health endpoints as pregnancy outcome (e.g., miscarriage and birth defects), neurodegenerative illnesses (e.g., Alzheimer's disease), cardiovascular disease, electromagnetic hypersensitivity (EHS, see sidebar titled "Related Topics"), and others. The concerns about the association between childhood leukemia and magnetic fields remains, but a causal role for magnetic fields is cast in significant doubt because of the persistent absence of effects on leukemia development in whole animals, the absence of an explanatory mechanism, and the uncertainties surrounding the epidemiology studies.

As context, the IARC classification of magnetic fields as a Group 2B (possibly carcinogenic to humans) was based to a major degree on two 'pooled' analyses of the epidemiology literature published in 2000 that addressed the association of magnetic fields with childhood leukemia. The term, pooled, means that the raw data from a collection of studies were combined as if constituting a single study. One analysis was conducted in the U.S. and the other in Europe using an overlapping but not identical set of studies, with the two arriving at similar conclusions. These studies reported statistically significant relative risks (RRs) of between 1.7 and 2.0 associated with average residential magnetic fields above 3 to 4 mG (see sidebar on relative risk). In 2010, an international group of investigators published a pooled analysis of the studies available since the IARC report. The updated pooled analysis reported a comparatively weaker association, relative risk of 1.44, that was not statistically significant. Although consistent with the earlier pooled studies the investigators concluded that, "[o]verall, the association is weaker in the most recently conducted studies, but these studies are small and lack methodological improvements needed to resolve scientific uncertainties regarding the apparent association. We conclude that recent studies on magnetic fields and childhood leukaemia do not alter the previous assessment that magnetic fields are possibly carcinogenic."

During this period, several studies reported the association of childhood leukemia with distance from overhead high voltage transmission lines. A study conducted in the UK of childhood cancer from 1962 to 1995 published in 2005 reported that although childhood leukemia was associated with close proximity to the transmission lines (within about 650 feet), the associations remained with a weaker though statistically significant relative risk at distances at which the magnetic fields from the lines are negligible (about 650 to 2,000 feet). Other cancers, including brain cancer, bore no relationship to distance from overhead transmission lines.

A follow-up study in the UK published in 2014 extended the period of observation to 2008, reporting that the childhood leukemia risk associated with proximity to overhead lines, though evident in the 1960s and 1970s, disappeared in subsequent decades. The fact that magnetic fields from the lines were a constant presence in residences located near the lines' corridors throughout the five-decade period, but the occurrence of leukemia in those residences diminished to background levels over the five-decade period, provided strong evidence that some other unknown factor aside from magnetic fields had played a role in the association with elevated risks of childhood leukemia in the earlier periods. Two other studies of the risk of childhood leukemia versus distance to transmission lines were conducted in France (2013) and in Denmark (2014) with inconclusive results. Finally, a large study of childhood leukemia (nearly 6,000 cases) and distance to overhead transmission lines across California is in its final stages with results expected in 2016.

The childhood leukemia studies summarized thus far addressed the question: Is the risk of an initial diagnosis of childhood leukemia associated with exposure to residential magnetic fields? In 2006 and 2007 two studies looked at a different question: After the initial diagnosis and treatment is the magnetic field in a child's residence associated with that child remaining disease-free? A U.S. study published in 2006, and a German study published in 2007 each suggested that survival was poorer in children living in residences with higher magnetic fields, but both studies had small sample sizes limiting one's ability to draw firm conclusions. To overcome this problem, investigators from eight countries pooled all of the available data from over 3,000 children to assess whether either the risk of relapse or overall survival was associated with residential magnetic fields. The results of the pooled analysis were published in 2012, concluding: "In this large pooled analysis of more than 3000 children diagnosed with ALL in eight countries, no statistically significant associations were observed between exposure to ELF–MF and event-free survival or overall survival of ALL. These results provide no evidence that ELF–MF has a role in predicting outcome of childhood ALL." This case serves to emphasize a point made earlier that it is premature to draw conclusions that rely on a small set of early studies with inadequate numbers of subjects.

Exposure Guidelines and Standards

As has been indicated, a mechanism through which low level EMF could cause biological effects has not been identified. The absence of a validated biological effect in whole animals or humans at low levels is consistent with the absence of a mechanism. However, at much higher exposure levels magnetic and electric fields can produce immediate (or 'acute') effects through established mechanisms. Magnetic fields 'couple' to people causing currents to flow within the body. Above a threshold level these currents stimulate nerve tissue, a phenomenon referred to as 'electrostimulation'. Electric fields also cause currents to flow in the body, but before an exposure threshold is reached that causes electrostimulation inside the body, electric fields can stimulate sensory receptors present on the surface of the body; this interaction is also grouped under the broader term of electrostimulation. At the levels at which magnetic and electric fields reach their respective perception thresholds, that is, levels at which they are just perceived or sensed, the effect does not produce any apparent harm or injury and ends when exposure at those levels ceases. However, as the exposure level is raised past the perception threshold, the effect can become annoying and ultimately painful, though reversible when exposure ceases.

The European-based International Commission for Non-Ionizing Radiation Protection (ICNIRP) and the U.S.-based Institute for Electrical and Electronic Engineers (IEEE) have each published reports that recommend exposure limits to protect against electrostimulation. Both sets of limits for the general public for power frequency fields are shown in Table 2. Though a bit different from one another, each builds in adequate safety margins that protect against aversive electrostimulation. Less stringent limits exist for workplace personnel, because those who work in high field environments are trained to be aware of the electromagnetic factors present. One cannot assume that all members of the public have received such training and to compensate, the public limits are lower compared to those for workers. The magnetic fields listed in Table 2 are rarely, if ever, encountered by the general public. The only location with access to the general public where electric fields at levels near guideline limits would be present is on rights-of-way (ROW) of overhead transmission lines of 230-345 kV or greater, with the maximum electric field found approximately beneath the outer conductors at the midpoint between two towers. Some individuals may feel a 'tingling' sensation when in such locations, with the effect disappearing upon moving away.

Table 2 – General Public Exposure Limits for Power Frequency Fields

Organization	Magnetic fi (gauss)*	Electric fi (kV/m)
ICNIRP	2.0	4.2 (60 Hz)/5.0 (50 Hz)
IEEE	9.1	5.0 (10.0 on ROW)

** 1 gauss = 1,000 milligauss (mG)*

With regard to acute effects and exposure limits, the 2007 WHO report (see above) concluded: "Acute biological effects have been established for exposure to ELF [extremely-low-frequency] electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection for acute effects."

EMF AND YOUR HEALTH

National Policies and Precautionary Limits

Regulatory agencies in the U.S. and Canada have not established national standards limiting exposure to EMF, although several states in the U.S. have established limits for electric fields within the ROW and for both electric and magnetic fields at the edge of the ROW. More than 50 countries worldwide have set exposure limits in some manner that vary widely from country-to-country (*www.emfs.info/compilation*; note: this link provides the latest update posted). Some countries have adopted the ICNIRP limits, some have country-specific safety limits similar to ICNIRP or IEEE, and still others have limits that apply to the ROW. Some countries have adopted more conservative limits for certain circumstances, such as for new residential construction.

With regard to field mitigation, WHO stated in its 2007 report, "…it is not recommended that the limit values in exposure guidelines be reduced to some arbitrary level in the name of precaution. Such practice undermines the scientific foundation on which the limits are based and is likely to be an expensive and not necessarily effective way of providing protection." WHO further recommended that field reduction could be considered when at "little or no cost."

The National Radiological Protection Board (now absorbed into PHE) in the United Kingdom reviewed the EMF literature in 2004, stating "the results of epidemiological studies, taken individually or as collectively reviewed by expert groups cannot be used as a basis for restrictions on exposure to EMFs." The clear message here was that the existing guidelines and standards provide protection against known effects with established mechanisms, and limits need not be reduced any further.

Prior to the WHO and NRPB recommendations, the California Public Utilities Commission (CPUC) set a policy in 1993, reaffirmed in 2006, "to mitigate EMF exposure for new utility transmission and substation projects. As a measure of low-cost mitigation, we [the CPUC] continue to use the benchmark of 4% of transmission and substation project costs for EMF mitigation, and combine linked transmission and substation projects in the calculation of this 4% benchmark."

An example of a low-cost intervention is illustrated in Figure 8, which shows a double-circuit 345-kV transmission line (Figure 3 illustrated a single-circuit 345-kV transmission line). As is evident from Figure 3, the cables (or conductors) on transmission lines come in groups of three, each of which is identified as a 'phase', A, B, and C. A double circuit line has two groups of three conductors. When the line is 'like' phased with phases A, B, and C symmetrically placed on the tower (A opposite A, etc.), the magnetic field is maximized. At virtually no cost (and if implemented during the initial construction) the double circuit can be phased in an 'unlike' manner, which drives down both the electric field and the magnetic field. The reason is because the unlike phases opposite each other have a cancelling effect on the field (whereas with like phasing the fields are reinforced and therefore greater). This same effect was shown in Figure 4 for a 230-kV double-circuit line in which the field profile for unlike phasing (green curve) is considerably lower than the profile for like phasing (brown curve).

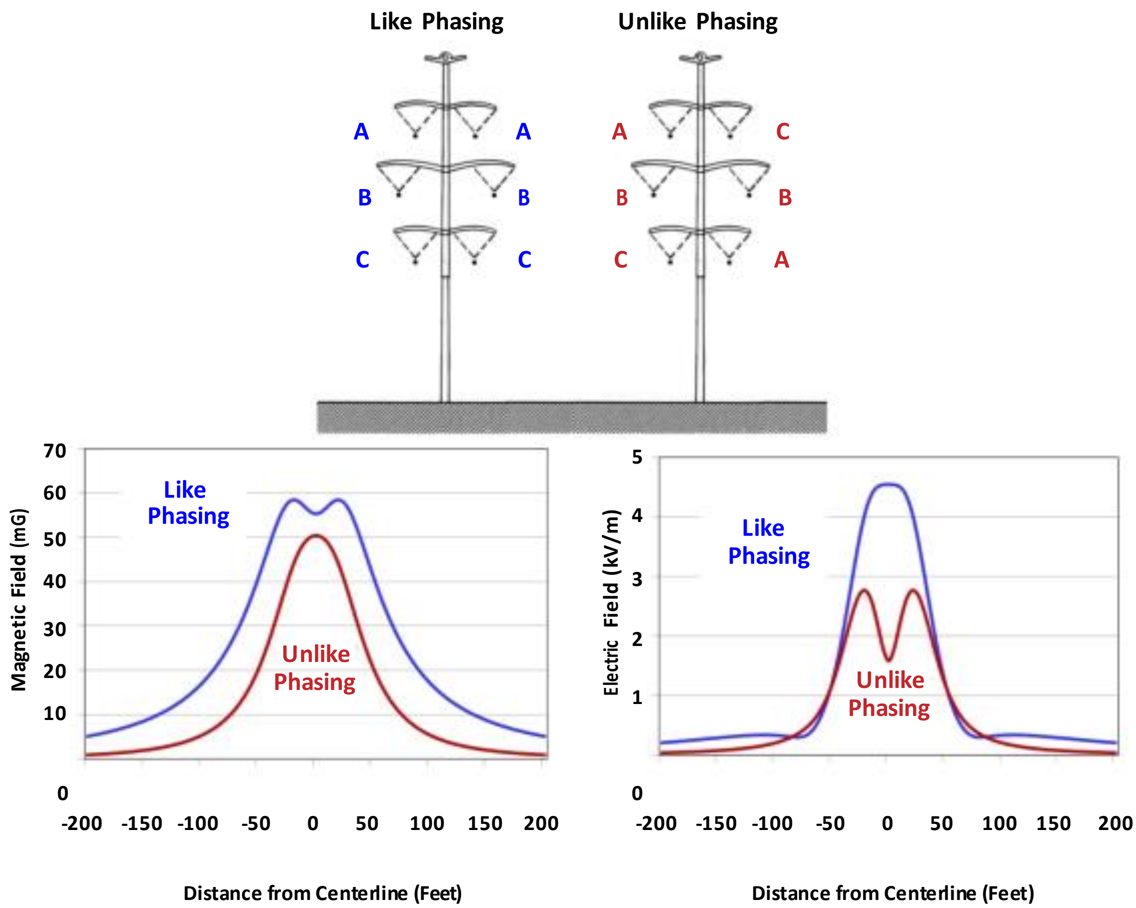

Figure 8 – Magnetic (left) and electric (right) fi profi from a double circuit 345-kV transmission line with like an unlike phasing (also, see Figure 4).

RELATED TOPICS

Occupational Studies: Studies of workers can offer a useful opportunity to examine environmental EMF exposures at higher levels than occur in residential settings. Many occupational studies of electrical workers and others exposed to higher magnetic fields have examined both cancer and other diseases. Overall, the occupational studies do not support a link between magnetic fields exposure and any form of cancer or other adverse effects.

Cancer Clusters: When several cancers occur close in time and space – that is, in a cluster, such as in a given school – people seek a reason, and at times EMF has been thought to be a possible culprit. Most often, upon further investigation, no actual cancer cluster is identified. The perception of a cluster arises partly because people do not always understand how common cancer is. In industrialized countries, one in 2-3 people will develop some type of cancer during their lifetimes. Cancer clusters can and do occur by chance, but distinguishing a chance occurrence from an occurrence with a common cause is difficult. As a result, cancer cluster investigations are rarely productive, and none have linked a cancer cluster to magnetic field exposure.

RELATED TOPICS (CONTINUED)

Electromagnetic Hypersensitivity (EHS): Some individuals experience a wide range of nonspecific symptoms such as headaches and sleep disturbance that can be quite debilitating, which they ascribe to EMF exposure. Further, some of these individuals believe that they can sense the presence of high fields, which trigger their symptoms. The consensus of the scientific community is that while some of these individuals clearly have health conditions and may react to factors in their environment, their symptoms are not related to EMF. This conclusion is based mostly on carefully conducted tests in the laboratory in which individuals self-identified as EHS cannot reliably detect the presence of fields, and their symptoms cannot be attributed to EMF. Several studies have indicated that the observed effects may be caused by an expectation that something harmful is going to happen. In light of the fact that an EMF basis for these individuals' conditions has not been observed, the condition has more recently been labeled 'Idiopathic Environmental Intolerance Attributed to Electromagnetic Fields'.

Pacemakers and Other Medical Devices: Cardiac pacemakers and defibrillators are the most commonly implanted medical devices, and research has indicated that they may be susceptible to interference under certain high field conditions. The sensitivity of these devices depends on manufacturer, design, and how they are used by a patient. Metallic case shielding, internal circuits, filters and bipolar sensing have contributed to improved immunity to interference, and in practice, interference is very rare. Many other medical assist devices are now deployed in patients, such as insulin pumps and brain stimulators, but interference to them from power frequency fields has not been addressed. International product standards generally call for implanted medical devices to maintain immunity to power frequency magnetic fields of 1 gauss (G) and 5 kV/m.

Animals and Vegetation: Research on how animals and plants might be affected by exposure to EMF has been conducted since the 1970's. EMF exposure has not been shown to have any consistent detectable, adverse effects on plant growth, crop yield or animal health. A separate issue is sometimes raised about potential harm to farm animals from 'stray voltages'. Stray voltage is a general term used to describe the small voltages that may exist at contact locations where they would not be necessarily expected. These voltages may arise from the normal operation of a 'multi-grounded' power system, and may originate from electricity systems both on and off a farm. Stray voltages may be enhanced by various abnormal and correctible situations, such as poor insulation or wiring errors.

Questions have arisen as to whether the environments within transmission line rights-of-way are inhospitable to native bees and honey bees, both crucial to agricultural production. The U.S. Geological Survey states (http://www.usgs.gov/blogs/features/usgs_top_story/the-buzz-on-native-bees/) that: "According to the USDA [US Department of Agriculture], bees of all sorts pollinate approximately 75 percent of the fruits, nuts and vegetables grown in the United States…bee pollination is responsible for more than $15 billion in increased crop value each year." Recent research has shown that high voltage transmission line easements can provide quality habitat for native bees, particularly when these areas are managed in a way that promotes the growth of native shrubs and flowering perennials. Honeybees in commercial hives with metallic components in high electric fields under high voltage transmission lines may experience tiny electrical discharges within the hives. These effects can be mitigated by shielding and grounding or moving the hives a short distance away from the line.

Theories of Mechanisms: Over the years, many theories have been advanced to explain how low level magnetic fields may interact with the cells and tissues within our bodies. For example, in the 1980s the 'cyclotron resonance' theory was introduced predicting how certain ions like calcium and lithium would be affected by magnetic fields of specific frequency and magnitude. Although the theory attracted attention at the time, further analyses and experiments did not support its plausibility, and scientific interest in it faded.

RELATED TOPICS (CONTINUED)

Another hypothesis suggested that tiny magnetic particles in the surface of cells in the human brain could be physically rotated in a magnetic field (like a compass) thereby altering signaling in the brain. However, the presence of such deposits in the human brain was never ascertained. Magnetic deposits, present in some animals, such as honey bees, may help them navigate using the earth's natural field as a guide, and we know for certain that magnetotactic bacteria contain large magnetic crystals that guide them to their source of nutrients.

A third example concerns a biological pathway through a small structure in the brain called the pineal gland that secretes melatonin, a substance that is instrumental in regulating our 24-hour biological cycle (called the 'circadian rhythm'). A suppression of melatonin in animal experiments increased the occurrence of hormonally dependent cancers, such as breast cancer. Early experiments reported promising results that magnetic fields suppressed melatonin, but after different scientists across different laboratories attempted replications, the effect was no longer apparent. In any case, the proponents of the melatonin hypothesis were unable to explain how a low level magnetic field could interact at the cellular level to set this proposed pathway in motion.

The one established mechanism in humans is electrostimulation, the stimulation of nerve tissue by magnetic or electric fields (or by direct contact with an electrical conductor), which occur above threshold exposure levels that are much greater than those present in our daily lives. As described under Exposure Guidelines and Standards, published exposure limits are structured to protect people against adverse electrostimulation.

Summary

This brochure addresses basic aspects about environmental EMF and contemporary issues related to potential health effects from EMF exposure. It was prepared as an update to the National Institute of Environmental Health Sciences (NIEHS) booklet entitled, "EMF: Electric and Magnetic Fields Associated with the Use of Electric Power – Questions & Answers," published in 2002.

Electricity and EMF

- Voltage may be thought of as electrical 'pressure'; the voltage on a conductor or appliance produces an electric field, expressed as volts per meter (V/m) or thousands of volts per meter (kV/m)
- Current is the flow of electricity through a conductor; current produces a magnetic field, with typical fields expressed in milligauss (mG; 1 gauss=1,000 mG). The international unit is microtesla (μT) and 1 μT = 10 mG.
- Electricity is generated and supplied at a frequency of 60 Hz in the U.S. (50 Hz in Europe); hertz means cycles per second, meaning voltage and current go through one full cycle 60 (or 50) times every second. These are 'power frequencies'.
- Power frequency fields neither damage cells like ionizing radiation, nor heat tissue like radio-frequency fields.

Electrical Transport

- At the generating station, voltage is stepped up feeding transmission lines that usually travel long distances to bring power to local substations.
- In the U.S., high voltage transmission lines operate from between about 115 kV to 765 kV
- At the substation the voltage is stepped down for distribution to neighborhoods.
- Distribution lines operate from between 4 kV and 35 kV.
- The distribution voltage is stepped down to the voltages that power our lights, electronics and appliances.

Environmental Magnetic Fields

- Directly beneath a high voltage transmission lines, the magnetic fields may reach from 10 to over 100 mG, depending on voltage class and current (load).
- Directly beneath a distribution line, the magnetic field may reach roughly between 10 and 30 mG.
- In most homes in the U.S. average magnetic field exposure is less than 3 mG, but activities near appliances and other sources can increase one's overall exposure level.
- A person's exposure over time can vary significantly depending on
  - the power lines in proximity to the home and activities within a home that involve local sources (appliances and electrical equipment), and
  - activities and sources at locations away from home, including work, school, retail stores and recreational facilities.

Environmental Health Research

- The evaluation of potential health risks that may be linked to environmental agents relies on a 'weight-of-evidence' evaluation, which factors in the results of
  - Epidemiology studies,
  - Studies in whole animals, and
  - Studies of isolated cells and tissues and analyses of potential mechanisms of action
- To evaluate environmental agents, government agencies and risk assessment organizations recruit scientific panels whose members have proven expertise and represent the diverse specialties required for an objective evaluation.

EMF Health Research

- Over the past 40 years, thousands of scientific articles concerned with EMF health research have been published.
- In 2001, International Agency for Research on Cancer classified power frequency magnetic fields as "possibly carcinogenic to humans" on the basis of 'limited' epidemiologic evidence.
- In 2002, after the completion of the U.S. RAPID program and report to the U.S. Congress, the NIEHS Q&A booklet concluded that, "For most health outcomes, there is no evidence that EMF exposures have adverse effects." With respect to 'limited' evidence of an association of residential magnetic fields with

childhood leukemia, NIEHS stated, "This association is difficult to interpret in the absence of reproducible laboratory evidence or a scientific explanation that links magnetic fields with childhood leukemia."

- Since the 2002 booklet was published, a variety of duly constituted expert scientific panels and governmental agencies have reviewed the EMF health literature, and collectively find no evidence of risks for pregnancy outcome, neurodegenerative diseases, cardiovascular disease and any other health condition. With respect to cancer, they see no persuasive evidence of risk for any adult or childhood cancers, with the sole uncertainty related to childhood leukemia.

Update on Childhood Leukemia Research

- Since 2002, several epidemiologic studies have examined the occurrence of childhood leukemia with respect to residential proximity to overhead transmission lines.
- Positive associations were reported for living close to transmission lines, but the association extended beyond the distance at which magnetic fields from the lines are negligible. A follow-up study reported decreasing risks by decade from the 1960s through the 1980s with the incidence of childhood leukemia close to transmission lines falling to background levels since the 1990s. These observations point to some other factor beside magnetic fields responsible for the positive associations reported in the epidemiologic literature.
- A pooled analysis of children with leukemia with data from eight countries reported no relationship between magnetic fields and relapse or overall survival, despite suggestive evidence from two earlier studies.

Guidelines and Standards

- Recommendations for electric and magnetic field exposure limits have been issued by the International Commission for Non-Ionizing Radiation Protection (ICNIRP) and the Institute for Electrical and Electronic Engineers (IEEE).
- The limits protect against adverse 'electrostimulation' (stimulation of nerve tissue by an electrical stimulus). Electrostimulation occurs in a threshold manner at exposure levels that people do not ordinarily encounter.
- For the general public, ICNIRP's magnetic field exposure limit at power frequency is 2.0 G, and IEEE's limit is 9.1 G.
- The World Health Organization (WHO) has stated that: Compliance with these guidelines [exposure limits] provides adequate protection for acute effects."

National Policies

- Agencies in the U.S. and Canada have not established nationwide regulations limiting EMF exposure, although several states in the U.S. limit electric and/or magnetic fields on the right-of-way.
- Over 50 countries around the world have adopted EMF exposure limits in some form.
- WHO has stated that, "…it is not recommended that the limit values in exposure guidelines be reduced to some arbitrary level in the name of precaution."
- The California Public Utilities Commission (CPUC) has implemented a '4% rule' whereby the state's investor-owned utilities must invest up to 4% of a transmission projects costs for low-cost magnetic field mitigation.

Conclusion

In 2000, the National Academy of Engineering announced the 20 greatest engineering achievements of the 20th century in rank order as determined by a distinguished panel deliberating nominations from 29 engineering societies. The main criterion was the role the achievement played in improving the quality of life. Electrification of modern society ranked first ahead of notable achievements that included the automobile, the airplane, the telephone and the U.S. interstate highway system. A common thread running through the evolution of these innovations was the requirement that any possible hazards associated with them were minimized to acceptable levels. Obvious examples include the inclusion of airbags in vehicles, oxygen masks when airplane cabin pressure drops, and adequate shoulders on highways for disabled vehicles. In the case of electrification, we had learned by the turn of the 20th century about the risks associated with electrical shock and the possibilities of sparks igniting fires. Accordingly safety practices were adopted into codes such as the National Electrical Code to ensure that building wiring practices protected occupants against fire and shock hazards. By the late 1960s-early 1970s transmission lines operating at voltages of up to 765 kV were being built prompting questions and concerns from the public about exposures to EMF and possible effects on health.

Over the past 40 years, a large body of research has accumulated addressing health and safety questions about EMF in our homes and workplaces. Since its founding in 1973, the Electric Power Research Institute has participated in every aspect of health and safety research on EMF coordinating its program with the U.S. DOE in the 1970s and 1980s, and interacting with international organizations, such as WHO, IARC and CIGRÉ. This brochure has covered key aspects of EMF health research since the publication of the 2002 NIEHS Q&A booklet.

Research is a continuing process whose purpose is to develop valid information in response to specific questions. In the case of EMF health research, researchers are interested in quantifying relationships (or lack thereof) between EMF exposure and diseases or other health-related outcomes. The two major research pathways involve epidemiologic studies of human populations and studies with whole animals. As research progresses, the major objective is to continually reduce uncertainties until a question is resolved in a manner that is acceptable to the scientific community and to the broader society. In this respect, EMF research sponsored since the 1970s by various organizations worldwide, including EPRI, has achieved a fair measure of success in reducing key uncertainties about potential effects from EMF, as reflected in the broad consensus of expert scientific panels. As described in this brochure, uncertainties remain as the focus of ongoing study.

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