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# EX. 5.3: Electric and Magnetic Fields: Greater Springfield Reliability Project – REVISED

Exponent®

*Health Sciences*

# Electric and Magnetic Fields: Greater Springfield Reliability Project

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# Acronyms and Abbreviations

| | |
|---|---|
| μT | microtesla |
| AC | alternating current |
| ALL | acute lymphoblastic leukemia |
| ALS | amyotrophic lateral sclerosis |
| CI | confidence interval |
| DC | direct current |
| ELF | extremely low frequency |
| EHC | Environmental Health Criteria |
| EMF | electric and magnetic fields (or electromagnetic fields) |
| G | gauss |
| GHz | GigaHertz |
| HCN | Health Council of the Netherlands |
| Hz | hertz |
| IARC | International Agency for Research on Cancer |
| ICNIRP | International Committee on Non-Ionizing Radiation Protection |
| IEEE | Institute of Electrical and Electronics Engineers |
| kV/m | kilovolt per meter |
| LPD | lymphoproliferative disorder |
| mG | milliGauss |
| MPD | myeloproliferative disorder |
| NCI | National Cancer Institute |
| NHL | non-Hodgkin lymphoma |
| NRPB | National Radiation Protection Board of Great Britain |
| OR | odds ratio |
| RR | relative risk |
| SSI | Swiss Radiation Protection Authority |
| T | tesla |
| UKCCS | United Kingdom Childhood Cancer Study Investigators |
| USEPA | United States Environmental Protection Agency |
| UV | ultraviolet |
| V/m | volts/meter |
| WHO | World Health Organization |

# 1 Executive Summary

Electric energy is a beneficial and indispensable component of human society. Over the past 30 years, potential health risks of the use of electric energy have been studied because of the ubiquitous exposures of populations to fields associated with the transport and use of electricity. This report provides basic information on electric and magnetic fields (EMF) in the extremely low frequency (ELF) range, discusses standard methods for interpreting health research, and provides an up-to-date summary and assessment of current research on EMF and health.

EMF are produced by both natural and man-made sources that surround us in our daily lives. The earth, for example, naturally produces a magnetic field that is used by compasses for navigation. Man-made EMF is found wherever electricity is generated, transmitted, or used. Power lines, wiring in homes, workplace equipment, electrical appliances, and motors all produce EMF

When evaluating if EMF may have an adverse impact on human health, it is important to consider the type and strength of research studies available for evaluation. Human health studies vary in methodological rigor and, therefore, in their capacity to extrapolate findings to the population at large. Furthermore, all studies in three fields (epidemiology, *in vivo* and *in vitro* research) must be evaluated to understand possible health risks.

The World Health Organization (WHO) published a status report on EMF and human health in 2007 critically reviewing the literature to date and taking into account the strength and quality of the studies.

The WHO Report provided the following overall conclusions:[1]

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 do not change the overall classification of ELF as a possible human carcinogen (p. 347).

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[1] More specific conclusions from the WHO report are provided in discussions of specific outcomes in the literature update (Section 5.2).

> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF 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. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (p. 355).

Studies published after the WHO report were also reviewed and these studies do not provide evidence to alter the opinion of the WHO and other national and international health and scientific agencies that electric or magnetic fields are not a cause of cancer or any other disease process at the levels we encounter in our everyday environment.

# 2 Introduction

Electric energy is a beneficial and indispensable component of human society, but questions have been raised as to whether exposure to EMF, which are associated with the generation, transmission, and use of electricity, may in some way result in adverse health outcomes. While there has been more than 100 years of biological research on EMF, largely for basic science and potential therapeutic purposes, the speculation that EMF could have adverse health effects, particularly relating to cancer, has arisen mainly from some epidemiologic studies conducted over the past 30 years. The research literature on the possible health effects of EMF now includes more than 1,000 epidemiologic and experimental studies on a variety of health issues.

In order to evaluate questions that have been raised regarding EMF and adverse health outcomes, this report provides basic information about EMF, describes the levels of EMF associated with the existing and proposed facilities, discusses relevant guidelines from regulatory authorities and the standard methodology used in the interpretation of health research, and provides an up-to-date summary and assessment of research on EMF and health.

EMF is produced by both natural and man-made sources that surround us in our daily lives. The earth itself produces a static magnetic field – it is this field that is used for compass navigation. Man-made EMF is found wherever electricity is generated, transmitted, or used. Power lines, wiring in homes, workplace equipment, electrical appliances, and motors all produce EMF.

Electric fields are the result of voltages applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m), where 1 kV/m is equal to 1,000 V/m. Magnetic fields are produced by the flow of electric currents. Electricity produced by generating stations flows through transmission and distribution lines and provides power to the many appliances and electrical devices we use in our homes, schools, and workplaces. A magnetic field is produced only when current is flowing (e.g., when an appliance is turned on), while an electric field is produced whenever a voltage is present. The strength of magnetic fields is expressed as magnetic flux density in units called gauss (G), or in milligauss (mG), where 1 G is equal to 1,000 mG. Magnetic field measurements may also be expressed as tesla (T) or microtesla (μT), which are equivalent to 10,000 G and 0.01 G, respectively.

# 3 Sources and Levels of EMF

## 3.1 Typical sources of EMF

Electrical power in the United States produces alternating current (AC) EMF that changes direction and intensity 60 times per second – a frequency of 60 Hertz (Hz). These fields are in the ELF range (30-300 Hz) on the electromagnetic spectrum. Fields at this frequency differ from higher frequency electromagnetic fields such as radio and television signals, microwaves from microwave ovens, and radiofrequency fields from cellular phones (which can have frequencies up to billions of Hz).

An important characteristic of both electric and magnetic fields is that their strength diminishes as one moves away from the source of the field. This is similar to the way that the heat from a candle or campfire will diminish farther from its source. Intervening objects that conduct electricity (e.g., fences, shrubbery and buildings) can block electric fields. In contrast, these ordinary objects do not block magnetic fields. This is one of the reasons that assessments of health outcomes related to EMF have focused primarily on magnetic field exposure.

With respect to electric fields, certain appliances within homes and workplaces are the major sources indoors, while overhead power lines and electric rail lines are the major sources outdoors. The strongest sources of magnetic fields that people encounter indoors are electrical appliances. Magnetic fields near appliances can vary over a wide range, from a fraction of a mG to a 1,000 mG or more. For example, Gauger (1985) reported the maximum magnetic field at 3 centimeters from a sampling of appliances to be 3,000 mG for a can opener, 2,000 mG for a hair dryer, 5 mG for an oven, and 0.7 mG for a refrigerator. These values vary with distance, the power being used, and the design and manufacturer of the device. In most homes, background magnetic field levels measured away from sources such as appliances average about 1 mG. Higher, indoor average magnetic fields are measured in homes in the vicinity of distribution lines, sub-transmission lines, and transmission lines (Savitz et al., 1989).

Considering EMF from the perspective of specific sources or environments (i.e., indoor vs. outdoor) does not fully reflect the variations in an individual's personal exposure. To illustrate this concept, magnetic field measurements were recorded using a meter worn by one individual while going about daily activities in a Connecticut town for two hours. The magnetic field measurements recorded are shown in Figure 1. Activities included going to the post office, visiting the library, walking along the street, getting ice cream, browsing in a bicycle shop, stopping in a chocolate shop, going to the bank ATM, driving along streets, shopping in a supermarket, stopping for gas, and eating at a fast food restaurant. The maximum magnetic field measured was 97.6 mG in the supermarket; however, the average magnetic field exposure was 4.6 mG and the median magnetic field exposure was 1.1 mG for the two-hour period. These observations show that, from moment to moment in everyday life, individuals encounter magnetic fields over a wide range of intensities and from a variety of sources.

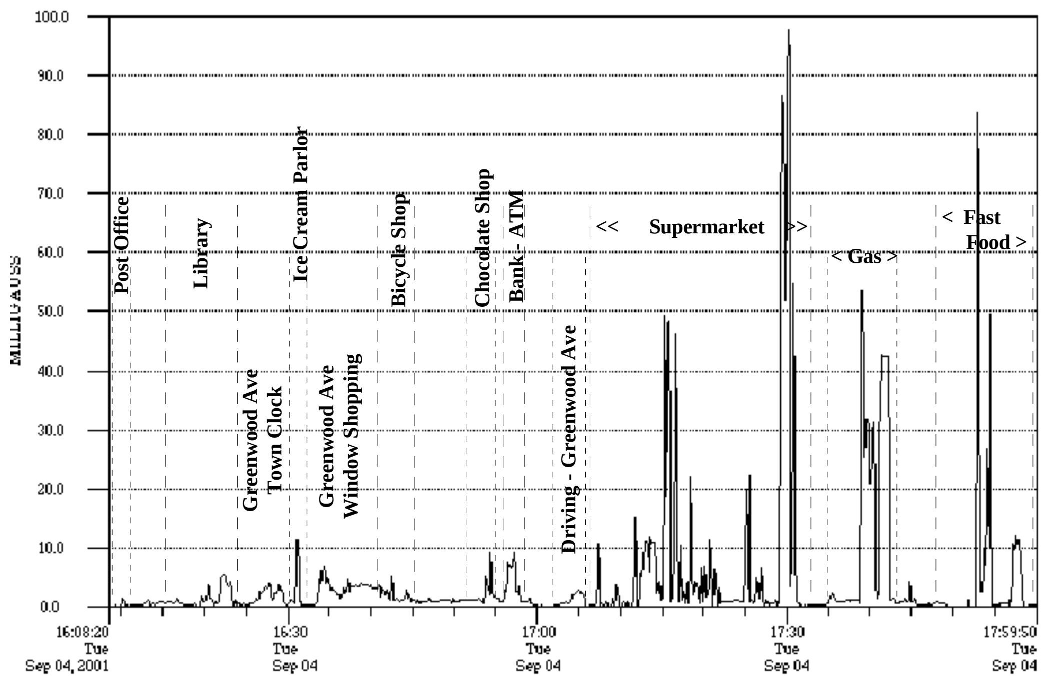


Figure 1. Magnetic field exposure for one individual during a two-hour period of a typical day

## 3.2 Project EMF sources and levels

Section 3.2 will describe existing and proposed facilities and summarize measurements and calculations of EMF to characterize pre- and post-construction levels of EMF.

# 4 Evaluation of Human Health Studies

The scientific process entails looking at *all* the evidence on a particular issue in a systematic and thorough manner to see if the overall data presents a logically coherent and consistent picture. This is often referred to as a weight-of-evidence review, in which all studies are considered together, giving more weight to studies of higher quality and using an established analytic framework to arrive at a conclusion about a possible causal relationship. Two steps precede a weight-of-evidence evaluation: a systematic review to identify the relevant literature and an evaluation of each study to determine its strengths and weaknesses. The following sections discuss important considerations in the evaluation of human health studies of EMF, including exposure considerations, study design, methods for estimating risk, bias, and the process of causal inference.

## 4.1 EMF exposure considerations

To fully characterize any exposure, it is necessary to consider the nature, dose, and timing of exposure. The nature of exposure relates to the specifics of that exposure (e.g., 60-Hz or 50-Hz and AC or direct current [DC] magnetic fields), including the ways in which persons may be exposed (e.g., occupationally or non-occupationally). While there are many different characteristics of magnetic fields (such as direction, polarization and harmonic content), these characteristics are typically not considered in the exposure assessment in epidemiologic studies. The dose of the exposure is the amount of the biologically relevant aspect of the exposure in tissue. Dose can be measured as the accumulated dose or as an exposure rate. The *biological dose* of exposure in tissue is correlated to exposure outside the body as the available dose and the encountered dose. The *available dose* of EMF is the maximum amount that a nearby source could emit. The encountered dose is less than or equal to the available dose. The amount of exposure that might possibly influence tissues in humans (i.e., the biological dose) is less than or equal to the amount of EMF that is available and encountered. Ultimately, it is this biological dose that has the potential, if any, to influence disease risk. The hierarchical nature of these dose categories is illustrated in Figure 2. The biological dose often cannot be measured, and most research studies measure the available or encountered dose.

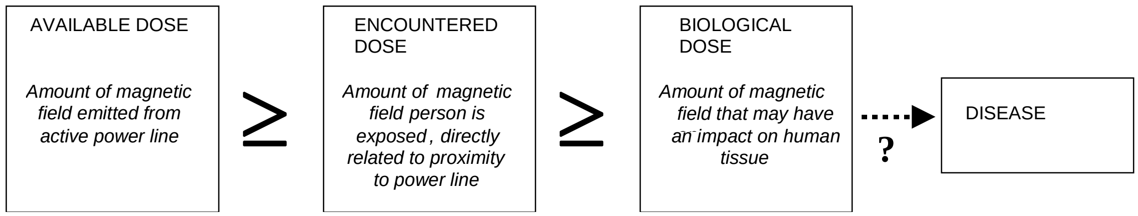


Figure 2. Relationship between dose categories, with an EMF-related example

(Source: Modified from Armstrong, White and Saracci, 2000, p. 12)

Time of exposure is characterized as: (1) when the exposure first begins, (2) when, if at all, the exposure ends, and (3) whether the exposure is continuous or occurs intermittently. Aspects to consider further when evaluating time of exposure are the duration of the exposure and whether there is a critical time window (i.e., an etiologically relevant exposure period) for the disease. This is particularly important for diseases that may have a long latency period between the start of the disease and when the disease is detected, e.g., cancer. For example, if scientists hypothesize that a particular childhood cancer is the result of prenatal exposures (e.g., maternal drinking habits), then the child's exposure history after birth is not relevant when considering disease etiology.

Dose and time are usually considered jointly to create summary exposure measures. Three common joint dose-time measures are: peak exposure, cumulative exposure, and average exposure. These measures can be considered just during the etiologically relevant time period or in terms of total lifetime exposure. Since it is often not known what the critical time window is for most diseases, these summary exposure measurements are often evaluated as: peak lifetime exposure, cumulative lifetime exposure, and average lifetime exposure. Most studies of EMF have made calculations or taken measurements over a 24-hour or 48-hour period to be used as an *estimate* of average lifetime exposure, and some occupational studies have also used job-exposure matrices to estimate a cumulative or peak exposure, or both

Another important consideration of EMF exposure is whether it has been measured directly or indirectly. For example, personal exposure to magnetic fields can be measured directly when an individual is wearing a device that records the amount of magnetic field encountered at frequent intervals (see example in Figure 1). EMF can be estimated indirectly by assigning an estimated amount of EMF exposure to an individual based on calculations considering nearby power installations or a person's job title. For example, a relative estimate of exposure could be assigned to all machine operators based on historical information on the magnitude of the magnetic field produced by the machine. Indirect measurements are not as accurate as direct measurements because they do not contain information specific to that person or the exposure situation. In the example of machine operators, the indirect measurement may not account for how much time any one individual spends working at that machine or any potential variability in magnetic fields produced by the machines over time, in addition to residential magnetic field exposures.

## 4.2 Types of health research studies

Prior to presenting the summary of research findings related to EMF and health, an overview of design aspects of health research studies is provided to aid in the interpretation of these studies. Research studies can be broadly classified into two groups: 1) epidemiologic observations of people, which are not experimental, and 2) experimental studies on animals, humans, cells and tissues in laboratory settings. Epidemiologic studies investigate how disease is distributed in populations and what factors influence or determine this disease distribution (Gordis, 2000). Epidemiologic studies attempt to establish causes for human disease while observing people as they go about their normal, daily lives. Such studies are designed to quantify and evaluate the associations between reported exposures to environmental factors and disease.

The most common types of epidemiologic studies in the EMF literature are case-control and cohort studies. In case-control studies, people with and without the disease of interest are identified and potential causative exposures are evaluated. Often, people are interviewed or their personal records (e.g., medical records or employment records) are reviewed in order establish the exposure history for each individual. The exposure histories are then compared between the diseased and non-diseased populations to determine whether any statistically significant differences in exposure histories exist. In cohort studies, on the other hand, individuals within a defined cohort of people (e.g., all persons working at a factory) are classified as exposed or non-exposed and followed over time for the incidence of disease. Researchers then compare disease incidence in the exposed and non-exposed groups.

Experimental studies are designed to test specific hypotheses under controlled conditions and are vital to assessing cause-and-effect relationships. An example of a human experimental study relevant to this area of research would be studies that measure the impact of magnetic field exposure on acute biological responses in humans, such as hormone levels. These studies are conducted in laboratories under controlled conditions. *In vivo* and *in vitro* experimental studies are also conducted under controlled conditions in laboratories. *In vivo* studies expose laboratory animals to very high levels of a chemical or physical agent to determine whether exposed animals develop cancer or other effects at higher rates than unexposed animals, while tightly controlling all other factors that could possibly affect disease rates (e.g., diet, genetics, etc.). *In vitro* studies of isolated cells and tissues are also important because they can help scientists understand biological responses as they relate to the same exposure in intact humans and animals. The results of experimental studies of animals, and particularly those of isolated tissues or cells, however, may not always be directly extrapolated to human populations. In the case of *in vitro* studies, the responses of cells and tissues outside the body may not reflect the response of those same cells if maintained in a living system, so their relevance cannot be assumed. Therefore, it is both necessary and desirable that agents that could present a potential health threat be explored by both epidemiologic and experimental studies.

Both of these approaches – epidemiologic and experimental laboratory studies – have been used to evaluate whether exposure to EMF has any adverse effects on human health. Epidemiologic studies are valuable because they are conducted in human populations, but they are limited by their non-experimental design and usual retrospective nature. In epidemiologic studies of EMF, for example, researchers cannot control the amount of individual exposure to EMF, how exposure occurs over time, the contribution of different field sources, or individual behaviors that could affect disease risk, such as diet. In valid risk assessments of EMF, epidemiologic studies have been considered alongside experimental studies of laboratory animals, while studies of isolated tissues and cells are generally acknowledged as being less relevant.

## 4.3 Estimating risk

Epidemiologists measure the statistical association between factors and disease in order to estimate "risk." Risk is a multi-faceted term that includes several related components, beyond just a simple statistical association. This brief summary of risk is included to provide a foundation for understanding and interpreting statistical associations in epidemiologic studies as risk estimates.

Two common types of risk estimates are absolute risk and relative risk (RR). Absolute risk, also known as incidence, is the amount of new disease that occurs in a given period of time. For example, the absolute risk of invasive childhood cancer in children ages 0-19 years for 2004 was 14.8 per 100,000 children (Ries et al., 2007). RRs are calculated to evaluate whether a particular exposure (EMF, diet, genetics, race, etc.) is associated with a disease outcome. This is calculated by looking at the absolute risk in one group relative to a comparison group. For example, white children in the 0-19 year age range had an estimated absolute risk of childhood cancer of 15.4 per 100,000 in 2004, and African American children had an estimated absolute risk of 13.3 per 100,000 in the same year. By dividing the absolute risk of white children by the absolute risk of African American children, we obtain a RR of 1.16. This RR estimate can be interpreted to mean that white children have a childhood cancer risk that is 16% greater than the risk of African American children. Additional statistical analysis is needed to evaluate whether this association is statistically significant.

It is important to understand that risk is estimated differently in cohort and case-control studies because of the way the studies are designed. Traditional cohort studies can provide a direct estimate of RR, while case-control studies can only provide indirect estimates of RR, called odds ratios (OR). For this reason, among others, cohort studies usually provide more reliable estimates of the risk associated with particular exposures.

Thus, the association between a particular disease and exposure is measured quantitatively in an epidemiology study as either the RR (cohort studies) or OR (case-control studies) estimate. The general interpretation of a risk estimate equal to 1.0 is that the exposure is not associated with an increased incidence of the disease. If the risk estimate is greater than 1.0, the inference is that the exposure is associated with an increased incidence of the disease. On the other hand, if the risk estimate is less than 1.0, the inference is that the exposure is associated with a reduced incidence of the disease. The magnitude of the risk estimate is often referred to as its strength (i.e., strong vs. weak).

## 4.4 Statistical significance

Statistical significance testing provides an idea of whether or not a statistical association is caused by chance alone, i.e., is the association likely to be observed this way upon repeated testing or is it simply a chance occurrence. The terms “statistically significant” or “statistically significant association” are used in epidemiologic studies to describe the tendency of the level of exposure and the occurrence of disease to be linked, with chance as an unlikely explanation. Statistically significant associations, however, are not automatically an indication of cause-and-effect, because the interpretation of statistical associations depends on many other factors associated with the design and conduct of the study, including, for example, how the data were collected and the size of the study.

Confidence intervals (CI) are typically reported along with RR and OR values. A CI is a range of values for an estimate of effect that has a specified probability (e.g., 95%) of including the “true” estimate of effect. A 95% CI indicates that, if the study were conducted a very large number of times, 95% of the measured estimates would be within the upper and lower confidence limits.

The range of the CI is also important for interpreting estimated associations, including the precision and statistical significance of the association. A very wide CI indicates great uncertainty in the value of the “true” risk estimate. This is usually due to a small number of observations. A narrow CI provides more certainty about where the “true” RR estimate lies. Another way of interpreting the CI is as follows: if the 95% CI does not include 1.0, the probability of an association being due to chance alone is 5% or lower and the result is considered statistically significant, as discussed above.

## 4.5 Bias in epidemiologic studies

One key reason that results of epidemiologic studies cannot directly provide evidence for cause-and-effect is the presence of bias. Bias is defined as “any systematic error in the design, conduct or analysis of a study that results in a mistaken estimate of an exposure’s effect on the risk of disease” (Gordis, 2000, p. 204). In other words, sources of bias are factors or research situations that can mask a true association or misrepresent an association that does not exist. As a result, the extent of bias, as well as its types and sources, are important considerations in the interpretation of epidemiologic studies. Since it is not possible to fully control human populations, perfectly measure their exposures, control for the effects of all other risk factors, etc., bias will exist in some form in all epidemiologic studies of human health.

One important source of bias occurs when two groups differ in ways other than just the variable of interest. An example of this is the relationship between diet and exercise. People who exercise more may tend to also consume healthier diets. Consider an example of a researcher whose study finds that people who exercise have a lower risk of diabetes compared to people who do not exercise. If the researcher does not control for the impact of diet, it is not possible to say with certainty that the lower risk of diabetes is due to exercise and not a healthier diet.

## 4.6 Cause vs. association and levels of evidence regarding causal associations

Epidemiologic studies can help suggest risk factors that may contribute to a disease risk, but they are not used as the sole basis for drawing inferences about cause-and-effect relationships. Since epidemiologists do not have control over the many other factors to which people are exposed (e.g., genetics, pollution, infections, etc.) and diseases can be caused by a complex interaction of many factors, the results of epidemiologic studies must be interpreted with caution. A single epidemiologic study is rarely unequivocally supportive or non-supportive of causation; rather, a weight is assigned to the study based on the validity of its methods.

In 1964, the Surgeon General of the United States published a landmark report on smoking-related diseases (U.S. Department of Health, Education and Welfare, 1964). As part of this report, nine criteria for evaluating epidemiology studies (along with experimental data) for causality were outlined. In a more recent version of this report, these criteria have been reorganized into seven criteria. In the earlier version, coherence, plausibility, and analogy were considered as distinct items, but are now summarized together because they have been treated in practice as essentially reflecting one concept (Department of Health and Human Services, 2004). Table 1 provides a listing and brief description of each of the criterion.

Table 1. Criteria for evaluating whether an association is causal

| Criteria | Description |
|---|---|
| Consistency | Repeated observation of an association between exposure and disease in multiple studies of adequate statistical power, in different populations, and at different times. |
| Strength of the association | The larger (stronger) the magnitude and statistical strength of an association is between exposure and disease, the less likely such an effect is the result of chance or unmeasured confounding. |
| Specificity | The exposure is the single (or one of a few) cause of disease. |
| Temporality | The exposure occurs prior to the onset of disease. |
| Coherence, plausibility, and analogy | The association cannot violate known scientific principles and the association must be consistent with experimentally demonstrated biologic mechanisms. |
| Biologic gradient | This is also known as a dose-response relationship, i.e., the observation that the stronger or greater the exposure is, the stronger or greater the effect. |
| Experiment | Observations that result from situations in which natural conditions imitate experimental conditions. Also stated as a change in disease outcome in response to a non-experimental change in exposure patterns in population. |

(Source: Department of Health and Human Services, 2004)

The criteria were meant to be applied to statistically significant associations that have been observed in the epidemiologic literature, i.e., if no statistically significant association has been observed for an exposure then the criteria are not relevant. It is important to note that these criteria were not intended to serve as a checklist; rather, they were intended to serve as a guide in evaluating associations for causal inference. Theoretically, it is possible for an exposure to meet all seven criteria, but still not be deemed a causal factor. Also, no one criterion can provide indisputable evidence for causation, nor can any one criterion rule out causation.

In summary, the judicious consideration of the above criteria are useful in assessing epidemiologic studies, but they cannot be used as the sole basis for drawing inferences about cause-and-effect relationships. In line with the criteria of "coherence, plausibility, and analogy," epidemiologic studies are considered along with *in vitro* and *in vivo* studies in a comprehensive review. Epidemiologic support for causality is usually based on high-quality studies reporting consistent results across many different populations and study designs that are supported by the experimental data collected from *in vitro* and *in vivo* studies.

## 4.7 Biological response vs. disease in human health

When interpreting research studies, it is important to distinguish between a reported biological response and an indicator of disease. This is relevant because exposure to EMF may elicit a biological response that is simply a normal response to environmental conditions. This response, however, may not be a disease or cause a disease. There are many exposures or factors encountered in day-to-day life that elicit a biological response, but the response is neither harmful nor a cause of disease. For example, when an individual walks from a dark room indoors to a sunny day outdoors, the pupils of the eye naturally constrict to limit the amount of light passing into the eye. This constriction of the pupil is considered a biological response to the change in light conditions. Pupil constriction, however, is neither a disease itself, nor is it known to cause disease.

# 5 Status of Research on EMF and Health

Concerns regarding possible health effects have arisen in the context of electric transmission and distribution lines, which produce EMF in the ELF range. The following sections describe the conclusions of a comprehensive WHO report of EMF exposure and health outcomes, including cancer, reproductive effects, and neurodegenerative diseases (WHO, 2007). The conclusions and perspectives of reviews conducted by other scientific organizations are discussed, where appropriate, to highlight consistencies and inconsistencies in conclusions. Following the description of the WHO report (Sections 5.1-5.2), a summary of research published since the completion of the report is provided (Section 5.3) to determine whether recent research alters the conclusions of the WHO report. Since the weight of the scientific evidence indicates that exposure to electric fields, below levels traditionally established for safety, does not cause adverse health effects (WHO, 2007) and safety concerns for electric fields are sufficiently addressed by adherence to the amended National Electrical Safety Code (NESC, 2007), concerns regarding EMF have largely focused on magnetic, rather than electric, fields.

## 5.1 The WHO: report methods and overall conclusions

The WHO is a scientific organization within the United Nations system whose mandate includes providing leadership on global health matters, shaping the health research agenda, and setting norms and standards. The WHO established the International EMF Project in 1996, in response to public concerns about exposures to EMF and possible adverse health outcomes. The project's membership includes 8 international organizations, 8 collaborating institutions and over 54 national authorities. The overall purpose of the Project is to assess health and environmental effects of exposure to static and time varying fields in the frequency range 0-300 GigaHertz (GHz). A key objective of the Project was to evaluate the scientific literature and make a status report on health effects to be used as the basis for a coherent international response, including the identification of important research gaps and the development of internationally acceptable standards for EMF exposure. The WHO published a Monograph in June 2007 as part of the WHO's Environmental Health Criteria (EHC) Programme summarizing a review of health research in the ELF frequency range that includes 60-Hz power frequency fields. The Monograph used standard scientific procedures, as outlined in its Preamble, to conduct the review. The Task Group responsible for the report's overall conclusions consisted of 21 scientists from around the world with expertise in a wide range of disciplines. The Task Group relied on the conclusions of previous weight-of-evidence reviews,[2] where possible, and (with regard to cancer) mainly focused on evaluating studies published after an International Agency for Research on Cancer (IARC) review in 2002. The Task Group and IARC use specific terms to describe the strength of the evidence in support of causality. *Limited evidence* describes a body of research where the findings are inconsistent or there are outstanding questions about study design or other methodological issues that preclude making strong conclusions. *Inadequate evidence* describes a body of research where it is unclear whether the data is supportive or unsupportive of causation because there is a lack of data or there are major quantitative or qualitative issues.

The WHO Report provided the following overall conclusions:[3]

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 do not change the overall classification of ELF as a possible human carcinogen (p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF 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. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore

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[2] The term "weight-of-evidence review" is used in this report to denote a systematic review process by a multidisciplinary, scientific panel involving experimental and epidemiologic research to arrive at conclusions about possible health risks. The WHO Monograph on EMF does not specifically describe their report as a weight-of-evidence review. Rather, they describe conducting a health risk assessment. Although the two terms are similar, a health risk assessment differs from a weight-of-evidence review in that it also incorporates an exposure and exposure-response assessment.

[3] More specific conclusions from the WHO report are provided in discussions of specific outcomes in the literature update (Section 5.2).

> exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (p. 355).

## 5.2 Outcome-specific WHO conclusions

### 5.2.1 Cancer Overall

The overwhelming majority of health research related to EMF has focused on the possibility of a relationship with cancer, including leukemia, lymphoma, breast cancer, and brain cancer. The vast majority of epidemiologic studies in this field are case-control studies; i.e., they enrolled persons with a specific cancer type (cases); selected a group of individuals similar to the cancer cases (controls); estimated past magnetic or electric field exposures, or both; and compared the exposures of the cases and controls to test for statistical differences. Some of these studies looked for statistical associations of these diseases with magnetic fields produced by nearby power lines or appliances (estimated through calculations or distance), while other studies actually measured magnetic field levels in homes or estimated personal magnetic field exposures from all sources. In studies of adult cancers, occupational magnetic field exposures were estimated in some studies, as well.

*In vivo* studies in this field exposed animals to high levels of magnetic fields (up to 50,000 mG) over the course of their entire lifetime to observe whether exposed animals had higher rates of cancer than unexposed animals. Some of these studies exposed animals to magnetic fields in tandem with a known carcinogen to test whether magnetic field exposure promoted carcinogenesis.

Researchers believe it is highly unlikely that electric or magnetic fields can directly damage DNA, because there is relatively low energy associated with ELF-EMF. Therefore, *in vitro* studies in this field have focused largely on investigating whether ELF-EMF could promote damage from other known carcinogens or cause cancer through a pathway other than DNA damage (e.g., hormonal or immune effects).

The IARC is the division of the WHO with responsibility to coordinate and conduct research on the causes of human cancer and the mechanisms of carcinogenesis and to develop scientific strategies for cancer control. The IARC convened a scientific panel in 2001 to conduct an extensive review and arrive at a conclusion about the possible carcinogenicity of EMF (IARC, 2002). The IARC has a standard method for classifying exposures based on scientific research in support of carcinogenicity. Categories include (from highest to lowest risk): carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, unclassifiable, and probably not carcinogenic to humans. As a result of two pooled analyses reporting an association between high, average magnetic field exposure and childhood leukemia, the epidemiologic data was classified as providing "limited evidence of carcinogenicity" in relation to childhood leukemia. The epidemiologic evidence was classified as inadequate with regard to all other cancer types. The IARC panel also reported that there was "inadequate evidence of carcinogenicity" in studies of experimental animals. Overall, magnetic fields were evaluated as "possibly carcinogenic to humans." The IARC usage of "possible" denotes an exposure in which epidemiologic evidence points to a statistical association, but other explanations cannot be ruled out as the cause of that statistical association (e.g., bias and confounding) and, therefore, the experimental data does not support a carcinogenic risk.

### 5.2.2 Childhood Leukemia

The issue that has received the most attention is childhood leukemia. Research in this area was prompted by a case-control study of children in the United States that reported a statistical association between childhood leukemia and a higher predicted magnetic field level in the home based on characteristics of nearby distribution and transmission lines (Wertheimer and Leeper, 1979). Subsequently, some case-control studies reported that children with leukemia were more likely to live closer to power lines or have higher estimates of magnetic field exposure (compared to children without leukemia), while other epidemiologic studies did not report this statistical association. Of note, the investigators who performed the largest case-control studies of childhood leukemia that actually measured personal magnetic field exposure (as opposed to estimating exposure through calculations or distance) did not report a consistent statistical association or a dose-response relationship with exposure to higher magnetic field levels (Linet et al., 1997; McBride et al., 1999; UKCCS, 1999).

In 2000, researchers combined the data from a selection of previously published case-control studies of magnetic fields and childhood leukemia that met specified criteria (Ahlbom et al., 2000; Greenland et al., 2000). The researchers pooled the data on the individuals from each of the studies, creating a study with a much larger number of subjects and, as a result, greater statistical power to detect an effect (should one exist) than any single study. In both pooled analyses, a weak association was reported between childhood leukemia and estimates of average magnetic field exposures greater than 3-4 mG. The authors were appropriately cautious in the interpretation of their analyses, and noted the uncertainty related to pooling estimates of exposure obtained by different methods from studies of diverse design, as did other researchers (e.g., Elwood, 2006). The results of the pooled analyses were not considered to provide strong epidemiologic support for a causal relationship because of the limitations associated with this epidemiologic data (e.g., a weak association, crude exposure assessments, and the unknown effects of confounding and selection bias[4]). Furthermore, *in vivo* studies have not found that magnetic fields induce or promote cancer in animals exposed under highly controlled conditions for their entire lifespan, nor have *in vitro* studies found a cellular mechanism by which magnetic fields could induce carcinogenesis. As discussed above, these findings resulted in the classification of magnetic fields as a possible carcinogen (IARC, 2002).

The WHO evaluated two more recently published studies related to childhood leukemia and magnetic fields (Draper et al, 2005; Kabuto et al., 2006). Draper et al. conducted a case-control study of childhood cancer, which included 9,700 children with leukemia (i.e., cases) and an equal number of children that did not have leukemia (i.e., controls). The study compared the distance of home address at birth to 275-kV, 400-kV, and some 132-kV transmission lines among cases and controls and reported a weak association between childhood leukemia and home address at birth within 600 meters of high-voltage transmission lines. No associations with central nervous system tumors, brain tumors or other types of childhood cancer and

[4] Selection bias occurs when there are differences in the type of person who participates in the study compared to the type of person who doesn't participate in the study.

distance were reported. Kabuto et al. conducted a smaller case-control study in Japan that measured the average weekly magnetic field level in the bedrooms of 312 children with leukemia and 603 children without leukemia. The investigators reported that children with leukemia were more likely to have average magnetic field levels >4 mG compared to children without leukemia.

The WHO did not assign a high weight or significance to these studies in their overall evaluation, stating that the low participation rate in Kabuto et al. and the use of distance as a proxy for magnetic field exposure in Draper et al. were important limitations. Less weight should be placed on these studies relative to studies that used good exposure assessment techniques and had high participation rates. The WHO described the results of these two recent studies as consistent with the classification of limited epidemiologic evidence in support of carcinogenicity and, together with the largely negative *in vivo* and *in vitro* research, consistent with the classification of magnetic fields as a possible carcinogen.

The WHO concluded that several factors might be fully, or partially, responsible for the consistent association observed between high, average magnetic fields and childhood leukemia, including misclassification of magnetic field exposure due to poor exposure assessment methods, confounding from unknown risk factors, and selection bias. The WHO concluded that reconciling the epidemiologic data on childhood leukemia and the negative (i.e., no hazard or risk observed) experimental findings through innovative research is currently the highest priority in the field of ELF-EMF research. Given that few children are expected to have average magnetic field exposures greater than 3-4 mG, however, the WHO stated that the public health impact of magnetic fields on childhood leukemia would be low if the association was determined to be causal.

### 5.2.3 Breast Cancer

Research on breast cancer has examined the possible effects of ELF-EMF from three sources: workplace exposures, residential exposure from power lines, and electric blankets. Some of the early epidemiologic studies reported a weak association between breast cancer and higher magnetic field exposures, while others did not; however, the conclusions that could be drawn from this initial body of research were limited because of study quality issues (e.g., poor exposure assessment, inadequate control for confounding variables, and small sample sizes within subgroups with reported associations). Review panels evaluating this initial body of research concluded that the evidence in support of an association was weak, but should be evaluated further with higher quality studies (NRPB, 2001a; IARC, 2002; ICNIRP, 2003).

A large number of studies on breast cancer and magnetic field exposure have been conducted since the publication of the IARC review in 2002. These studies were systematically reviewed by the WHO and included seven studies that estimated residential magnetic field exposure, four studies evaluating associations with electric blanket usage, and nine studies that estimated occupational magnetic field exposure. No consistent observations regarding associations between magnetic field exposure and breast cancer were reported in these studies. The WHO concluded that this recent body of research was higher in quality compared with previous studies, and, for that reason, provides strong support to previous consensus statements that magnetic field exposure does not influence the risk of breast cancer. In summary, the WHO stated "[w]ith these [recent] studies, the evidence for an association between ELF magnetic field exposure and the risk of female breast cancer is weakened considerably and does not support an association of this kind" (p. 9). The WHO recommended no further research with respect to breast cancer and magnetic field exposure.

### 5.2.4 Adult leukemia and brain cancer

A large number of studies of varying quality and with a wide range of techniques have been conducted in both occupational and residential settings to explore the possible relationship between EMF exposure and adult brain cancer and leukemia. The scientific committees assembled by the IARC, National Radiation Protection Board of Great Britain (NRPB)[5] and the International Committee on Non-Ionizing Radiation Protection (ICNIRP) concluded that the evidence is weak and does not support a role for electric or magnetic fields in the etiology of brain cancer or leukemia among adults (NRPB, 2001a; IARC, 2002; ICNIRP, 2003).

[5] The NRPB merged with the Health Protection Agency (HPA) of Great Britain in 2005.

The WHO reviewed the body of research published since the time of these reviews, including three cohort studies estimating residential exposure, four cohort studies estimating occupational exposures, and eight case-control studies reporting on occupation and brain cancer or leukemia risk. The WHO concluded,

> In the case of adult brain cancer and leukaemia, the new studies published after the IARC monograph do not change the conclusion that the overall evidence for an association between ELF [EMF] and the risk of these disease remains inadequate (p. 307).

The WHO panel recommended updating the existing cohorts of occupationally exposed individuals in Europe and then pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

### 5.2.5 *In vivo* and *in vitro* experimental research on carcinogenesis

It is standard procedure to conduct studies of laboratory animals to determine whether exposure to a specific agent leads to the development of cancer (USEPA, 2005). This approach is used because all known human carcinogens cause cancer in laboratory animals. In the field of ELF-EMF research, a number of research laboratories have exposed rodents with a particular genetic susceptibility to cancer to high levels of magnetic fields over the course of their lifetime and performed tissue evaluations to assess the incidence of cancer in many organs. In these studies, magnetic field exposure has been administered alone (to test for the ability of magnetic fields to act as a complete carcinogen), in combination with a known carcinogen (to test for a promotional or co-carcinogenic effect), or in combination with a known carcinogen and a known promoter (to test for a co-promotional effect). The WHO described four large-scale, long-term studies of rodents exposed to magnetic fields over the course of their lifetime that did not report increases in any type of cancer (Mandeville et al., 1997; Yasui et al., 1997; McCormick et al., 1999; Boorman et al., 2001a,b). No directly relevant animal model for childhood acute lymphoblastic leukemia (ALL) currently exists; however, some animals develop a type of lymphoma similar to childhood ALL. Studies exposing transgenic mice predisposed to this lymphoma to power-frequency magnetic fields have not reported an increased incidence of lymphoma associated with exposure (Harris et al., 1998; McCormick et al., 1998; Sommer and Lerchel 2004).

Studies investigating whether exposure to magnetic fields can promote cancer or act as a co-carcinogen used known cancer-causing agents, such as ionizing radiation, UV radiation or other chemicals. No effects were observed for studies on chemically-induced preneoplastic liver lesions, leukemia/lymphoma, skin tumors, or brain tumors; however, the incidence of chemicallyinduced mammary tumors was increased with magnetic field exposure in a series of experiments, suggesting that magnetic field exposure increased the proliferation of mammary tumor cells (Löscher et al., 1993, 1994, 1997; Mevissen et al., 1993a,b, 1996a,b, 1998; Baum et al., 1995; Löscher and Mevissen, 1995). These results were not replicated in a subsequent series of experiments in another laboratory (Anderson et al., 1999; Boorman et al.1999; NTP, 1999), possibly due to differences in experimental protocol and the species strain (Fedrowitz et al., 2004). One study has reported an increase in genotoxic effects among exposed animals (e.g., DNA strand breaks in the brains of mice) (Lai and Singh, 2004), although the results have not been replicated.

In summary, the WHO concluded with respect to *in vivo* research, "[t]here is no evidence that ELF exposure alone causes tumours. The evidence that ELF field exposure can enhance tumour development in combination with carcinogens is inadequate" (p. 10, WHO, 2007). Recommendations for future research include the development of a rodent model for childhood ALL and the continued investigation of whether magnetic fields can act as a co-carcinogen.

*In vitro* studies are widely used to investigate the mechanisms for effects that are observed in humans and animals. As discussed in Section 4.2, the relative value of *in vitro* tests to human health risk assessment, however, is much less than that of *in vivo* and epidemiologic studies. Responses of cells and tissues outside the body may not always reflect the response of those same cells if maintained in a living system, so the relevance of *in vitro* studies cannot be assumed (IARC, 1992).

The IARC and other scientific review panels that systematically evaluated *in vitro* studies concluded that there is no clear evidence indicating how ELF magnetic fields could adversely affect biological processes in cells (IARC, 2002; ICNIRP, 2003; NRPB, 2004). The WHO panel reviewed the *in vitro* research published since the time of these reviews and reached the same conclusion. The WHO noted that previous studies have not indicated a genotoxic effect of ELF magnetic fields on mammalian cells, however, a recent series of experiments reported DNA damage in human fibroblasts exposed intermittently to 50-Hz magnetic fields (Ivancsits et al., 2002a,b, 2003a,b). These findings have not been replicated by other laboratories (Scarfi et al., 2005), and the WHO recommended continued research in this area. Research in the field of *in vitro* genotoxicity of magnetic fields combined with known DNA-damaging agents is also recommended, following suggestive findings from several laboratories. As noted by the Swedish Radiation Protection Authority (SSI), the levels at which these effects were observed are much higher than the levels we are exposed to in our everyday environments and are therefore not directly relevant to questions about low-level, chronic exposures (SSI, 2007). *In vitro* studies investigating other possible mechanisms, including gene activation, cell proliferation, apoptosis, calcium signaling, intercellular communication, heat shock protein expression and malignant transformation, have produced “inconsistent and inconclusive” results (p. 347, WHO, 2007).

### 5.2.6 Reproductive effects

Epidemiologic studies have been conducted to observe whether maternal or paternal EMF exposures are associated with adverse reproductive effects, including effects on fertility, reproduction, miscarriage, and prenatal and postnatal growth and development. A body of *in vivo* literature is also available on this topic. Early studies on the potential effect of EMF exposures on reproductive outcomes were limited because the majority of the studies used surrogate measures of exposure (including visual display terminal use, electric blanket use or wire code data) or assessed exposure retrospectively.

Two recent studies related to miscarriage improved exposure assessment by directly measuring magnetic field exposure. These two studies reported a positive association between miscarriage and exposure to high maximum, or instantaneous, peak magnetic fields (Lee et al., 2000, 2002; Li et al., 2002); however, no consistent associations were reported with high, average magnetic field levels, the typical method for assessing magnetic field exposure. The WHO noted a few of the issues that have been raised by other investigators and scientific review panels concerning the validity of these associations (HCN, 2004; NRPB, 2004; Feychting et al., 2005; Mezei et al., 2005; Savitz et al., 2006). First, the studies had a low response rate, which means that the case and control groups may not be comparable because those who participated in the study may have differed from those who declined (i.e., selection bias). Second, in the study by Lee et al. magnetic field measurements were taken 30 weeks after a woman's last menstrual period. Some of these women had already miscarried at 30 weeks when magnetic field exposure was measured. This introduces the possibility for bias because pregnancy may alter physical activity levels and physical activity may be associated with magnetic field exposure in pregnant women, as recently confirmed in a study by Savitz et al. (2006). It is possible that the women who miscarried prior to 30 weeks in the study by Lee et al. (2002) subsequently increased their physical activity levels (i.e., returned to work or their normal routine), which resulted in greater opportunities to encounter higher peak magnetic field levels. Furthermore, there is no biological basis to indicate that EMF increases the risk of reproductive effects. The WHO report stated that *in vivo* studies exposing animals to high levels of EMF reported no significant, adverse developmental effects. The WHO report further stated that *in vivo* studies on other reproductive outcomes are inadequate at this time.

The WHO concluded that, overall, the body of research does not suggest that maternal or paternal exposures to ELF-EMF cause adverse reproductive outcomes. The evidence from epidemiologic studies on miscarriage is inadequate, and further research on this possible association is recommended, although low priority was given to this recommendation.

### 5.2.7 Neurodegenerative diseases

Research into the possible effect of magnetic fields on the development of neurodegenerative diseases began in 1995, and the majority of research since then has focused on Alzheimer's disease and a specific type of motor neuron disease called amyotrophic lateral sclerosis (ALS), which is also known as Lou Gehrig's disease. The inconsistency of the Alzheimer's studies prompted the NRPB to conclude that there is "only weak evidence to suggest that it [extremely low frequency magnetic fields] could cause Alzheimer's disease" (p. 20, NRPB, 2001b). Early studies on ALS, which had no obvious biases and were well conducted, reported an association between ALS mortality and estimated occupational magnetic field exposure. The review panels, however, were hesitant to conclude that the associations provided strong support for a causal relationship. The scientific panels felt that an alternative explanation (i.e., electric shocks received at work) may be the source of the observed association. The NRPB concluded: "In summary, the epidemiological evidence suggests that employment in electrical occupations may increase the risk of ALS, possibly, however, as a result of the increased risk of receiving an electric shock rather than from the increased exposure to electromagnetic fields" (p.20, NRPB, 2001b).

The majority of recent studies reported associations between occupational magnetic field exposure and mortality from Alzheimer's disease and ALS, although the design and methods of these studies were relatively weak (e.g., disease status was based on death certificate data, exposure was based on incomplete occupational information from census data, and there was no control for confounding factors). There is currently no biological data to support an association between magnetic fields and neurodegenerative diseases. The WHO concluded that there is inadequate data in support of an association between magnetic fields and Alzheimer's disease or ALS. The panel highly recommended that further studies be conducted in this area, particularly studies where the association between magnetic fields and ALS is estimated while controlling for the possible confounding effect of electric shocks.

## 5.3 Studies published after the WHO report

The WHO report was published in June 2007. Because of the time needed to review newly published research critically, the WHO report only included studies published through approximately December 2005. Since most of the uncertainty arises from epidemiologic studies in this area, this update systematically addresses epidemiology studies, but relies largely on reviews and the conclusions of other scientific panels with regard to *in vivo studies* and studies of mechanism. The following sections provide a summary of epidemiologic studies published December 1, 2005 through April 23, 2008, to evaluate whether the findings of these recent studies alter the conclusions published by the WHO in 2007 report.

### 5.3.1 Childhood cancers

Studies of childhood leukemia published since the WHO report have addressed a variety of new questions, including:[6]

- Do magnetic fields contribute to the higher rate of childhood leukemia among genetically susceptible children? (Mejia-Arangure et al., 2007)
- Do magnetic fields contribute to a worse prognosis among those already diagnosed with childhood leukemia? (Foliart et al., 2006, 2007; Svendson et al., 2007)
- Is the association more strongly influenced by nighttime magnetic field exposures? (Schüz et al., 2007)

Mejia-Arangure et al. evaluated whether higher estimated magnetic field exposure was associated with childhood leukemia in children with Down's syndrome residing in Mexico City. Children with Down's syndrome are at higher risk of developing acute leukemia than the general population. Thus, the intent of this study was to assess the hypothesis that magnetic field exposure could enhance the risk for childhood leukemia among a genetically susceptible population.

Exposure to magnetic fields was estimated with a spot measurement taken at the front door of the residence and compared between 42 children with acute leukemia and Down's syndrome (cases) and 124 Down's syndrome children without acute leukemia (controls) (Mejia-Arangure et al., 2007). While taking into consideration other factors that may be linked to childhood leukemia, such as traffic density, location of residence, age, and sex, the authors observed that cases were more frequently observed in the group with exposures greater than 6 mG measured at the door, compared with the group with less than 1 mG measured at the door. There was no association between case-control status and exposures between 1 and 6 mG. Limitations of this study include its small sample size, use of spot measurements taken after the onset of disease as an estimate of exposure prior to diagnosis, and limited control for confounders. The study provides a suggestion of an association in this genetically susceptible population, but given its limitations, further confirmatory research is needed before any conclusions can be drawn.

[6] Lowenthal et al. (2007) also included cases of leukemia among children, although most cases were among adults so this study is included in the adult leukemia section (Section 5.3.2).

Two recent studies evaluated whether magnetic fields contribute to a worse prognosis among those already diagnosed with childhood leukemia (Foliart et al., 2006, 2007; Svendson et al., 2007). In a study of 386 children in the United States with ALL, adverse events (failure to attain remission, relapse, diagnosis with a secondary cancer, or death) were evaluated in relation to estimated magnetic field exposure (Foliart et al., 2006, 2007). Exposure was categorized using a 24-hour personal exposure measurement. The authors observed increased deaths (from all causes) in the highest exposure category (≥ 3 mG) compared to the lowest exposure category (< 1 mG), but the result was based on only four deaths and there was only borderline evidence for a dose-response relationship, i.e., increasing risk with increasing exposure. A subsequent publication on the same study population reported that magnetic field exposure ≥ 3 mG was not associated with markers of poorer ALL prognosis (e.g., particular chromosomal rearrangements, clinical factors such as platelet counts, etc.), suggesting that the association observed in the earlier study is not caused by a magnetic-field effect on these variables (Foliart et al., 2007). The studies were limited by a very low participation rate (29%), small numbers in the highest exposure categories, and a lack of prospective information on magnetic field levels among residentially mobile children.

In follow-up to the observations of the Foliart et al. study, the risk of death in relation to magnetic-field exposure was evaluated in a cohort of 595 German children after diagnosis with ALL (Svendon et al, 2007). Twenty-four hour measurements of magnetic field exposure were taken in the children's bedrooms up to a few years after diagnosis. Information about the prognostic risk category (standard, medium, or high) was available for 486 of the children. After taking into consideration this prognostic risk category, age at diagnosis, year of diagnosis, and sex, children with high exposure (≥ 2 mG) were at a 3-fold statistically significant increased risk of death from all causes, in comparison to children with low magnetic field exposure (< 1 mG). Children in the medium exposure category were at a 2.8-fold increased risk, but this was not statistically significant. The interpretation of these results, similar to Foliart et al., is limited by low participation rates, small numbers in the highest exposure categories, and the lack of relevant and prospective information on magnetic field exposures (measurements were made in the house where the child lived the longest *before* diagnosis). Furthermore, the associations reported in this analysis are puzzling because magnetic field exposures in the range of 1-2 mG are common. Given these limitations, neither of these authors concluded that there was a causal relationship between magnetic-field exposure and the risk of death following ALL diagnosis.

It has been hypothesized that nighttime residential exposure may be a more biologically relevant measurement of magnetic field exposure in children. This hypothesis was evaluated by Schüz et al. (2007) in a pooled analysis of previously published studies, in which magnetic field exposure was based on measurements obtained between 10:00 PM and 6:00 AM. The authors observed similar associations between leukemia and nighttime exposures as in the original analyses of associations with 24- and 48-hour exposures (Ahlbom et al., 2000), leading them to conclude that the results "do not support the hypothesis that leukemia risk in children is more strongly associated with residential ELF-EMF exposure measurements taken at night" and that the similarity of risk estimates between measurements "indicates that the nighttime component cannot, on its own, account for the pattern observed." This finding is supported by a recent experimental study, which reported that mice exposed to magnetic fields only at night exhibit no increased risk of cancer (Sommer and Lerchl, 2006).

The recent literature also includes a case-control study conducted in Iran (Feizi and Arabi, 2007). In this case-control study, interviews were conducted with the mothers of 60 children with leukemia and 59 children without leukemia to determine the distance from their home to any nearby power lines. The authors reported that living within 500 meters of a transmission line or having estimated exposures greater than 4.5 mG (using crude formulas to calculate magnetic-field exposures from power lines) were associated with acute leukemia (ALL and AML combined) (Feizi and Arabi, 2007). This study was based on consecutively diagnosed cases from hospitals in one city. Its validity is significantly limited by its small size, possible selection bias, lack of assessment of confounding variables (such as socioeconomic status and mobility), and reliance upon distance as a proxy for exposure. The results are similar to, but much more limited than, the much larger study by Draper et al. in 2005, which reported that birth addresses of leukemia cases were more likely to be within 600 meters of a high-voltage transmission line. The WHO concluded the following, with respect to the Draper et al. findings:

> [the] observation of the excess risk so far from the power lines, both noted by the authors and others, is surprising. Furthermore, distance is known to

> be a very poor predictor of magnetic field exposure, and therefore, results of this material based on calculated magnetic fields, when completed, should be much more informative. (p. 270)

The same conclusions apply to Feizi and Arabi (2007). Both the recent Iranian and Japanese case-control studies (Kabuto et al., 2006) reported results that are consistent with the previously observed association between magnetic field exposures greater than 3-4 mG and childhood leukemia. When these studies are examined individually for methodological soundness, however, and then evaluated in the context of the entire body of literature, neither study provides evidence to change the conclusion that the observed association provides limited support for a causal relationship. The uncertainty surrounding the impact of selection bias in Kabuto et al. (as discussed in Section 5.2.2) and the small study size and crude methods for estimating exposure in Feizi and Arabi suggest that less weight should be placed on these studies relative to studies of magnetic fields and childhood leukemia that were population based and also had good exposure assessments, but did not have low participation rates (e.g., Linet et al., 1997; McBride et al., 1999; UKCCS et al., 2000).

A meta-analysis of studies on childhood brain tumors and residential magnetic field exposure was also published by Mezei et al. in 2008. The goal of the analysis was to combine inconsistent results from previous studies to see if an association existed with larger sample sizes. Thirteen epidemiologic studies were identified that used various proxies of magnetic field exposure (distance, wire codes, calculated magnetic fields, and measured magnetic fields). For all of the exposure proxies considered, the combined effect estimate was close to 1.0 and not statistically significant, indicating no association between magnetic field exposure and childhood brain tumors. The exception was a meta-analysis of five studies with information on childhood brain tumors and calculated or measured magnetic fields greater than 3-4 mG; the combined OR was elevated but not statistically significant (OR=1.68, 95% CI=0.83-3.43). The authors suggested two explanations for this elevated OR. First, they stated that an increased risk of childhood brain tumors could not be excluded at high exposure levels (i.e., >3-4 mG). They also stated that the similarity of this result to the findings of the pooled analyses of childhood leukemia studies for exposures greater than 3-4 mG suggests that control selection bias is operating in both analyses. Control selection bias means that there are important differences between the control group used in the study and the population from which the controls came, such that we see an error in the estimate of risk. Overall, the authors concluded that the analysis did not find a significant increase in childhood brain cancer risk using various proxies of residential exposure to magnetic fields.

#### Conclusion

The recently published studies reported an association between childhood leukemia and residence within 500 meters of a transmission line and magnetic field levels greater than approximately 4 mG, but there was no dose-response relationship and small numbers in the upper exposure categories limit inferences. Several studies also suggest that there may be an association between overall survival after a diagnosis of leukemia and average magnetic field levels greater than 4 mG, although no associations were observed between clinical indices of poorer survival and magnetic field exposure. None of these recent studies, however, are sufficiently strong methodologically to alter previous conclusions that the epidemiologic evidence on magnetic fields and childhood leukemia is limited. Chance, confounding, and several sources of bias cannot be ruled out.

It is also important to recognize these studies address just one of the many exposures being studied with respect to the etiology of childhood leukemia, including pesticides, benzene, paternal alcohol consumption, ionizing radiation and infections (McNally and Parker, 2006).

### 5.3.2 Adult Leukemia and lymphoma

Five studies have been published since the time of the WHO report that evaluate exposure to magnetic fields in relation to adult leukemia (Johansen et al., 2007; Roosli et al., 2007), lymphomas (Mester et al., 2006; Karipidis et al., 2007a; Roosli et al., 2007), or a combined category of leukemia and lymphoma (Lowenthal et al., 2007). Mester et al. is not considered further because exposure was based solely on self-reported occupation and industry.

In the two studies of leukemia, occupational exposure to EMF was evaluated in relation to leukemia risk in updates of previously published cohort studies; one cohort update was conducted among 28,000 Danish utility workers (Johansen et al., 2007) and the other cohort update was conducted among 20,000 Swiss railway workers (Roosli et al., 2007). In Johansen et al., the workers were followed for the incidence of cancer and classified into magnetic field exposure categories (high, medium and background) based on their first reported job title. The authors reported that male employees in high exposure jobs were no more likely to be diagnosed with leukemia than persons in medium or background exposure jobs.

Roosli et al. estimated cumulative magnetic field exposure by linking each cohort member's occupational history with exposures based on measurements and modeling. The previous publication on this cohort provided some evidence to support an association between leukemia mortality and increased magnetic field exposure (Minder and Pfluger, 2001). The current study, however, which was based on 29 additional deaths due to leukemia, did not report an association between overall leukemia mortality and increasing magnetic field exposure. Leukemia and lymphoma mortality was also compared between stationmasters (who spent most of their time in the station and on the platforms) and train attendants (who were exposed to magnetic fields from the 16.7-Hz AC engines). The authors noted more than a 3-fold greater risk among alpine train drivers, lowland train drivers, shunting yard engineers, and train attendants when compared with stationmasters, but the associations were not statistically significant.

Thus, neither study found a statistically significant association between occupational EMF exposure and leukemia risk. Roosli et al. was limited by the use of death certificate data[7] and small numbers, while Johansen et al. was based on a relatively large number of incident cancer cases. Neither cohort controlled for possible confounding factors. Both cohorts, however, had a long period of follow-up and consisted of persons who were presumably occupationally exposed to high levels of magnetic fields.

In an Australian case-control study, Lowenthal et al. (2007) grouped cases in five cancer diagnostic categories (including ALL) as lymphoproliferative disorders (LPD), and three

[7] Death certificates may not always contain the diagnosis of interest because they may only report immediate, and not underlying, causes of death. Furthermore, survival is increasing for many cancers and lymphomas. Thus, if a person survives their cancer, the cancer diagnosis will not be listed on their death certificate. Both of these limitations result in an under-ascertainment of cases, which could bias risk estimates toward 1.0.

diagnostic categories (including some types of leukemia) as myeloproliferative disorders (MPD). These groups included both adults and children of all ages. The authors estimated exposure by obtaining a lifetime residential history and assessing distance of residences from 88-kV, 110-kV, or 220-kV power lines. An individual's exposure was based on the closest distance ever having lived from a power line, grouped in categories of 0-50 meters, 51-300 meters, and > 300 meters. Lowenthal et al. reported elevated ORs for those who lived within 50 meters of any of these power lines, and an indication of decreasing ORs with increasing distance. The number of observed cases was small, however, and chance could not be ruled out as a factor in any of these results. The authors also reported an increased OR when only considering exposures that occurred up to the age of 15; the authors presented the concept of a possible effect of childhood exposure on long-term disease risk as a "novel finding" deserving further study.

This study of LPD and MPD by Lowenthal et al. included many limitations that may introduce bias, reduce validity, and detract from its findings. For example, data was obtained from cases by interview, but information was obtained from controls by postal questionnaires, thus breaking a cardinal rule in epidemiology that information from cases and controls should be obtained in the same manner. The distance measure, a poor surrogate for residential magnetic field exposure, is further reduced in value because the power lines in question were at three different voltages. If, as is likely, these lines carried different loads, then magnetic fields at any given distance would differ among the lines.

As the discussions above and previous sections illustrate, epidemiologic studies typically evaluate each different type of cancer individually. There are reasons why studies of EMF have not combined different types of cancer, or adults and children, together, as Lowenthal et al. have done. This is because differences among cancers in patterns of age at diagnosis, cell type, rate of growth and response to different treatments illustrate the unique aspect of each cancer diagnosis. Therefore, studies of possible causes are studied separately for each type of cancer because each cancer has a distinct etiology. The combination of different diseases and age groups, the highly imprecise exposure surrogate, the different methods for evaluating cases and controls, and the role of chance diminish the implications of the findings from this study.

In another Australian case-control study, occupational history was evaluated for associations with non-Hodgkin lymphoma (NHL) (Karpidis et al., 2007a). The authors estimated cumulative exposure to magnetic fields based on reported occupations. When considering other factors, including age, sex, place of residence, ethnic origin, and exposure to solvents (other than benzene) and to wood dust and particles, the authors observed a significant trend of more cases than controls classified with higher cumulative exposure to magnetic fields. The highest category of exposure had a non-significant 1.3-fold increased risk of NHL occurrence. In the study of Swiss railway workers, however, there was no association with EMF-exposed occupations and risk of death from NHL (Roosli et al., 2007). Overall, the Australian study was well conducted, with its most significant limitation being the possibility of uncontrolled confounding because little is known about the causes of NHL. This is one of the first population-based studies examining an association between NHL and magnetic field exposure using calculated exposure estimates. Therefore, it is still a hypothesis-generating[8] study, and further research is required before any conclusions can be provided.

**Conclusion**

In conclusion, the recently published updates of large cohorts occupationally exposed to magnetic fields are in line with the previous summary conclusions from IARC, ICNIRP, and WHO with regard to adult leukemia. The cumulative body of evidence does not support an epidemiologic association between magnetic fields and adult leukemia. Lowenthal et al. reported findings for distance from power lines that cannot be distinguished from a chance finding. The reported association between early exposure and later cancer cannot be evaluated without additional testing.

### 5.3.3 Adult brain cancer

Four studies have been published since the time of the WHO report that evaluate exposure to occupational magnetic fields in relation to adult brain cancer, including the two cohort updates

[8] Studies generate and test scientific questions, or hypotheses. The first studies reporting results on a specific scientific question are called hypothesis-generating to highlight that there is little available data with which to compare the results. In addition, certain study designs are useful for screening different hypotheses but are not specific enough to produce results definitive enough for assessing cause-and-effect. Therefore, hypothesis-

described above (Johansen et al., 2007; Roosli et al., 2007). In these retrospective cohort studies of all brain tumors, Johansen et al. and Roosli et al. classify EMF exposure based on occupation in Danish utility workers and Swiss railway workers, respectively. No associations of EMF were observed for brain tumor incidence in the Danish study or brain tumor mortality in the Swiss study. Details of these studies are reported above in the adult leukemia/lymphoma Section 5.3.2.

Two other studies evaluated specific brain cancer types, acoustic neuroma and glioma (Forssén et al., 2006; Karipidis et al., 2007b, respectively). Forssén et al. is the first case-control study to report on the association between magnetic field exposure and acoustic neuroma, a benign (non-cancerous) and rare brain tumor for which causes are unknown. The large study consisted of all diagnoses of acoustic neuroma in Sweden over a 12-year period (N=793) and controls randomly selected from the entire Swedish population (N=101,762). Time-weighted average and peak occupational magnetic field exposure were estimated using a job-exposure matrix[9] based on actual measurements and occupations listed on the country's census forms. The authors did not find any evidence that magnetic field exposure increases the risk of acoustic neuroma, regardless of the exposure level or the time period considered. This study was advanced because selection bias, recall bias, and participation bias were not an issue because no participation was required of the cases or controls; however, incomplete occupational data was an important limitation.

Glioma risk was evaluated in a case-control study of men and women in Melbourne, Australia (Karipidis et al, 2007b). Occupational history was obtained for each subject by an in-person interview, and magnetic field exposure was classified in three ways: self-reported exposure, exposure determined by an industrial hygienist, and a job-exposure matrix. No statistically significant associations with glioma were observed for men or for women based on any of three exposure classifications. This study had a number of significant limitations (low participation

generating studies cannot provide strong conclusions because the questions being considered require further study.

9 A job-exposure matrix cross-classifies job titles and exposure estimates. Job-exposure matrices are used to estimate cumulative occupational exposure (e.g., magnetic field exposure) based on an individual's job history.

rates and a high percentage of proxy interviews among cases) that may have influenced the findings.

**Conclusion**

Overall, the results of these four studies do not support an association between occupational EMF exposure and brain tumor risk in adults. Thus, recent studies add support to the previous weight-of-evidence review conclusions that the data does not indicate a cause-and-effect relationship between magnetic fields and brain cancer.

### 5.3.4 Breast cancer

Since the publication of the WHO report, two case-control studies have estimated the association between EMF exposure and breast cancer, both of which focused on occupational exposures (McElroy et al., 2007; Ray et al., 2007).[10] Two additional studies evaluated occupational EMF exposure, but are not considered further in this report because the exposure assessment did not extend beyond job titles. The excluded studies include a brief report of a proportionate mortality analysis conducted on a select group of occupational titles the authors believed to be associated with electric typewriter use (Milham and Ossiander 2007) and a case-control study of female breast cancer reporting associations for a wide range of occupations and industries (Peplonska et al., 2007).

In a large case-control study of female breast cancer in the United States, women were classified as having background, low, medium, or high occupational EMF exposure by industrial hygienists based on their reported occupational history (industry, job title, and job duties) (McElroy et al., 2007). The authors reported increasing risk with increasing categories of exposure (low, medium and high), but the ORs were very small and not statistically significant (1.05, 1.11, and 1.17, respectively). Although the overall sample size was large, only 1% of the

[10] An additional case-control study was published post-2005 that examined residential magnetic field exposure and breast cancer (Davis and Mirick, 2007), although it was not fully evaluated in this report because it was a re-analysis of a study published by the same investigators in 2001 (Davis et al., 2001a) with the addition of a few variables.

study population was classified as having high exposure, which the authors felt limited the power of the study.

Ray et al. (2007) was a nested case-control study in a cohort of approximately 250,000 textile workers in China followed for breast cancer incidence; EMF exposure (yes/no) was estimated according to a job-exposure matrix and categorized according to years of exposure. Breast cancer cases were no more likely than the women in the cohort who did not develop breast cancer to have EMF-exposed jobs. The strength of the study was its large size and nested design, but, as noted by the authors, "duration of employment in EMF-exposed jobs was too crude a dose metric to detect a weak to modest association" (p. 390). According to the authors, research will continue on this Chinese cohort to estimate exposure quantitatively.

The previously discussed retrospective cohort of Danish utility workers also evaluated female breast cancer risk (Johansen et al., 2007); male breast cancer cases were excluded. No increased risk for female breast cancer was observed in this study.

**Conclusion**

Neither of these two recently published studies provides strong evidence contradicting the WHO conclusion that an association between ELF-EMF exposure and breast cancer is not supported by the published evidence to-date. This conclusion is consistent with a recently published review of the literature by Feychting and Forssén (2006) in Sweden, which concluded the following:

> … considering the results of the latest well designed studies performed specifically to test the hypothesis that ELF magnetic field exposure increase breast cancer risk, one must conclude that the weight of the evidence available today suggest that power frequency magnetic field exposure most likely is not a risk factor for breast cancer development. (p. 557)

### 5.3.5 Reproductive and developmental effects

No studies were identified that evaluated EMF exposure and adverse reproductive outcomes since the WHO review. A study related to developmental outcomes and ELF-EMF exposure, however, was recently published (Fadel et al., 2006). Fadel et al. (2006) was a cross-sectional study of 390 children living in Abu-Sultan, with residences within 50 meters of high-voltage power lines, and 390 children living in El-Shiekh Zayed, with residences not located near power lines. The authors reported that children living in the region near power lines had a statistically significant lower weight at birth and a reduced head and chest circumference and height at all ages.

There are three notable limitations of this study. First, it is a cross-sectional study, meaning that the dynamic characteristics such as height and weight were measured at a single point in time. Second, although the authors noted that socioeconomic status was similar between the two regions, they did not collect or provide data to support this assertion, nor did they account for some key factors that might influence growth, such as nutrition, in their analyses. The final limitation is that the authors observed statistically significant associations, but did not discuss the biological importance of their findings.

The WHO concluded in 2007 that "Overall the evidence for developmental effects and for reproductive effects is inadequate" (p. 254). This study does not provide sufficient evidence to alter that conclusion.

### 5.3.6. Neurodegenerative diseases

Garcia et al. (2008) conducted a systematic review and meta-analysis of studies of occupational EMF exposure and Alzheimer disease published through April 2006. The authors identified 14 epidemiologic studies with information on the risk of AD related to occupational exposure to ELF EMF; the majority of these studies were considered by the WHO in their 2007 review. A statistically significant association between AD and occupational EMF exposure was observed for both case-control and cohort studies (OR =2.03, 95% CI=1.38-3.00 and RR =1.62, 95% CI=1.16-2.27, respectively), although the results from the individual studies were so different that the authors cautioned against the validity of these combined results. While some subgroup analyses had statistically significant increased risks and were not significantly heterogeneous between studies, the findings were contradictory between study design types (e.g., elevated pooled risk estimates were reported for *men* in cohort studies and elevated pooled risk estimates were reported for *women* in case-control studies). The authors found no exposure-response patterns and publication bias was apparent. The authors concluded that their work suggests an association between AD and occupational magnetic field exposure, but noted the numerous limitations associated with these studies, including the difficulty of assessing EMF exposure during the appropriate time period, case ascertainment issues due to diagnostic difficulties, and differences in control selection. They recommended further research that uses more advanced methods.

Three original studies on neurodegenerative diseases and magnetic field exposures have been published since the WHO report; none of these studies were included in the meta-analysis discussed above. Davanipour et al. (2007) extended the early hypothesis-generating study by Sobel et al. by collecting cases from eight California Alzheimer's Disease Diagnostic and Treatment Centers (Sobel et al. examined the 9$^{th}$ Center in 1996). Occupational information (i.e., self-reported primary occupation) was collected from verified diagnoses of Alzheimer's disease and compared to occupational information collected from persons diagnosed with other dementia-related problems at the Centers. The results of this study were consistent with the previous studies by Sobel et al.; cases were approximately twice as likely to be classified as having medium/high magnetic field exposures, compared with controls. When the authors analyzed the data for males and females separately, the association was statistically significant among females, but not among males. The strengths of this study included its large size, self-reported occupational information, and that disease status was based on expert diagnosis. The main limitation was that the exposure assessment only considered a person's primary occupation, classified as low, medium or high magnetic field exposure. The WHO noted limitations of the 1996 publication that are relevant to this publication as well, including the use of controls with dementia (which some studies report have an increased risk of Alzheimer's disease) and the classification of seamstresses, dressmakers and tailors as "high exposure" occupations, which drives the increase in risk.

Death from several neurodegenerative conditions was also evaluated in the cohort of more than 20,000 Swiss railway workers described above (Roosli et al., 2007b). Magnetic field exposure was characterized by specific job titles as recorded in employment records; station masters were considered to be in the lowest exposure category and were, therefore, used as the reference group, train drivers were considered to have the highest exposure, and shunting yard engineers and train attendants were considered to have exposure intermediate to these two groups. Cumulative magnetic field exposure was also calculated for each occupation using on-site measurements and modeling of past exposures. The authors reported an excess of senile dementia disease among train drivers, compared to station masters, however, the difference was not statistically significant; the association was larger when restricted to Alzheimer's disease, but was still not statistically significant (hazard ratio=3.15, 95% CI=0.90-11.04). No elevation in mortality was reported for multiple sclerosis, Parkinson's disease, or ALS among train drivers, shunting yard engineers, or train attendants, compared with stationmasters, nor were more deaths from these causes observed for higher estimated magnetic field exposures. Similar to another recent Swedish study (Feychting et al., 2003), the authors reported that more recent exposure is more strongly associated with risk than earlier exposure.

This study has several unique advantages relative to the existing body of data, as described by the study authors:

> Swiss railway employees are an appealing study population for several reasons. They are generally employed long-term, with limited job changes. The exposure circumstances at a given workplace are well characterized but vary greatly across different occupations, with train drivers being exposed to very high ELFMF levels, whereas exposure in other employees is comparable to the general population. Detailed company registers reduce the potential for selection bias and allow assessments of ELF-MF exposure that are based on individual job histories. Exposures to chemicals or electric shocks, which often occur in other occupational settings (for example in electric utility workers or welders) are rare. (p. 198)

Sorahan and Kheifets (2007) followed a cohort of approximately 84,000 electrical and generation workers in the United Kingdom for deaths attributed to neurodegenerative disease on death certificates. Cumulative magnetic field exposure was calculated for each worker, using job and facility information. The authors reported that the cohort did not have a significantly greater number of deaths due to Alzheimer's disease or motor neuron disease, compared to the general United Kingdom population. They also reported that persons with higher estimated magnetic field exposures did not have a consistent excess of death due to Alzheimer's disease or motor neuron disease, compared to persons with lower estimated magnetic field exposure. A statistically significant excess of deaths due to Parkinson's disease was observed in the cohort, although there was no association between calculated magnetic field exposure and Parkinson's disease. The authors concluded "our results provide no convincing evidence for an association between occupational exposure to magnetic fields and neurodegenerative disease" (p. 14). This result is consistent with two other Alzheimer's mortality follow-up studies of electric utility workers in the United States (Savitz et al., 1998) and Denmark (Johansen and Olsen, 1998). The findings may be limited by the use of death certificate data, but are strengthened by the detailed exposure assessment.

As noted in Section 5.2.7, studies of neurodegenerative disease and magnetic field exposure have had significant methodological limitations that make them difficult to interpret. The onset of Alzheimer's disease occurs late in life and is difficult to define precisely because it is preceded by a period of dementia that is difficult to distinguish from other etiologies, such as cerebrovascular disease. Since magnetic field exposure occurs throughout a person's life, it is also a challenge to design studies that ascertain lifetime exposure accurately and at the etiologically relevant time period (Brown et al., 2005). An advantage of the more recent cohort studies is that they estimated cumulative magnetic field exposure based on a person's known job tasks in the electric or railway industries (Roosli et al., 2007b; Sorahan and Kheifets 2007). A complication, however, is that these studies used death certificates to ascertain cases. Use of death certificates or other mortality data is likely to result in a large number of missed cases, and therefore possible bias, because a large percentage of elderly Alzheimer's patients die from other causes and Alzheimer's disease may not be mentioned on the death certificate (Brown et al., 2005). Furthermore, none of these studies estimated residential exposure and most did not control for the possible confounding effect of other risk factors for Alzheimer's disease (increasing age, family history, Down's syndrome, and a genetic predisposition).

**Conclusion**

The WHO stated that there is inadequate data in support of an association between magnetic field exposure and Alzheimer's disease or ALS; the recent studies do not alter this conclusion. The meta-analysis by Garcia et al. confirmed that the associations reported in these studies are highly inconsistent and the studies have many limitations. Overall, the three recent, original studies contribute some valuable information to the growing body of literature regarding magnetic field exposure and neurodegenerative diseases, particularly the well-conducted cohort study by Roosli et al. Further studies are still required, however, because of study design limitations. Moreover, there are no consistent biological data that would support the plausibility of such an association. The WHO panel highly recommended that further studies be conducted with regard to neurodegenerative diseases, particularly studies where the association between magnetic fields and ALS is estimated while controlling for the possible confounding effect of electric shocks.

# 6 Summary

Nearly 30 epidemiologic studies have been published on electric and magnetic fields and health since December 2005.  Overall, very few of these studies used high quality methods, meaning there is little evidence available from these new studies that could alter previous conclusions. Many of the recent epidemiologic studies still used proxy measures for exposure and suffered from significant study design limitations.  A few epidemiologic studies tested new hypotheses that require further study, such as the reported statistical association between magnetic fields and childhood leukemia survival and the incidence of childhood leukemia in Down's syndrome patients.

The weak statistical association between high, average magnetic fields and childhood leukemia remains unexplained.  Recent research (which focused largely on occupational exposures) supports the conclusion that there is no association between magnetic fields and adult leukemia/lymphoma, brain cancer and breast cancer.  Although the current body of evidence does not provide strong evidence in support of a causal relationship, further research is required on Alzheimer's disease and ALS to clarify the association observed in some studies.  In conclusion, the recent studies do not provide evidence to alter the conclusion that the body of research suggests that electric or magnetic fields are not the cause of cancer or any other disease process at the levels we encounter in our everyday environment

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