Appendix F

Electric and Magnetic Fields Research on Health Effects

Exponent®

Health Sciences

Update of EMF Research - 2009

Update of EMF Research - 2009

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Contents

List of Figures

List of Tables

Introduction

Electrical objects produce two field types – electric fields and magnetic fields. The term "field" is used to describe the way an object influences its surrounding area. A temperature field, for example, surrounds a warm object, such as a space heater. Electric and magnetic fields (EMF) surround any object that is generating, transmitting or using electricity, including appliances, wiring, office equipment, generators, batteries and any other electrical devices. EMFs are invisible and they cannot be felt or heard.

Electric fields occur as a result of the electric potential (or voltage) on these objects, and **magnetic fields** occur as a result of current flow through these objects.[1] Just like a temperature field, electric and magnetic fields can be measured and their levels depend on, among other things:

- Properties of the source of the field (voltage, current, configuration, etc.)
- Distance from the source of the field

Both electric and magnetic fields decrease rapidly with distance from the source, such that a magnetic field of 300 milligauss (mG) within 6 inches of a vacuum cleaner diminishes to 1 mG at 4 feet (NIEHS, 2002). This is similar to the way that the heat from a candle or campfire lessens as you move farther away. Although ordinary objects do not block magnetic fields, objects such as trees and buildings easily block electric fields.

The electrical power system in the United States (US) produces alternating current (AC) EMF that changes direction and intensity 60 times per second – i.e., a frequency of 60 Hertz (Hz).[2] This frequency is in the extremely low frequency (ELF) range of the electromagnetic spectrum. Electricity produced by generating stations flows as 60 Hz current through transmission and distribution lines and provides power to the many appliances and electrical devices that we use

1 The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m); one kilovolt per meter is equal to 1,000 V/m. 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.

2 Europe's electrical system produces 50 Hz EMF. Since 50 Hz EMF is also in the ELF range, research on 50 Hz EMF is relevant to questions on 60 Hz EMF.

in our homes, schools, and workplaces. Because electricity powers so many things in our daily lives, from lighting, heating and cooling our homes to powering our refrigerators and computers, magnetic fields are found throughout our daily environments.

Questions about whether these ubiquitous exposures could affect our health were raised in the 1970s. Since then, researchers from many different scientific disciplines have investigated this question and hundreds of studies have been conducted. The public frequently expresses concern about EMF, particularly in the context of new transmission lines. The intent of this report is to describe what this large body of research has told us about EMF and the precautions, if any, we should take to reduce or avoid exposures.

The Bonneville Power Administration (BPA) requested that Exponent update a report from July 2007 to provide a current summary of the status of the research on EMF.[3] The focus of the July 2007 report was on the conclusions of a comprehensive, weight-of-evidence review published by the World Health Organization (WHO) in June 2007, since that report represented the most recent review of the literature by a multidisciplinary scientific panel. The WHO organized a multidisciplinary Task Group of 21 scientists from around the world to draft a Monograph that summarized the research and provided conclusions as to whether there are risks associated with ELF-EMF and, if so, at what exposure levels (WHO, 2007a). The report concluded that the only established effects of ELF-EMF exposure are acute neurostimulatory effects that occur at very high levels of exposure; these exposure levels are not encountered in ordinary residential or occupational environments. The factsheet from this report is attached as Appendix 1 (WHO, 2007b) and can be found at http://www.who.int/mediacentre/factsheets/fs322/en/print.html.

Research is a constantly evolving process. Despite the volume of research available on EMF and the large reduction in uncertainty that research has achieved over the years, research continues with the goal of clarifying and replicating old findings and testing new hypotheses. New studies on ELF-EMF are published each year. To update its perspective on EMF research, this supplemental report identifies newly published studies and provides the reader with

3 Exponent. Assessment of Research Regarding EMF and Health and Environmental Effects. Olympic Peninsula Reinforcement Transmission Line Project. July 2007.

perspective on if, and how, these recent studies have strengthened or changed the WHO conclusions.

A short section on the methods that scientists use to conduct studies and make decisions about health risks is also included as a framework for understanding later discussions (Section 1). The discussion of new research is broadly grouped by disease – cancer, reproductive/developmental effects, and neurodegenerative diseases – in Section 2. Both epidemiologic and *in vivo* research is summarized within the disease category and *in vitro* research is discussed separately. The possible effects of EMF on the functioning of pacemakers (Section 3) and on flora and fauna (Section 4) are also discussed.[4] Finally, guidelines for ELF-EMF exposure developed by scientific organizations to prevent against established health effects are summarized in Section 5.

4 Neither of these topics was covered in the WHO report, but a discussion is provided to determine whether recent studies alter statements from Exponent's 2007 BPA report.

1 Scientific Methods

Weight-of-evidence review

Most things that we encounter in our environment have no effect on our health. But, there are some things that may affect our health in a harmful or beneficial way. These include things that we encounter in the environment, such as sunlight, or things we eat, such as certain foods. Much time and money is spent by scientists around the world designing, conducting and publishing research to determine what factors may affect our health, including environmental exposures (like EMF), infectious agents and our genetics. The process for arriving at a conclusion about whether there is a health risk associated with any of these factors is usually not as straightforward or definitive as reporting by the lay media may suggest. Rather, it is a long process that requires repeated hypothesis generation and testing.

The process begins when a scientist forms a hypothesis and conducts a study to test that hypothesis. Studies are conducted by scientists at academic universities and scientific institutions around the world. Once the study is complete, the authors submit it to a scientific journal for publication, where it undergoes peer review prior to publication. The evidence to evaluate any health risk, therefore, is all of the relevant studies published in the peer-reviewed literature.

These individual research studies can be thought of as puzzle pieces. When all of the research is placed together, we have some understanding of possible health effects; however, no conclusions can be reached by looking at only one study, just as no picture can be formed with just one puzzle piece. Each study provides a different piece of information to the puzzle because of its unique strengths and weaknesses – if the study used valid methods and had no obvious sources of bias, it may provide a wealth of information or, if the study was not well done, it may provide little (if any) information.

This process of evaluating all of the research together to determine whether something poses a health risk (or benefit) is referred to as a weight-of-evidence review. There are three types of research that are considered in a weight-of-evidence review: epidemiologic observations in people, experimental studies in animals (*in vivo* research), and experimental studies in cells and tissues (*in vitro* research). It is important to consider all three types of research together because they provide complementary information:

- For epidemiology studies, scientists collect observational data about human populations in their day-to-day environments to determine whether there are patterns between exposures and diseases. These studies measure statistical associations to evaluate whether a disease and exposure occur together more often than expected. An important limitation of these studies is that, if an association is measured, they do not tell scientists how the exposure is truly related to the disease. That conclusion can only be reached by considering the entire body of research. Most of the studies evaluating EMF look at whether people with disease have higher estimates of EMF exposure in the past compared to people without disease.

- Experimental studies in which scientists expose animals (*in vivo*) to varying levels of electric or magnetic fields (some as high as 50,000 mG) are an important source of information. These studies compare the amount of disease they observe in exposed animals to the amount of disease they observe in animals that have not been exposed. The strength of animal studies is that scientists are able to control all aspects of the animals' lives to minimize the potential confounding effects of factors other than the exposure of interest. Of these studies, the most valuable for understanding disease are those in which the animals receive life-long exposures.

- A second type of experimental EMF study involves the exposure of isolated cells and tissues *in vitro* to EMF, and compares the characteristics of exposed and unexposed samples to look for differences that are indicative of a disease process. These studies are limited because what happens in cells or tissue outside a human body may not be the same as what happens inside a body.

Scientists, scientific organizations, and regulatory agencies use the weight-of-evidence approach worldwide to assess the possible health risks associated with exposures. A weight-of-evidence review begins with a systematic review of published, peer-reviewed scientific research in the fields of epidemiology, *in vivo* research, and *in vitro* research. The weight that individual studies provide to the overall conclusions is not equal – studies vary widely in terms of the sophistication and validity of their methods. Therefore, each study from each discipline must be critically evaluated and assigned a weight. A final conclusion is then reached by considering the cumulative body of research, giving more weight to studies of higher quality (see Figure 1).

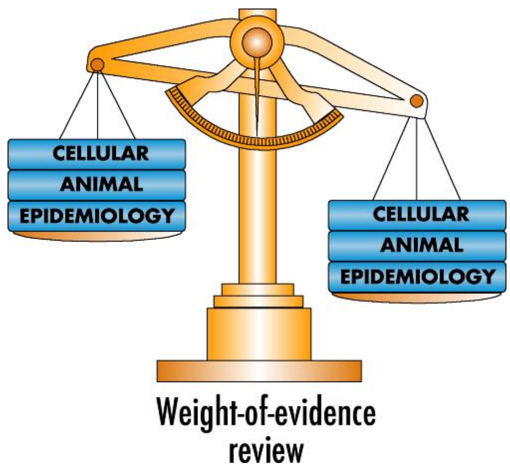

Figure 1. Weight-of-evidence reviews consider three types of research

Continuing with the puzzle example from above, the picture that is formed when the individual studies (or puzzle pieces) are assembled can take on many different shapes. In some cases (e.g., smoking and lung cancer), a clear picture of an adverse health effect was presented by the research within a relatively short time. In most cases, however, the picture is unclear and more questions are raised. It is impossible to prove the negative in science – i.e., to say that any exposure is completely safe – therefore, when it appears that there is little risk, research studies endeavor to reduce the uncertainty that there is a health effect through continued research. The only way to reduce this uncertainty is to conduct high quality studies with meaningful results that are replicated across study populations. Thus, in most areas of research, unless the data clearly indicates an increased risk at defined exposure levels, scientific panels will conclude that the research is inadequate and requires future research, until the uncertainty has been reduced below an acceptable level. While the public may interpret this conclusion as indicating concern, it is natural for scientists to recommend future research to either reduce uncertainty around a largely "negative" body of research or replicate findings that appear "positive" in nature.

Established scientific and health agencies organize panels to conduct weight-of-evidence reviews. These panels consist of experts from around the world in the areas of interest (e.g., epidemiology, neurophysiology, toxicology), and they follow standard scientific methods for arriving at conclusions about possible health risks. The conclusions of these reviews are looked to for the current scientific consensus on a particular topic and form the basis of recommendations made by organizations and governments on exposure standards and precautionary measures.

Numerous national and international organizations responsible for public health have convened multidisciplinary panels of scientists to conduct weight-of-evidence reviews and arrive at conclusions about the possible risks associated with ELF-EMF. These organizations include the following (in ascending, chronological order of their most recent publication):

- The **National Institute for Environmental Health Sciences** (**NIEHS**) assembled a 30-person Working Group to review the cumulative body of epidemiologic and experimental data and provide conclusions and recommendations to the United States government (NIEHS, 1998, 1999).

- The **International Agency for Research on Cancer** (**IARC**) completed a full carcinogenic evaluation of electric and magnetic fields in 2002.

- The **International Commission on Non-Ionizing Radiation Protection** (**ICNIRP**), the formally recognized organization for providing guidance on standards for non-ionizing radiation exposure for the WHO**,** published a review of the cumulative body of epidemiologic and experimental data on ELF-EMF in 2003.

- The **National Radiological Protection Board** (**NRPB**)[5] of the United Kingdom (UK) issued full evaluations of the research in 1992, 2001 and 2004, with supplemental updates (1993, 1994a) and topic-specific reports (1994b; 2001b; HPA, 2006) published in the interim.

- The **World Health Organization (WHO)** released a review in June 2007 as part of its International EMF Program to assess the scientific evidence of possible health effects of EMF in the frequency range from 0 to 300 GHz.

- The SSI of the **Swedish Radiation Protection Authority**, using other major scientific reviews as a starting point, evaluated recent studies in consecutive annual reports (SSI, 2007; SSI, 2008).

- The **Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)** issued a report in March 2007 and March 2009 updating previous conclusions (SSC, 1998; CSTEE, 2001) to the Health Directorate of the European Commission.

In August 2007, an *ad hoc* group of 14 scientists and public health and policy "experts" published a report, referred to as the BioInitiative Report, online to "assess scientific evidence on health impacts from electromagnetic radiation below current public exposure limits and evaluate what changes in these limits are warranted now to reduce possible public health risks in the future" (p. 4). The report was followed by two publications that summarized some of the online report's conclusions (Hardell and Sage, 2008; Davanipour and Sobel, 2009). The individuals who comprised this group did not represent any well-established regulatory agency, nor were they convened by a recognized scientific authority. The report has been criticized by scientific agencies because it did not follow the methods of a standard weight-of-evidence review and, for this reason, its conclusions and recommendations are not considered further in this report (HCN, 2008).[6] Appendix 2 provides a full criticism of the report.

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[5] The NRPB merged with the Health Protection Agency (HPA) in April 2005 to form its new Radiation Protection Division.

[6] http://www.gr.nl/pdf.php?ID=1743&p=1

Epidemiology basics

For reference, this section briefly describes the main types of epidemiology studies and the major issues that are relevant to evaluating their results. The two, main types of epidemiology studies are cohort studies and case-control studies (see Figure 2).

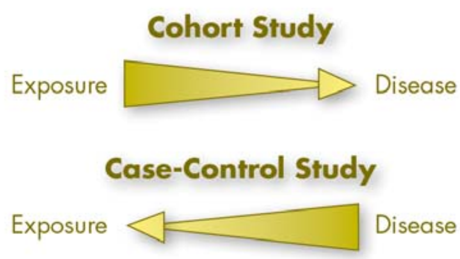

Figure 2. Basic design of cohort and case-control studies

A case-control study is a type of epidemiology study that compares the characteristics of people that have been diagnosed with a disease (i.e., cases) to a similar group of people who do not have the disease (i.e., controls). The prevalence and extent of past exposure to a particular agent is estimated in both groups to assess whether the cases have a higher exposure level than the controls, or vice versa.

In a case-control study, this comparison (or statistical association) is estimated quantitatively with an odds ratio (OR). An odds ratio is the ratio of the odds of exposure among persons with a disease to the odds of exposure among persons without a disease. The general interpretation of an odds ratio equal to 1.0 is that the odds of exposure are the same in the case and control groups (i.e., there is no statistical association between the exposure and disease). If the odds ratio is greater than 1.0, the inference is that the odds of exposure are greater in the case group or, in other words, the exposure may increase the risk of the disease (see Figure 3 below).

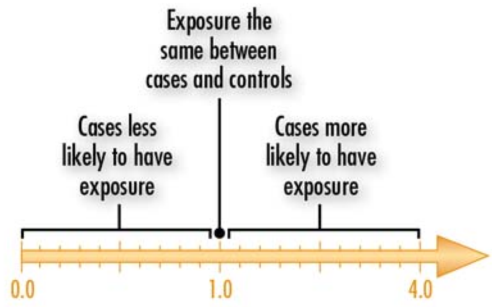

Figure 3. Interpretation of an odds ratio in a case-control study

Each OR is reported with a confidence interval (CI), which is a range of OR values that have a specified probability of occurring if the study is assumed to be repeated a large number of times. A 95% CI, for example, provides the range of values that are likely to occur in 95% of repeated experiments. In short, a CI tells you how certain (or confident) you are about the OR you calculated from your data; if the CI includes 1.0, for example, you cannot statistically exclude the possibility that the OR is 1.0, meaning the odds of exposure are the same in the case and control groups.

A cohort study is the reverse of a case-control study – researchers study a population without disease and follow them over time to see if persons with a certain exposure develop disease at a higher rate than unexposed persons. The mathematics of cohort studies are similar to a case-control studies, although the risk estimate is referred to as a relative risk (RR). The RR is equal to rate of disease in the exposed group divided by the rate of disease in the unexposed group, with values greater than 1.0 suggesting that the exposed group has a higher rate of disease.

A RR or OR value is simply a measure of how often a disease and exposure occur together in a particular study population – it does not mean that there is a known or causal relationship. Before any conclusions can be drawn, all studies must be identified and each study must be evaluated to determine the possible role that factors such as chance, bias and/or confounding may have played in the study's results.

- *Chance* refers to a random event, like a coincidence. An association can be observed between an exposure and disease that is simply the result of a chance occurrence. Statistics, such as the CI, are calculated to determine whether chance is a likely explanation for the findings.
- *Bias* refers to any error in the design, conduct, or analysis of a study that results in a distorted estimate of an exposure's effect on the risk of disease. There are many different types of bias; for example, selection bias may occur if the characteristics of cases that participate in a study differ in a meaningful way from the characteristics of those subjects that do not participate (e.g., if cases that live near a power line are more likely to participate because they are concerned about this possible exposure).
- *Confounding* is a situation in which an association is distorted because the exposure being studied is associated with other risk factors for the disease. For example, a link between coffee drinking in mothers and low birth weight babies may be observed in a study. However, some women who drink coffee also smoke cigarettes. When the smoking habits of mothers are taken into account, coffee drinking may not be associated with low birth weight babies because the confounding effect of smoking has been removed.

As part of the weight-of-evidence review process, each study's design and methods are critically evaluated to determine if and how chance, bias, and confounding may have affected the results, and, as a result, the weight that should be placed on the study's findings.

IARC classifications

This section briefly describes the method that the IARC uses following a weight-of-evidence review to classify exposures based on the evidence in support of carcinogenicity. The WHO adopted this method in their 2007 report on ELF-EMF, and other scientific agencies refer to it as well.

First, each research type (epidemiology, *in vivo* and *in vitro*) is evaluated to determine the strength of evidence in support of carcinogenicity (as defined in Figure 4). With regard to epidemiologic studies, *sufficient evidence* is used to describe a body of research where an association is found and chance, bias and confounding can be ruled out with "reasonable confidence." *Limited evidence* is used to describe a body of research where the findings are inconsistent, or where an association is observed but 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 same overall categories apply for *in vivo* research (see Figure 4). *In vitro* research, although not described in Figure 4, is used to a lesser degree in evaluating carcinogenicity and is classified as strong, moderate or weak.

Agents are then classified into the following categories using the combined categories from epidemiology, *in vivo* and *in vitro* research: carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, unclassifiable, and probably not carcinogenic to humans (from highest to lowest risk). For example, the category "possibly carcinogenic to humans" typically denotes exposures for which there is limited evidence of carcinogenicity in epidemiology studies and less than sufficient evidence of carcinogenicity in *in vivo* studies.

The IARC has reviewed over 900 substances and exposure circumstances to evaluate their potential carcinogenicity. For context, Figure 5 provides examples of some of the more common exposures that have been classified in each category. As Figure 5 shows, over 80% of exposures fall in the categories "possible carcinogen" (27%) or "non-classifiable" (55%). This occurs because, as described above, it is nearly impossible to prove that something is completely safe and few exposures show a clear-cut or probable risk, so most agents will end up in either of these two categories. Note that throughout the entire history of the IARC only one agent has been classified in the category "probably not carcinogenic," which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

Over half of the agents are *not classifiable* in terms of carcinogenicity, i.e., it is unclear whether they can cause cancer, and hair coloring products, jet fuel and tea are included in this category. *Possible carcinogens* include occupation as a firefighter, coffee, and pickled vegetables, in addition to magnetic fields. Exposures identified as *probable carcinogens* include high temperature frying of food, occupation as a hairdresser, and use of sun beds. Finally, *known carcinogens* include benzene, asbestos, solar radiation and tobacco smoke. As Figure 5 shows, there is much uncertainty about whether certain agents will lead to cancer, and possible and probable carcinogens include substances to which we are commonly exposed or are common exposure circumstances.

	Epidemiology Studies				Animal Studies			
	Sufficient evidence	Limited evidence	Inadequate evidence	Evidence suggesting lack of carcinogenicity	Sufficient evidence	Limited evidence	Inadequate evidence	Evidence suggesting lack of carcinogenicity
Known Carcinogen	✓							
Probable Carcinogen		✓			✓			
Possible Carcinogen		✓				✓	✓	
Not Classifiable			✓			✓	✓	
Probably not a Carcinogen				✓				✓

Sufficient evidence in epidemiology studies—A positive association is observed between the exposure and cancer in studies, in which chance, bias and confounding were ruled out with "reasonable confidence."

Limited evidence in epidemiology studies—A positive association has been observed between the exposure and cancer for which a causal interpretation is considered to be credible, but chance, bias or confounding could not be ruled out with "reasonable confidence."

Inadequate evidence in epidemiology studies—The available studies are of insufficient quality, consistency or statistical power to permit a conclusion regarding the presence or absence of a causal association between exposure and cancer, or no data on cancer in humans are available.

Evidence suggesting a lack of carcinogenicity in epidemiology studies—There are several adequate studies covering the full range of levels of exposure that humans are known to encounter, which are mutually consistent in not showing a positive association between exposure to the agent and any studied cancer at any observed level of exposure. The results from these studies alone or combined should have narrow confidence intervals with an upper limit close to the null value (e.g. a relative risk of 1.0). Bias and confounding should be ruled out with reasonable confidence, and the studies should have an adequate length of follow-up.

Sufficient evidence in animal studies—An increased incidence of malignant neoplasms is observed in (a) two or more species of animals or (b) two or more independent studies in one species carried out at different times or indifferent laboratories or under different protocols. An increased incidence of tumors in both sexes of a single species in a well-conducted study, ideally conducted under Good Laboratory Practices, can also provide sufficient evidence.

Limited evidence in animal studies—The data suggest a carcinogenic effect but are limited for making a definitive evaluation, e.g. (a) the evidence of carcinogenicity is restricted to a single experiment; (b) there are unresolved questions regarding the adequacy of the design, conduct or interpretation of the studies; etc.

Inadequate evidence in animal studies—The studies cannot be interpreted as showing either the presence or absence of a carcinogenic effect because of major qualitative or quantitative limitations, or no data on cancer in experimental animals are available

Evidence suggesting a lack of carcinogenicity in animal studies—Adequate studies involving at least two species are available which show that, within the limits of the tests used, the agent is not carcinogenic.

Figure 4. Basic IARC method for classifying exposures based on potential carcinogenicity

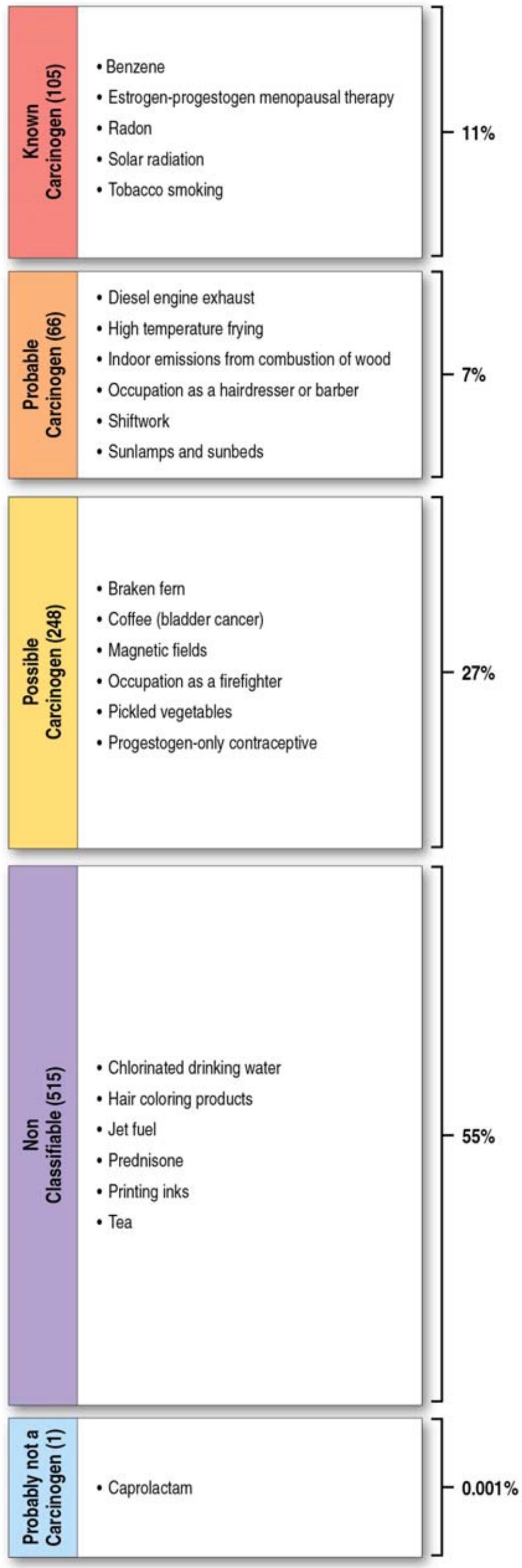

Figure 5. Percentage of substances classified in each IARC category with examples

2 Human Health Research

The following sections describe peer-reviewed research published between January 1, 2006 and March 20, 2009. A literature review was conducted to identify new epidemiologic, *in vivo* and *in vitro* research published on 50 or 60 Hz ELF-EMF. A large number of search strings referencing the exposure and diseases of interest, as well as authors that regularly publish in this area, were included as search terms in a database known as PubMed (http://www.ncbi.nlm.nih.gov/PubMed/).[7] A scientist with experience in this area reviewed the search results to identify relevant studies. This report focuses on the diseases that have received the most attention – cancer, reproductive or developmental effects, and neurodegenerative diseases. Many other health effects have been studied (suicide, depression, electrical hypersensitivity, cardiovascular effects, etc.), but for brevity and because research on these topics evolves slowly, these topics are not summarized here. The WHO report provides a good resource for the status of research on these additional health effects.

This update focuses on identifying and summarizing new epidemiologic and *in vivo* research, since this research is the most informative for risk assessment in this field; for the status of *in vitro* research, we include our discussion from the July 2007 report.

Cancer

Childhood leukemia

What was previously known about childhood leukemia and what did the WHO report conclude?

Scientific panels have concluded consistently that magnetic fields are a “possible carcinogen” largely because of findings from case-control studies of childhood leukemia. Since 1979, approximately 35 studies from the US, Canada, Europe, New Zealand and Asia have evaluated the relationship between childhood leukemia and some proxy of magnetic field exposure,

[7] PubMed is a service of the U.S. National Library of Medicine that includes over 17 million citations from MEDLINE and other life science journals for biomedical articles back to the 1950s. PubMed includes links to full text articles and other related resources.

including: long-term (48 hour) personal monitoring; spot or long-term (24 or 48 hours) measurements in structures and outdoors; calculations using loading, line configuration, and distance of nearby power installations to estimate historical, residential exposure; and wire code categories.[8] As a group of independent studies, they did not show a clear or consistent association between magnetic fields and childhood leukemia. The largest and most methodologically sound case-control studies to directly estimate magnetic field exposure did not report a consistent relationship, for example (Linet et al., 1997; McBride et al., 1999; UKCCS, 2000). When two independent pooled analyses combined the data from these case-control studies, however, an approximate 2-fold statistically significant association was observed between rare average magnetic field exposure above 3-4 mG and childhood leukemia (Ahlbom et al., 2000; Greenland et al., 2000); in other words, children with leukemia were about 2 times more likely to have had estimated magnetic field exposures above 3-4 mG. Average exposures at this level are rare; according to the WHO, results from several extensive surveys showed that approximately 0.5–7% of children had time-averaged exposures in excess of 3 mG and 0.4–3.3% had time-averaged exposures in excess of 4 mG (WHO, 2007a).

The most significant limitation of these studies is their methods for estimating exposure, in that (at best) spot or long-term measurements and calculations post-diagnosis are used to approximate cumulative exposure pre-diagnosis in the absence of any information on the etiologically relevant exposure metric or window. Most studies have used the time-weighted average (TWA) exposure metric, meaning the average of all exposures encountered over the day, but it is possible that other metrics may be more biologically relevant to disease causation, such as the percentage of time above a certain threshold or exposure to peak magnetic fields. Pooled analyses are limited because they combine data that was collected in very different ways. Since the individual epidemiology studies and the pooled analyses are limited in many ways (including the way that they estimate exposure), it is unclear whether this association is causal in nature – i.e., whether exposure to magnetic fields in the range of 3-4 mG has any relationship with the development of childhood leukemia or whether the association is simply a consequence of an error in the study's design. Furthermore, *in vivo* studies do not provide any evidence to suggest that the association is causal in nature: these studies have not indicated any consistent

[8] Wire code categories are categories used to classify the potential magnetic field exposures at residences based on the characteristics of nearby power installations.

increase in cancer in animals when they are exposed to high levels of magnetic fields over the course of their lifetime (see section "*In vivo* studies of carcinogenesis"), and there is no known mechanism by which magnetic fields cause cancer (see section "*In vitro* studies of carcinogenesis").

Since chance, bias and confounding could not be ruled out as an explanation for the association, the IARC concluded in 2002 that the data on childhood leukemia provided limited evidence of carcinogenicity. In 2007, the WHO reviewed studies published since the 2002 IARC review and concluded that the new epidemiologic studies were 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 (see Figure 4).[9]

Since it is unclear whether the association is real, the WHO report evaluated other factors that might be partially, or fully, responsible for the association, including: chance, control selection bias, confounding from hypothesized or unknown risk factors, and misclassification of magnetic field exposure, as noted below and exemplified in Figure 6. See page 8 for a description of these technical terms.

- ✓ The WHO report concluded that **chance** is an unlikely explanation since the pooled analyses had a larger sample size and decreased variability.

- ✓ **Control selection bias** occurs when the controls that decide to participate in the study do not represent the true exposure experience of the non-diseased population. In the case of magnetic fields, the WHO speculates that controls with a higher socioeconomic status (SES) may participate in studies more than lower SES controls and, since higher SES persons may have lower magnetic field exposures or tend to live farther from transmission lines, the control group's magnetic field exposure may be artificially low. Thus, when the exposure experience of the control group is compared to the case group, it appears that there is a difference between the case and control group. The WHO

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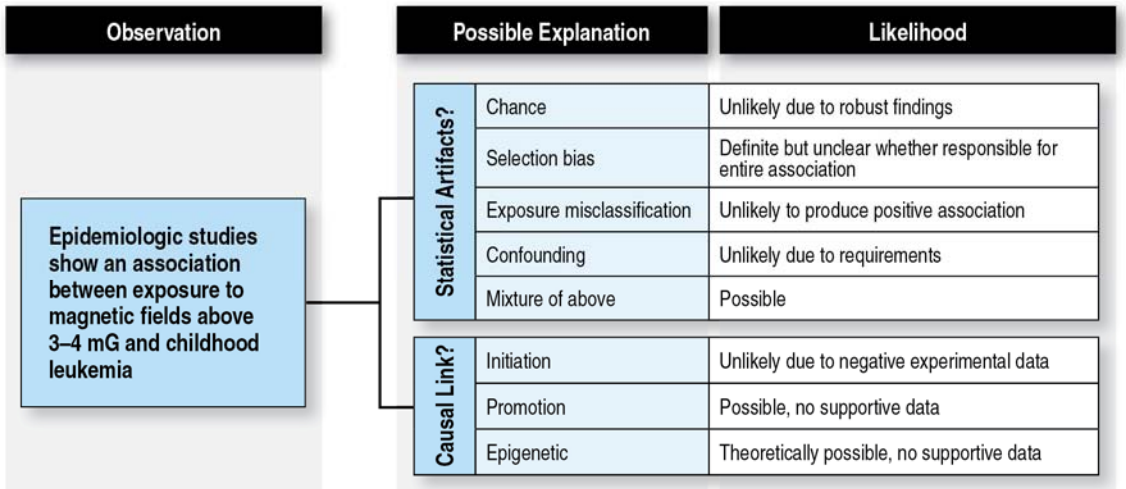
[9] The WHO concluded the following: "Consistent epidemiological evidence suggests that chronic low intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted" (p. 355-6, WHO, 2007a).

concluded that **control selection bias** is probably occurring in these studies and would result in an overestimate of the true association, but would not explain the entire observed statistical association

- ✓ The WHO panel concluded that it is less likely that **confounding** is causing the observed association, although the possibility that some yet-to-be identified confounder is responsible for the association cannot be fully excluded. Suggested risk factors that may be confounding the relationship include SES, residential mobility, contact currents, and traffic density.[10]

- ✓ The WHO stated that the possible effects of **exposure misclassification** are the most difficult to predict. EMF presents unique challenges in exposure assessment because it is ubiquitous, imperceptible, and has many sources (Kheifets and Oksuzyan, 2008). No target exposure or exposure window has been identified, and the numerous methods of estimating exposure likely result in a different degree of error within and between studies. Most reviews have concluded that exposure misclassification would likely result in an underestimate of the true association, meaning the association we observe is lower than the true value; however, the extent to which this might occur varies widely and is difficult to assess (Greenland et al., 2000). The WHO concluded that exposure misclassification is likely present in these studies, but is unlikely to provide an entire explanation for the association.

[10] For example, if dwellings near power lines encounter higher traffic density and pollution from traffic density causes childhood leukemia, traffic density may cause an observed association between magnetic field exposure and childhood leukemia.



Source: Adapted from Schüz and Ahlbom (2008)

Figure 6. Possible explanations for the observed association between magnetic fields and childhood leukemia

The WHO stated 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.

What relevant studies have been published since the WHO report?

Several relevant studies published after the WHO review (see Table 1) report statistically significant associations between estimates of magnetic field exposure and childhood leukemia, including reports of an association between childhood leukemia and magnetic field levels greater than approximately 6 mG in children genetically susceptible to leukemia (Mejia-Arangure et al., 2007) and greater than approximately 4 mG in children with poor outcomes following a leukemia diagnosis (Foliart et al., 2006, 2007; Svendsen et al., 2007). There was no consistent exposure-response relationship in these studies, however, and small numbers in the upper exposure categories limit the overall conclusions we can make about these studies.

In a pooled analysis of previously published studies, Schüz et al. (2007) evaluated the hypothesis that nighttime residential magnetic-field exposure may be a more biologically relevant exposure for leukemia risk. The authors observed associations between leukemia and nighttime exposures that were similar to those observed in the original pooled analyses of 24- and 48-hour exposures (Ahlbom et al., 2000), suggesting that nighttime exposure does not reduce exposure misclassification and result in a stronger association.

A relationship between residential distance within 500 meters of a power line and childhood leukemia was reported in a recent study in Iran (Feizi and Arabi, 2007). The validity of this study is limited significantly by its small size, possible selection bias, lack of assessment of possible confounding variables (such as SES and mobility), and reliance upon distance as a proxy for exposure. The WHO noted that distance is a poor proxy of magnetic field exposure[11] and a recent re-analysis of data from two case-control studies in the UK and Germany confirmed this statement. Maslanyj et al. (2009) reported that only 23% of homes in a 200-meter corridor of 220-440 kV lines had a magnetic field level above 2 mG. This finding calls into question the relevance of the associations reported in the large case-control study by Draper et al. in 2005 and in the later study by Feizi and Arabia. The fact that the association is observed at distances greater than where magnetic or electric fields from a transmission line could be measured and there is very little correlation between distance and magnetic field levels argues against magnetic fields as the explanation for the statistical association.

Most childhood leukemias are characterized by a genetic anomaly that can be identified prenatally, but not all children with these anomalies go on to develop childhood leukemia (Buffler et al., 2005). It has been suggested that other postnatal events (e.g., environmental or viral exposures) are necessary for childhood leukemia to occur, although little research has been done in this area. This hypothesis suggests that the association may be concentrated in subgroups of the population that have both the genetic anomaly and some other exposure.

[11] The WHO concluded the following, with respect to the Draper et al. (2005) 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, WHO 2007a).

The first study to examine a magnetic field-gene interaction in relation to childhood leukemia was published recently in China (Yang et al., 2008). They evaluated residential distance from power lines and the genetic variation of five genes associated with DNA repair in a group of children with childhood leukemia. The authors illustrated that a variation of one gene involved in DNA repair (but not four other genes) was more likely to be measured in children with leukemia living within 100 meters from a power line or transformer, compared to children with leukemia living at a farther distance. The significance of this finding is unknown and, as with all genetic epidemiology studies, the results cannot be deemed reliable until they are replicated. Several major limitations of the study are important to consider: (1) since this study enrolled only cases of childhood leukemia and no control group, the authors do not provide any information about the distribution of this DNA repair variation in children without leukemia and, as a result, no conclusions can be drawn about the relationship of this gene to childhood leukemia risk or etiology, (2) it is unknown what role (if any) DNA repair genes play in the development of childhood leukemia, and (3) distance is a poor proxy for magnetic field exposure. Although a positive association between distance and one specific gene was observed in this study, the results do not provide information to draw any conclusions about gene-magnetic field interactions in the etiology of childhood leukemia at this time. A study that could truly elucidate magnetic field-gene interactions has been proposed in the Danish National Birth Cohort (Greenland and Kheifets, 2009).

Mezei et al. (2008b) assessed the likelihood that control selection bias could be causing the observed association in a previously published study of childhood leukemia in Canada (McBride et al., 1999). This study evaluated whether there were differences between the controls that participated and the controls that did not participate in the 1999 study. The goal of the study was to assess whether the non-participating controls had a higher prevalence of some factor that made them more likely to have a higher magnetic field exposure than the participating controls and, thus, resulted in an under-representation of exposure prevalence in the control group and an overestimation of the risk estimate. The study suggested that control selection bias was operating to some extent, although the authors noted the inherent problems associated with estimating magnetic field exposure and, therefore, concluded, "the role of selection bias cannot entirely be dismissed on the basis of these results alone" (p. 1).

In response to the WHO recommendations to "focus on new aspects of exposure, potential interaction with other factors or on high exposure groups" (p. 17), some recent research has been innovative in the area of childhood leukemia and magnetic field exposure. These recent studies, like some early studies, have observed associations between estimates of high average magnetic field exposure/distance and childhood leukemia, although recent data suggests that control selection bias may play some role in this observed association. None of these recent studies are sufficiently strong methodologically, nor do the findings display causal patterns (exposure-response, consistency and strength) 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. The lack of evidence from recent *in vivo* research supports this conclusion (see section "*In vivo* studies of carcinogenicity" below).

This conclusion is supported by recent reviews (Kheifets and Oksuzyan, 2008; Schüz and Ahlbom, 2008) and the recent conclusions of scientific organizations (SSI, 2007; SSI, 2008; HCN, 2009; SCENIHR, 2009).

Do researchers investigating childhood leukemia consider magnetic fields a very important area of research?

Researchers will continue to investigate the magnetic field-childhood leukemia association. Magnetic fields, however, are just one area of study in the large body of research on the possible causes of childhood leukemia. There are many other hypotheses that are under investigation that point to possible genetic, environmental, and infectious explanations for childhood leukemia. There are other hypotheses with similar or stronger support in epidemiology studies; magnetic fields are one among many research priorities in the field of childhood leukemia (Ries et al., 1999; McNally and Parker, 2006; Belson et al., 2007; Rossig and Juergens, 2008).

Table 1. Relevant studies of childhood leukemia published after WHO report

Authors	Year	Study
Feizi and Arabi	2007	Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines – a risk factor in Iran
Foliart, et al.	2006	Magnetic field exposure and long-term survival among children with leukaemia.
Foliart, et al.	2007	Magnetic field exposure and prognostic factors in childhood leukemia.
Maslanyj, et al.	2009	Power frequency magnetic fields and risk of childhood leukaemia: Misclassification of exposure from the use of the distance from power line' exposure surrogate.
Mejia-Arangure, et al.	2007	Magnetic fields and acute leukemia in children with Down Syndrome.
Mezei, et al.	2008b	Assessment of selection bias in the Canadian case-control study of residential magnetic field exposure and childhood leukemia.
Svendsen, et al.	2007	Exposure to magnetic fields and survival after diagnosis of childhood leukemia: a German cohort study.
Schüz, et al.	2007	Nighttime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis.
Yang, et al.	2008	Case-only of interactions between DNA repair genes (hMLH1, APEX1, MGMT, XRCC1 and XPD) and low-frequency electromagnetic fields in childhood acute leukemia

Childhood brain cancer

What was previously known about childhood brain cancer and what did the WHO report conclude?

The research related to magnetic fields and childhood brain cancer has been less consistent than that observed for childhood leukemia. The WHO report recommended the following:

> As with childhood leukaemia, a pooled analysis of childhood brain cancer studies should be very informative and is therefore recommended. A pooled analysis of this kind can inexpensively provide a greater and improved insight into the existing data, including the possibility of selection bias and, if the studies are sufficiently homogeneous, can offer the best estimate of risk (p. 18, WHO 2007a).

What relevant studies have been published since the WHO report?

The two relevant studies of childhood brain cancer and magnetic field exposure are listed in Table 2 below. In response to the WHO recommendation, Mezei et al. (2008a) performed a meta-analysis of studies on childhood brain tumors and residential magnetic field exposure. 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. A sub-group of five studies, however, with information on childhood brain tumors and calculated or measured magnetic fields greater than 3-4 mG reported a combined OR that 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). Second, they stated that the similarity of this result to the findings of the pooled analyses of childhood leukemia suggests that control selection bias is operating in both analyses. 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.

Studies of parental occupational magnetic field exposure and childhood brain tumors have been inconsistent. In a pooled analysis of two Canadian case-control studies, Li et al. (2009) calculated individual maternal occupational magnetic field exposure pre- and post-conception and analyzed these estimates in relation to brain cancer in their offspring. The study provided some indication of an association with all brain cancer and average maternal occupational magnetic field exposure and confirmed a previously observed association with the occupation of seamstress. More research is required to understand if magnetic fields during or before pregnancy are related to the development of childhood brain cancer.

These two studies do not change the classification of the epidemiologic evidence as inadequate in relation to childhood brain cancer. Although the meta-analysis of brain cancer observed an association, it could not be distinguished from a chance finding.

Table 2. Relevant studies of childhood brain cancer published after WHO report

Authors	Year	Study
Li, et al.	2009	Maternal occupational exposure to extremely low frequency magnetic fields and the risk of brain cancer in the offspring.
Mezei et al.	2008a	Residential magnetic field exposure and childhood brain cancer: a meta-analysis.

Breast cancer

What was previously known about breast cancer and what did the WHO report conclude?

The WHO reviewed studies of breast cancer and residential magnetic field exposure, electric blanket usage, and occupational magnetic field exposure. These studies did not report consistent associations between magnetic field exposure and breast cancer, and the WHO concluded that, since the recent body of research was higher in quality compared with previous studies, it provided strong support to previous consensus statements that magnetic field exposure does not influence the risk of breast cancer.[12]

Breast cancer received particular attention because researchers hypothesized that it could be related to magnetic field exposure through a pathway involving the hormone melatonin. While this hypothesis was novel, it did not receive consistent or strong support from epidemiology or experimental studies. While research will continue in this area, scientific reviews have been strong in their conclusion that the part of this hypothesis linking magnetic fields to breast cancer is unlikely (NRPB, 2006; WHO, 2007a).

The WHO recommended no further research with respect to breast cancer and magnetic field exposure.

What relevant studies have been published since the WHO report?

Two case-control studies have recently been published, both of which qualitatively estimated occupational magnetic field exposure among breast cancer cases and compared it to controls.[13] 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, and McElroy et al. (2007) evaluated occupational exposures to high, low, medium, or background EMF levels in a large number of breast cancer cases and controls. Neither study observed a significant association between breast cancer and higher estimated magnetic field exposure. A large cohort study of utility workers in Denmark also recently reported that women exposed to higher occupational magnetic field levels did not have higher rates of breast cancer (Johansen et al., 2007).

[12] The WHO concluded, "Subsequent to the IARC monograph a number of reports have been published concerning the risk of female breast cancer in adults associated with ELF magnetic field exposure. These studies are larger than the previous ones and less susceptible to bias, and overall are negative. With these studies, the evidence for an association between ELF exposure and the risk of breast cancer is weakened considerably and does not support an association of this kind" (p. 307, WHO 2007a).

[13] Peplonska et al. (2007) is a case-control study of female breast cancer reporting associations for a wide range of occupations and industries. It is not considered in depth in this report because no qualitative or quantitative estimates of magnetic field exposure were made, beyond occupation and industry titles.

These studies, particularly the large cohort of utility workers, add to growing support against a role for magnetic fields in breast cancer. This is consistent with the recent conclusion by the SCENIHR, which stated that the association is "unlikely" (p. 7, SCENIHR 2007).

Table 3. Relevant studies of breast cancer published after WHO report

Authors	Year	Study
Johansen, et al.	2007	Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up.
McElroy, et al.	2007	Occupational exposure to electromagnetic field and breast cancer risk in a large, population-based, case-control study in the United States.
Ray, et al.	2007	Occupational exposures and breast cancer among women textile workers in Shanghai.

Other adult cancers

What was previously known about other adult cancers and what did the WHO report conclude?

In general, scientific panels have concluded that there is not a strong or consistent relationship between other adult cancers (leukemia, lymphoma, or brain cancers) and exposure to magnetic fields; however, the possibility cannot be entirely ruled out because the findings have been inconsistent (IARC, 2002; WHO 2007a). The fact that stronger findings have not been observed in studies with better exposure assessment methods has led the scientific panels to conclude that the evidence for an association is weak and the observed inconsistency is probably due to chance or bias. The IARC classified the epidemiologic data with regard to adult leukemia, lymphoma and brain cancer as "inadequate" in 2002, and the WHO confirmed this classification in 2007, with the remaining uncertainty attributed mainly to limitations in exposure assessment methods.

Much of the research on EMF and adult cancers is related to occupational exposures, given the higher range of exposures encountered in the occupational environment. The main limitation of these studies, however, has been the methods used to assess exposure, with early studies relying simply on a person's occupational title (often taken from a death certificate) and later studies linking a person's full or partial occupational history to representative average exposures for each occupation (i.e., a job exposure matrix). The latter method, while advanced, still has some important limitations, as highlighted recently in a review summarizing an expert panel's findings by Kheifets et al. (2009).[14] While a person's occupation may provide some indication of the overall magnitude of their occupational magnetic field exposure, it does not take into account the possible variation in exposure due to different job tasks within occupational titles, the frequency and intensity of contact to relevant exposure sources, or variation by calendar time. Furthermore, since scientists do not know any mechanism by which magnetic fields could lead to cancer, an appropriate exposure metric is unknown.

Therefore, in order to reduce the remaining uncertainty about whether there is an association between magnetic fields and these cancers, researchers have recommended (1) meta-analyses to clarify the inconsistency of the data and (2) better exposure assessment methods that incorporate a greater level of detail on tasks and exposure characteristics such as spark discharge, contact current, harmonics, etc. (WHO, 2007a; Kheifets et al., 2009).

Adult brain cancer

What was previously known about adult brain cancer and what did the WHO report conclude?

As described above, the WHO classified the epidemiologic data on adult brain cancer as inadequate[15] and recommended (1) updating the existing cohorts of occupationally-exposed individuals in Europe and (2) pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

What relevant studies have been published since the WHO report?

Epidemiologic studies published after 2006 on adult brain cancer and EMF exposure are listed in Table 6 and include two case-control studies, two cohort studies, and a meta-analysis, all of which are related to occupational magnetic field exposure.

In response to the WHO recommendation, two cohorts of approximately 20,000 occupationally-exposed persons each were updated: a cohort of utility workers in Denmark and a cohort of

[14] Kheifets et al. (2009) reports on the conclusions of an independent panel organized by the Energy Networks Association in the UK in 2006 to review the current status of the science on occupational EMF exposure and identify the highest priority research needs.

[15] 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, WHO 2007a).

railway workers in Switzerland (Johansen et al., 2007; Röösli et al, 2007a). In both cohorts, brain cancer rates were similar between jobs with high magnetic field exposure and jobs with lower exposures. A case-control study of gliomas was conducted in Australia and reported no associations with higher estimated magnetic field exposure, using a standard job-exposure matrix (Karipidis et al., 2007a). Forssén et al. (2006) performed a large registry-based case-control study of acoustic neuroma and reported no association between higher occupational magnetic field exposures and this benign and rare brain cancer type. Another large case-control study was recently published of gliomas and meningiomas in the United States (Coble et al., 2009). For the first time, the exposure metric in this study incorporated the frequency of exposure to EMF sources, as well as the distance people worked from these sources, on an individual basis. The authors also evaluated exposure metrics aside from TWA exposure (maximum exposed job, total years of exposure above 1.5 mG, cumulative lifetime exposure, and average lifetime exposure). No association was reported between any of these exposure metrics and brain cancer.

As recommended in the WHO report, a meta-analysis of occupationally exposed cohorts was performed by Khefeits et al. (2008). All relevant publications of occupational EMF exposure and adult leukemia or brain cancer were collected and summary risk estimates were calculated using various schemes to weight and categorize the study data. The authors reported a small and statistically significant increase of leukemia and brain cancer in relation to the highest estimate of magnetic field exposure in the individual studies. Several findings, however, led the authors to conclude that magnetic field exposure is not responsible for the observed associations with leukemia and brain cancer, including the lack of a consistent pattern among leukemia subtypes when the past and new meta-analyses were compared. In addition, for brain cancer, the recent meta-analysis reported a weaker estimated association than the previous meta-analysis, whereas a stronger association would be expected since the quality of studies has increased over time. The authors concluded, "the lack of a clear pattern of EMF exposure and outcome risk does not support a hypothesis that these exposures are responsible for the observed excess risk" (p. 677).

Recent studies have reduced possible exposure misclassification by improving exposure assessment methods (i.e., the expanded job-exposure matrix in Coble et al., 2009) and attempted to clarify inconsistencies by updating studies and meta-analyzing data (Johansen et al., 2007; Röösli et al., 2007a; Kheifets et al., 2008); however, despite these advancements, no association has been observed. While an association still cannot be *entirely* ruled out because of the remaining deficiencies in exposure assessment methods, the current database of studies provides weak evidence of an association between magnetic fields and brain cancer.[16] The lack of evidence from *in vivo* research supports this conclusion (see section "*In vivo* studies of carcinogenicity" below). The recent report by the SCENIHR described the data on brain cancers as "uncertain" (p. 43, SCENIHR 2009).

Table 4. Relevant studies of adult brain cancer published after WHO report

Authors	Year	Study
Coble et al.	2009	Occupational exposure to magnetic fields and the risk of brain tumors.
Forssén et al.	2006	Occupational magnetic field exposure and the risk of acoustic neuroma.
Johansen et al.	2007	Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up.
Karipidis et al.	2007a	Occupational exposure to low frequency magnetic fields and the risk of low grade and high grade glioma.
Kheifets et al.	2008	Occupational electromagnetic fields and leukemia and brain cancer: An update to two meta-analyses.
Röösli et al.	2007a	Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees.

Adult leukemia and lymphoma

What was previously known about adult leukemia/lymphoma and what did the WHO report conclude?

The same issues discussed above with regard to adult brain cancer are relevant to research on adult leukemia/lymphoma. The WHO classified the epidemiologic evidence as "inadequate" and recommended updating the existing occupationally exposed cohorts in Europe and the meta-analysis on occupational magnetic field exposure[17] (p. 307, WHO 2007a).

What relevant studies have been published since the WHO report?

Two cohorts of occupationally exposed workers and a meta-analysis of occupational magnetic field exposure (all of which were described above) reported on the possible association of

[16] A recent consensus statement by the National Cancer Institute's Brain Tumor Epidemiology Consortium confirms this statement. They classified residential power frequency EMF in the category "probably not risk factors" and described the epidemiologic data as "unresolved" (p. 1958, Bondy et al., 2008).

[17] No specific conclusions were provided by the WHO with regard to lymphoma.

occupational magnetic field exposure and adult leukemia. Also, a case-control study described patterns of estimated residential magnetic field exposure and combined lymphoma and leukemia diagnostic categories.

In the occupational cohort of Swiss railway workers, the authors noted a stronger association among occupations with higher estimates of magnetic field exposures, but the associations were not statistically significant (Röösli et al, 2007a). In the study of Danish utility workers, no increases in leukemia rates were observed in job titles that involved higher exposures to magnetic fields (Johansen et al., 2007). As described above, the updated meta-analysis by Kheifets et al. (2008) reported a weak association between estimated occupational magnetic field exposure and leukemia, but the authors felt that the data was not indicative of a true association.

Lowenthal et al. (2007) grouped cases in five diagnostic categories as lymphoproliferative disorders (LPD) (including acute lymphoblastic leukemia [ALL]) and cases in three diagnostic categories (including acute myeloid leukemia [AML] and other leukemias) 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, and 220-kV power lines. They reported elevated, but not statistically significant, ORs for those who lived within 50 meters of any of these power lines, and an indication of decreasing ORs with increasing distance. This study adds very little to the existing database of information on adult leukemia and residential exposure, however, because of fundamental limitations. For example, different cancer types were combined and for different ages of diagnosis. It is well known that cancer etiology varies by cancer type, cancer subtype and diagnostic age.

Very little is known about the etiology of Non-Hodgkin lymphoma (NHL) in general and few studies have been conducted in relation to magnetic field exposure. In one of the first studies to estimate cumulative occupational magnetic field exposure among NHL cases, Karipidis et al. (2007b) reported a statistically significant association between NHL and the highest category of exposure (OR=1.59, 95% CI=1.07-2.36). Overall, the study was well conducted, with its most significant limitation being the possibility of uncontrolled confounding. Since this is one of the first studies on NHL and magnetic field exposure, further research is required. Of note, the cohort of railway workers in Switzerland did not report an increase in NHL deaths among the more highly exposed workers (Röösli et al, 2007a).

The recent literature also includes a novel study examining whether there are differences in the activity of the natural killer (NK) cell, which is known to control cancer development, among persons occupationally exposed to magnetic fields (Gobba et al., 2008). Higher measured magnetic field levels during three complete work shifts (i.e., > 10 mG) were associated with reduced NK activity. This is suggests a cancer-causing mechanism, but future studies are required to replicate this finding and understand the significance of NK activity in cancer causation.

Recent studies of adult leukemia have attempted to clarify inconsistencies by updating studies and meta-analyzing data (Johansen et al., 2007; Kheifets et al., 2008; Röösli et al, 2007a); however, despite these advancements, no clear or statistically significant association has been observed. While an association still cannot be *entirely* ruled out because of the remaining deficiencies in exposure assessment methods, the current database of studies provides weak evidence of an association between magnetic fields and leukemia. The lack of evidence from *in vivo* research (see section "*In vivo* studies of carcinogenicity" below) supports this conclusion. Preliminary results related to NHL have been published and require further investigation, although *in vivo* research does not suggest a relationship between lymphoma and magnetic fields.

Table 5. Relevant studies of adult leukemia/lymphoma published after WHO report

Authors	Year	Study
Gobba et al.	2008	Extremely low frequency-magnetic fields (ELF-EMF) occupational exposure and natural killer activity in peripheral blood lymphocytes.
Johansen et al.	2007	Risk for leukaemia and brain and breast cancer among Danish utility workers: A second follow-up.
Karipidis et al.	2007b	Occupational exposure to power frequency magnetic fields and risk of non-Hodgkin lymphoma
Lowenthal et al.	2007	Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study.
Röösli et al.	2007a	Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees.

In vivo studies of carcinogenesis

What was previously known about *in vivo* studies of carcinogenesis and what did the WHO report conclude?

It is standard procedure to conduct studies on 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, including those 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-carcinogenetic 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; Boorman et al., 1999a, b; McCormick et al., 1999). No directly relevant animal model for childhood ALL existed at the time of the WHO report. Some animals, however, develop a type of lymphoma similar to childhood ALL and studies exposing transgenic mice predisposed to this lymphoma to ELF magnetic fields did not report an increased incidence of lymphoma (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 7,12-dimethylbenz[a]anthracene (DMBA)-induced mammary tumors was increased with magnetic field exposure in a series of experiments in Germany (Löscher et al., 1993, 1994, 1997; Baum et al., 1995; Löscher and Mevissen, 1995; Mevissen et al., 1993a,b, 1996a,b, 1998), suggesting that magnetic field exposure increased the proliferation of mammary tumor cells. These results were not replicated in subsequent series of experiments in a US laboratory (Anderson et al., 1999; Boorman et al.1999a,b; NTP, 1999), possibly due to differences in experimental protocol and the species strain. In Fedrowitz et al. (2004), exposure enhanced mammary tumor development in one sub-strain (Fischer 344 rats), but not in another sub-strain that was obtained from the same breeder, which argues against a promotional effect of magnetic fields.[18]

Some studies have 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 the following with respect to *in vivo* research: "There 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. 322, WHO 2007a). Recommendations for future research included the development of a rodent model for childhood ALL and the continued investigation of whether magnetic fields can act as a promoter or co-carcinogen.

What relevant studies have been published since the WHO report?

Pursuant to the WHO recommendation and in view of the available evidence that exposure to magnetic fields *alone* does not increase the occurrence of cancer, the literature published following the WHO report includes numerous *in vivo* studies testing different hypotheses of cancer promotion, including effects on brain cancer (Chung et al., 2008), breast cancer (Fedrowitz and Löscher, 2008), and lymphoma/leukemia (Bernard et al., 2008; Negishi et al., 2008), as referenced below. In each of these studies, the animals were treated first with chemicals known to initiate the cancer process in cells. Initiated animals are more likely to develop cancer, and a subsequent exposure, known as a promoter, is often needed for an initiated cell to reproduce into many cancer cells. Recent studies first treated the animals with the initiators ethylnitrosourea (ENU) (Chung et al., 2008), n-butylnitrosourea (BNU) (Bernard et al., 2008), or DMBA (Fedrowitz and Löscher, 2008; Negishi et al., 2008). An additional

[18] The WHO concluded with respect to the German studies of mammary carcinogenesis, "Inconsistent results were obtained that may be due in whole or in part to differences in experimental protocols, such as the use of specific substrains" (p. 321, WHO 2007a).

study by Sommer and Lerchel (2006) tested whether magnetic fields alone increased the incidence of lymphoma in mice virally predisposed to lymphoblastic lymphoma.

Chung et al. (2008) examined the possible role of 60 Hz magnetic fields in promoting brain tumors initiated by ENU injections *in utero*; the authors concluded that there was no evidence from this study that 60 Hz magnetic field exposures up to 5,000 mG promoted tumor development.

Fedrowitz and Löscher (2008) is the most recent study from the German laboratory that previously reported increases in DMBA-induced mammary tumors with high magnetic field exposure. In this recent study, the researchers exposed DMBA-treated Fischer 344 rats (the strain of inbred rats used in previous experiments) to either high levels of magnetic fields (1,000 mG) or no exposure for 26 weeks and reported that the incidence of mammary tumors was significantly elevated in the group exposed to magnetic fields (Fedrowitz and Löscher, 2008). No independent replication of this experiment has yet occurred and questions still remain about the effect of experimental protocol and species strain.

Sommer and Lerchl (2006) is a follow-up to an earlier study (Sommer and Lerchl, 2004) that reported no increases in lymphoma among predisposed animals chronically exposed to magnetic fields (up to 1,000 mG for 24 hours per day for 32 weeks). Sommer and Lerchl (2006) increased magnetic field exposure to 10,000 mG and exposed some of the animals only during the night to test the hypothesis that nighttime exposure may have a stronger effect than continuous exposure. Magnetic fields did not influence body weight, time to tumor, cancer incidence, or survival time in this study. In another study of lymphatic system cancers, researchers treated newborn mice with DMBA and magnetic fields up to 3,500 mG (Negishi et al., 2008). The authors reported that the percentage of mice with lymphoma/lymphatic leukemia was not higher in magnetic field-exposed groups, compared to the sham-exposed group.

A recent study by Bernard et al. (2008) provides a significant development, in that it is the first study to use an animal model of ALL, the leukemia type that has been associated with high magnetic field exposure in children. All rats were exposed to BNU to initiate the leukemogenic process, and a sub-group of rats was exposed to 1,000 mG 18 hours per day for 52 weeks. No difference in leukemia incidence was observed between the BNU-treated group exposed to magnetic fields and the BNU-treated unexposed group. This study supports the hypothesis that magnetic fields do not affect the development of ALL and provides additional support to the conclusion that experimental data is not supportive for a role of magnetic fields in the incidence of childhood leukemia. The researchers followed guidelines for the experimentation and care of laboratory animals and conducted the analyses blind to the treatment group. Experience with this strain of rat is limited, however, so it is unclear whether the results are more or less reliable than other animal models; replication is required.

Thus, aside from the most recent replication of enhanced mammary carcinogenesis in a specific sub-strain of rats in a German laboratory, recent studies provide further evidence against a role for magnetic fields as a co-carcinogen (i.e., agents that enhance the effect of known carcinogens). These studies strengthen the conclusion that there is inadequate evidence of carcinogenicity from *in vivo* research, although independent confirmation of the German results is of high priority.

Table 6. Relevant *in vivo* studies of carcinogenesis published after WHO report

Authors	Year	Study
Bernard et al.	2008	Assessing the potential Leukemogenic effects of 50 Hz and their harmonics using an animal leukemia model.
Chung et al.	2008	Lack of a co-promotion effect of 60 Hz rotating magnetic fields on n-ethyl-n-nitrosourea induced neurogenic tumors in F344 rats.
Fedrowitz and Löscher	2008	Exposure of Fischer 344 rats to a weak power frequency magnetic field facilitates mammary tumorigenesis in the DMBA model of breast cancer.
Negishi et al.	2008	Lack of promotion effects of 50 Hz magnetic fields on 7,12-dimethylbenz(a)anthracene-induced malignant lymphoma/lymphatic leukemia in mice
Sommer and Lerchl	2006	50 Hz magnetic fields of 1 mT do not promote lymphoma development in AKR/J mice.

In vitro studies of carcinogenesis

What did the WHO and other scientific panels conclude with respect to *in vitro* studies of carcinogenesis?

In vitro studies are widely used to investigate the mechanisms for effects that are observed in humans and animals. The relative value of *in vitro* tests to human health risk assessment, however, is much less than that of *in vivo* and epidemiology 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; Ivancsits et al., 2003a,b). These findings have not been replicated by other laboratories (Scarfi et al., 2005), and the WHO recommended continued research in this area. Recently, investigators reported that they were unable to confirm any evidence for damage to DNA in cells exposed to magnetic fields over a range of exposures from 50 to 10,000 mG (Burdak-Rothkamm et al., 2009). 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 SSI, however, 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, according to the WHO (p. 347, WHO, 2007a).

Reproductive and developmental effects

What was previously known about reproductive and developmental effects and what did the WHO report conclude?

Two studies received considerable attention because of a reported association between peak magnetic field exposure greater than approximately 16 mG and miscarriage: a prospective cohort study of women in early pregnancy (Li et al., 2002) and a nested case-control study of women who miscarried compared to their late-pregnancy counterparts (Lee et al., 2002).

These two studies improved on the existing body of literature because average exposure was assessed using 24-hour personal magnetic field measurements (early studies on miscarriage were limited because they used surrogate measures of exposure, including visual display terminal use, electric blanket use or wire code data). Following the publication of these two studies, however, a hypothesis was put forth that the observed association may be the result of behavioral differences between women with "healthy" pregnancies that went to term (less physically active) and women who miscarried (more physically active) (Savitz, 2002). It was proposed that physical activity is associated with an increased opportunity for peak magnetic field exposures, and the nausea experienced in early, healthy pregnancies and the cumbersomeness of late, healthy pregnancies would reduce physical activity levels, thereby decreasing the opportunity for exposure to peak magnetic fields. Furthermore, nearly half of the miscarriages reported in the cohort by Li et al. had magnetic field measurements taken after miscarriage occurred, when changes in physical activity may have already occurred, and all measurements in Lee et al. occurred post-miscarriage.

The scientific panels that have considered these two studies concluded that the possibility of this bias precludes making any conclusions about the effect of magnetic fields on miscarriage (NRPB, 2004; FPTRPC, 2005; WHO, 2007a). The WHO concluded, "There is some evidence for increased risk of miscarriage associated with measured maternal magnetic field exposure, but this evidence is inadequate" (p. 254, WHO 2007a). The WHO stated that, given the potentially high public health impact of such an association, further epidemiologic research is recommended.

What relevant studies have been published since the WHO report?

No new original studies on magnetic field exposure and miscarriage have been conducted; however, recent methodological studies evaluated the likelihood that the observed association was due to the proposed bias.

It is not possible to directly "test" for the effects of this bias in the original studies, but two recent analyses examined whether reduced physical activity was associated with a lower probability of encountering peak magnetic fields (Mezei et al., 2006; Savitz et al., 2006). In a seven-day study of personal magnetic field measurements in 100 pregnant women, Savitz et al. reported that active pregnant women were more likely to encounter peak magnetic fields. In addition, an analysis by Mezei et al. of pre-existing databases of magnetic field measurements among pregnant and non-pregnant women found that increased activity levels were associated with peak magnetic fields (Mezei et al., 2006). These findings are broadly supportive of the hypothesis that reduced activity among women in early pregnancies because of nausea and in later pregnancies because of cumbersomeness may explain the observed association between peak magnetic fields and miscarriage. As noted in a recent commentary on this issue, however, the possibility that there is a relationship between peak magnetic field exposure and miscarriage still cannot be excluded and further research that accounts for this possible bias should be conducted (Neutra and Li, 2008; Mezei et al., 2006). There remains no biological basis to indicate that magnetic field exposure increases the risk of miscarriage (WHO, 2007a).

An additional study was recently published related to developmental outcomes. Fadel et al. (2006) conducted a cross-sectional study in Egypt of 390 children 0-12 years of age living in an area within 50 meters of an electrical power line and 390 children 0-12 years of age living in a region with no power lines in close proximity. Measurements were taken as proxies of growth retardation, and radiological assessments were performed on carpal bones. 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. The authors concluded that "exposure to low frequency electromagnetic fields emerged [*sic*] from high voltage electric power lines increases the incidence of growth retardation among children" (p. 211). However, this conclusion fails to adequately take into account the many limitations of their cross-sectional analysis (namely, inadequate control for the possible confounding effects of nutritional and SES status) and the pre-existing body of literature, which does not support such an association (WHO, 2007a).

The recent research does not provide sufficient evidence to alter the conclusion that the evidence for developmental or reproductive effects is inadequate. Recent studies of animals *in vivo* also do not provide evidence to change the conclusions expressed by the WHO (Al-Akhras et al., 2006; Anselmo et al., 2006; Okundan et al., 2006; Kim et al., 2009).

Table 7. Relevant studies of reproductive and developmental effects published after WHO report

Authors	Year	Study
Al-Akhras et al.	2006	Influence of 50 Hz magnetic field on sex hormones and other fertility parameters of adult male rats.
Anselmo et al.	2006	Influence of a 60 Hz, 3 microT, electromagnetic field on the reflex maturation of Wistar rats offspring from mothers fed a regional basic diet during pregnancy.
Fadel et al.	2006	Growth assessment of children exposed to low frequency electromagnetic fields at the Abu Sultan area in Ismailia (Egypt).
Kim et al.	2009	Effects of 60 Hz 14 µT magnetic field on the apoptosis of testicular germ cell in mice.
Mezei et al.	2006	Analyses of magnetic-field peak-exposure summary measures.
Okundan et al.	2006	DEXA analysis on the bones of rats exposed in utero and neonatally to static and 50 Hz electric fields.
Savitz et al.	2006	Physical activity and magnetic field exposure in pregnancy.

Neurodegenerative disease

What was previously known about neurodegenerative disease and what did the WHO report conclude?

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 disease studies prompted the NRPB to conclude that there is "only weak evidence to suggest that it [ELF magnetic fields] could cause Alzheimer's disease" (p. 20, NRPB, 2001). 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. Rather, they felt that an alternative explanation (i.e., electric shocks received at work) may be the source of the observed association.

The majority of the more recent studies discussed by the WHO reported statistically significant 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).

Furthermore, there was no biological data to support an association between magnetic fields and neurodegenerative diseases. The WHO panel concluded that there is "inadequate" data in support of an association between magnetic fields and Alzheimer's disease or ALS.[19] The panel recommended more research in this area using better methods; in particular, studies that enrolled incident Alzheimer's disease cases (rather than ascertaining cases from death certificates) and studies that estimated electrical shock history in ALS cases were recommended.

What relevant studies have been published since the WHO report?

Numerous studies have been published since the WHO report. Two occupational cohorts were followed for neurodegenerative diseases – approximately 20,000 railroad workers in Switzerland (Röösli et al., 2007b) and over 80,000 electrical and generation workers in the UK (Sorahan and Kheifets, 2007). Two case-control studies collected incident cases of Alzheimer's disease and estimated occupational magnetic field exposure (Davanipour et al., 2007; Seidler et al., 2007), and a meta-analysis was conducted of occupational magnetic field exposure and Alzheimer's disease studies (García et al., 2008). The first study of non-occupational exposure followed the Swiss population to evaluate associations with residential distance to power lines and death due to neurodegenerative diseases (Huss et al., 2009).

García et al. (2008) identified 14 epidemiologic studies with information on Alzheimer's disease and occupational EMF exposure; the WHO considered the majority of these studies in their 2007 review. A statistically significant association between Alzheimer's disease 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).

[19] After considering the entire body of literature and its limitations, the WHO report concluded, "When evaluated across all the studies, there is only very limited evidence of an association between estimated ELF exposure and [Alzheimer's] disease risk" (p. 194, WHO 2007a).

The authors concluded that their results suggest an association between Alzheimer's disease 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.

An earlier publication by the same group of investigators documented the relatively poor quality of the studies included in the meta-analysis. Santibáñez et al. (2007) evaluated studies related to occupational exposures and Alzheimer's disease, which included seven of the studies in the García et al. meta-analysis. Two epidemiologists blindly evaluated each of these studies using a questionnaire to assess the possibility of a number of biases, with a score assigned to each study that represents the percentage of possible points that the study obtained (range 0 – 100%). Only one of the seven studies obtained a score above 50% (a retrospective cohort study by Savitz et al. in 1998), and disease and exposure misclassifications were the most prevalent biases.

Davanipour et al. (2007) extended the early hypothesis-generating study by Sobel et al. (1996) by collecting cases from eight California Alzheimer's Disease Diagnostic and Treatment Centers. Self-reported primary occupation was collected from patients with 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. The strengths of this study included its large size and self-reported occupational information. The main limitation of this study 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.

Seidler et al. (2007) conducted a similar case-control study in Germany, except cases included all types of dementia (55% of which had Alzheimer's disease). Cumulative magnetic field exposure was estimated from occupational histories taken from proxy respondents, and no difference was reported between cases of dementia or probable Alzheimer's disease and controls, although an association was reported among electrical and electronics workers. The authors reported that exposure misclassification was likely to be a significant problem, and concluded that their results indicate a strong effect of low-dose EMF is "rather improbable" (p. 114).

Death from several neurodegenerative conditions was also evaluated in the cohort of more than 20,000 Swiss railway workers described above (Röösli et al., 2007b). Magnetic field exposure was characterized by specific job titles as recorded in employment records; stationmasters 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 stationmasters and train drivers. Cumulative magnetic field exposure was also estimated 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 [HR]=3.15, 95% CI=0.90-11.04); an association was observed between cumulative magnetic field exposure and Alzheimer's disease/senile dementia. 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 recent exposure was more strongly associated with Alzheimer's disease than past exposure.

There are several strengths of this study relative to the existing body of data. First, there is little turnover among Swiss railway employees, which means that study participants are enrolled in the cohort and possibly exposed for long periods of time. The wide variation in exposure levels between different occupations in the same industry allows for comparison of similar workers with different levels of exposure. Another advantage is that the company kept detailed registers of employees, which means that there is less potential for bias in the enumeration of the cohort and reconstruction of exposures. Finally, the authors reported that exposures to chemicals or electric shocks, which often occur in other occupational settings (for example, in electric utility workers or welders), are rare in this occupation.

Sorahan and Kheifets (2007) followed a cohort of approximately 84,000 electrical and generation workers in the UK 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 UK 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 US (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.

Another cohort study conducted in Switzerland linked all persons older than 30 years of age at the 2000 census with a national database of death certificates from 2000 through 2005 (Huss et al., 2009). Residential location was also extracted from 1990 and 2000 census data and the closest distance of a person's home in 2000 to nearby 220-380 kV transmission lines was calculated. The authors reported that persons living within 50 meters of these high-voltage transmission lines were more likely to have died from Alzheimer's disease, compared to those living farther than 600 meters, although chance could not be ruled out as an explanation (HR=1.24, 95% CI=0.80-1.92). The association was stronger for persons that lived at the residence for at least 15 years (HR=2.00, 95% CI=1.21-3.33). Associations of similar magnitude were reported for senile dementia and residence within 50 meters of a high-voltage line. No associations were reported beyond 50 meters for Alzheimer's disease or senile dementia, and no associations were reported at any distance for Parkinson's disease, ALS, or multiple sclerosis.

The study's main limitation is the use of residential distance from transmission lines as a proxy for magnetic-field exposure (Maslanyj et al, 2009). It is also limited by the use of death certificate data, which are known to under-report Alzheimer's disease, and the lack of a full residential and occupational history. Furthermore, while the underlying cohort was very large, relatively few cases of Alzheimer's disease lived within 50 meters of a high-voltage transmission line – 20 cases total and 15 cases who lived at the residence for at least 15 years. This means that misclassification of a small number of cases could have a large impact on the risk estimate.

In summary, two cohort studies of the Swiss population of relatively high quality were recently followed for death due to neurodegenerative disease. Röösli et al. (2007b) reported an association between Alzheimer's disease/senile dementia and occupational magnetic-field exposure, while Huss et al. (2009) reported an association between Alzheimer's disease/senile dementia and living within 50 meters of a high-voltage transmission line for at least 15 years. Neither study reported an association with any other neurodegenerative disease, including ALS. A cohort of utility workers, however, did not confirm an association with Alzheimer's disease mortality and magnetic field exposure. The meta-analysis and supporting evaluation of study quality by García, Santibáñez and colleagues confirmed that the associations reported in previous occupational studies are highly inconsistent and the studies have many limitations (Santibáñez et al., 2007; García et al., 2008).

The main limitations of these studies include the difficulty in diagnosing Alzheimer's disease; the difficulty of identifying a relevant exposure window given the long and nebulous course of this disease; the difficulty of estimating magnetic field exposure prior to appearance of the disease; the under-reporting of Alzheimer's disease on death certificates; crude exposure evaluations that are often based on the recollection of occupational histories by friends and family given the cognitive impairment of the study participants; and the lack of consideration of both residential and occupational exposures or confounding variables.

The recent epidemiologic studies do not alter the conclusion that there is "inadequate" data on Alzheimer's disease or ALS. While a good number of studies have been published since the WHO report, little progress has been made on clarifying these associations. Further research is still required, particularly on electrical occupations and ALS (Kheifets et al., 2008). There is currently no body of *in vivo* research to suggest an effect, and a recent study reported no effect of magnetic fields on ALS progression (Poulletier de Gannes et al., 2008). These conclusions are consistent with the recent review by the SCENIHR (SCENIHR, 2009).

Table 8. Relevant studies of neurodegenerative disease published after WHO report

Authors	Year	Study
Davanipour et al.,	2007	A case-control study of occupational magnetic field exposure and Alzheimer's disease: results from the California Alzheimer's Disease Diagnosis and Treatment Centers.
García, et al.	2008	Occupational exposure to extremely low frequency electric and magnetic fields and Alzheimer disease: a meta-analysis.
Huss, et al.	2009	Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population.
Poulletier de Gannes et al.	2008	Amyotrophic lateral sclerosis (ALS) and extremely-low frequency (ELF) magnetic fields: a study in the SOD-1 transgenic mouse model.
Röösli, et al.	2007b	Mortality from neurodegenerative disease and exposure to extremely low-frequency magnetic fields: 31 years of observations on Swiss railway employees.
Santibáñez, et al.	2007	Occupational risk factors in Alzheimer's disease: a review assessing the quality of published epidemiological studies.
Seidler et al.	2007	Occupational exposure to low frequency magnetic fields and dementia: a case-control study.
Sorahan and Kheifets	2007	Mortality from Alzheimer's, motor neurone and Parkinson's disease in relation to magnetic field exposure: findings from the study of UK electricity generation and transmission workers, 1973-2004.

3 Possible Effects of ELF Electric and Magnetic Fields on Implanted Cardiac Devices

The sensing system of pacemakers and other implanted cardiac devices (ICD) is designed to be responsive to the heart's electrical signal. For this reason, other electrical signals can potentially interfere with the normal functioning of pacemakers and ICDs, a phenomenon called electromagnetic interference (EMI). Most sources of EMF are too weak to affect a pacemaker or ICD; however, EMF from certain sources, e.g., some appliances and industrial equipment, may cause interference. This section considers potential electromagnetic interference with implanted cardiac devices such as pacemakers and defibrillators.

In the presence of electromagnetic fields, devices can respond in different ways, defined as modes. The likelihood of interference occurring, and the mode of the response depend on the strength of the interference signal, the patient's orientation in the electromagnetic field, the exact location of the device and the variable parameters of the device that are specific to a patient. Experimental research has been conducted to assess whether interference may occur when currents are induced in the patient's body by environmental electric and magnetic fields.

We performed an extensive search on PubMed for literature related to the effects of EMI on pacemakers and ICDs dating back to 1990. The studies (Toivonen et al., 1991; Astridge et al., 1993; Scholten et al., 2001) showed that the unipolar pacemakers, in general, were sensitive to electric fields of approximately 1 kV/m and above. Bipolar devices, which are specifically designed to reduce the effects of EMI, were much less sensitive and interference effects were observed at electric field strengths of 4-5 kV/m and above.

To prevent against pacemaker EMI, the American Conference of Governmental Industrial Hygienists (ACGIH) and the Electric Power Research Institute (EPRI) suggest that exposures be kept below 1.5-2 kV/m for electric fields and the ACGIH recommends 1 G for magnetic fields (ACGIH 2001, EPRI 2004). These recommendations are general in nature and do not address the fact that classes of pacemakers from some manufacturers are quite immune to interference even at levels much greater than the above recommendations. All standards recommend that the patient consult their physicians and the respective pacemaker manufacturer before following the standard guidelines.

Out of the approximately 12 cardiac device manufacturers only 2, Boston Scientific and Medtronic, are known to provide a general guideline for electric and magnetic field exposure limits (Hauser, 2007). Boston Scientific recommends values below 1-4 kV/m and 1 G at 60 Hz, based in part on the guidelines issued by ACGIH and EPRI (Boston Scientific, 2006). Medtronic recommends an electric field exposure below 6 kV/m for their implanted devices.

In order to reduce the potential effects of environmental exposure to electric and magnetic fields, the Center for Devices and Radiological Health of the United States Food and Drug Administration (FDA) has issued guidelines for both the development of pacemakers and the design of new electrical devices to minimize susceptibility to electrical interference from any source. Pacemakers today are designed to filter out electrical stimuli from sources other than the heart, e.g., the muscles of the chest, currents encountered from touching household appliances, or currents induced by external electric or magnetic fields. Used in both temporary and permanent pacemakers, these electrical filters increase the pacemaker's ability to distinguish extraneous signals from legitimate cardiac signals (Toivonen et al., 1991). Furthermore, most circuitry of modern pacemakers is encapsulated by titanium metal, which insulates the device by shielding the pacemaker's pulse generator from electric fields. Some pacemakers may also be programmed to automatically pace the heart if interference from electric and magnetic fields is detected (fixed pacing mode). This supports cardiac function and allows the subject to feel the pacing and move away from the source.

Due to recent design improvements, many pacemakers currently in use would not be susceptible to low intensity electric fields. There remains a very small possibility that some pacemakers, particularly those of older design and with single-lead electrodes (i.e., unipolar devices), may sense potentials induced on the electrodes and leads of the pacemaker and provide unnecessary stimulation to the heart.

In summary, interference from strong electric fields is theoretically possible under certain circumstances. The likelihood of interference occurring is low, however, particularly with respect to sources that produce low levels of electric fields and when modern devices are implanted. It is recommended that concerned patients contact their doctor to discuss the make and model of their implanted device, their clinical condition, and any lifestyle factors that put them in close contact with strong fields.

4 Fauna and Flora Research

Fauna

Our previous report concluded that the research to date did not suggest that electric or magnetic fields result in any adverse effects on the health, behavior or productivity of fauna, including livestock such as cows, sheep, and pigs, and a variety of small mammals, deer, elk, birds and bees. The research indicates that some species of animals, unlike humans, are able to detect magnetic fields at levels that may be associated with transmission lines, and this detection may be important for navigational purposes in particular species such as birds. Detection, however, does not imply that the fields result in any effects, or that these effects are adverse. Furthermore, studies of small mammals and birds associated with the research programs by the U.S. Navy and the Bonneville Power Administration reported that there were not any changes in the movement patterns of these animals to suggest that they were avoiding areas near high-voltage rights-of-way (ROW), nor were there any physiological changes or alterations in homing behavior. Reports by two investigators found that commercial honeybee hives can be impacted by EMF from transmission lines because of a current induced by metal parts on the hive; however, this effect is easily remedied and does not apply to wild bees. In summary, the research did not suggest that EMF exposure, or audible noise, would cause any harm to fauna living in the vicinity of high-voltage transmission lines.

Subsequent to Exponent's 2007 report, one study has been published on the possible effects of AC EMF on fauna (Burchard et al., 2007). This study is the most recent publication in a long series of controlled studies at McGill University on the possible effects of strong and continuous EMF exposure on the health, behavior and productivity of dairy cattle (Burchard et al., 1996; Burchard et al., 1998a,b,c; Burchard et al., 1999; Rodriquez et al., 2002; Burchard et al., 2003; Rodriquez et al., 2003; Burchard et al., 2004; Rodriguez et al., 2004). The goal of the research program was to assess whether EMF exposure could mimic the effect of days with long periods of light and *increase* milk production and feed intake through a hormonal pathway involving melatonin. In previous studies, some differences were reported between EMF-exposed and unexposed cows; however, they were not reported consistently between studies, the changes were still within the range of what is considered normal, and it did not appear that the changes were adverse in nature or had any ecological significance. The study by Burchard et al. in 2007 differed from previous studies in that the exposure was restricted to magnetic fields; the outcomes evaluated included the hormones progesterone, melatonin, prolactin, and insulin-like growth factor 1 (IGF-1), as well as feed consumption. No significant differences in melatonin levels, progesterone levels, or feed intake were reported. Significant decreases in prolactin and IGF-1 levels were reported, which is inconsistent with the authors' theory that EMF exposure may increase these hormone levels.

Thus, similar to the previous studies by this group of investigators, Burchard et al. (2007) did not report findings that suggest magnetic fields cause changes in the melatonin pathway that could result in effects on reproduction or production. The authors concluded the following: "The absence of abnormal clinical signs and the absolute magnitude of the significant changes detected during MF [magnetic field] exposure, make it plausible to preclude any major animal health hazard" (p. 471).

Flora

The previous report described the body of research on the possible effects of EMF on forest species and agriculture crops, concluding that researchers have found no adverse effects on plant responses at the levels of EMF produced by high-voltage transmission lines, excluding some corona-related effects from high-voltage lines on the growth of nearby trees.

A recent study by Huang and Wang (2008) evaluated the effects of magnetic fields induced by an inverter system on the early seed germination of mung beans. The exposures were applied at six different frequencies between 10-60 Hz, producing magnetic field levels from 6-20 mG. At 20 and 60 Hz, magnetic field exposure enhanced early growth of the mung beans, while magnetic fields induced by other frequencies had an inhibitory effect on early growth of the mung beans.

5 Standards and Guidelines

Following a thorough review of the research, scientific agencies develop exposure standards to protect against known health effects. The major purpose of a weight-of-evidence review is to identify the lowest exposure level below which no health hazards have been found (i.e., a threshold). Exposure limits are then set well below the threshold level to account for any individual variability or sensitivities that may exist.

Several scientific organizations have published guidelines for exposure to EMF based on acute health effects that can occur at very high field levels. The ICNIRP reviewed the epidemiologic and experimental evidence through 1997 and concluded that there was insufficient evidence to warrant the development of standards or guidelines on the basis of hypothesized long-term adverse health effects such as cancer; rather, the guidelines put forth in their 1998 document set limits to protect against acute health effects (i.e., the stimulation of nerves and muscles) that occur at much higher field levels. The ICNIRP recommends a residential screening value of 833 mG and an occupational exposure screening value of 4,200 mG (ICNIRP, 1998). If exposures exceed these screening values, then additional dosimetry evaluations are needed to determine whether basic restrictions on induced current densities are exceeded.

The International Committee on Electromagnetic Safety (ICES) also recommends limiting magnetic field exposures at high levels because of the risk of acute effects, although their guidelines are higher than ICNIRP's guidelines; the ICES recommends a residential exposure limit of 9,040 mG and an occupational exposure limit of 27,100 mG (ICES, 2002). The ICNIRP and ICES guidelines provide guidance to national agencies and only become legally binding if a country adopts them into legislation. The WHO strongly recommends that countries adopt the ICNIRP guidelines, or use a scientifically sound framework for formulating any new guidelines (WHO, 2006).

There are no national or state standards in the United States limiting exposures to ELF fields based on health effects. Two states, Florida and New York, have enacted standards to limit magnetic fields at the edge of the right-of-way from transmission lines (150 mG and 200 mG, respectively) (NYPSC, 1978; FDER, 1989; NYPSC, 1990; FDEP, 1996). The basis for limiting magnetic fields from transmission lines was to maintain the "status quo" so that fields from new transmission lines would be no higher than those produced by existing transmission lines.

Table 9. Screening guidelines for EMF exposure

Exposure (60 Hz)	Electric field	Magnetic field
ICNIRP		
Occupational	8.3 kV/m	4.2 G (4,200 mG)
General Public	4.2 kV/m	0.833 G (833 mG)
ICES		
Occupational	20 kV/m	27.1 G (27,100 mG)
General Public	5 kV/m^	9.040 G (9,040 mG)

Sources: ICNIRP, 1998; ICES, 2002
^Within power line right-of-ways, the guideline is 10 kV/m under normal load conditions.

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Appendix 1 – WHO Fact Sheet

Fact sheet N°322
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Electromagnetic fields and public health
Exposure to extremely low frequency fields

The use of electricity has become an integral part of everyday life. Whenever electricity flows, both electric and magnetic fields exist close to the lines that carry electricity, and close to appliances. Since the late 1970s, questions have been raised whether exposure to these extremely low frequency (ELF) electric and magnetic fields (EMF) produces adverse health consequences. Since then, much research has been done, successfully resolving important issues and narrowing the focus of future research.

In 1996, the World Health Organization (WHO) established the International Electromagnetic Fields Project to investigate potential health risks associated with technologies emitting EMF. A WHO Task Group recently concluded a review of the health implications of ELF fields (WHO, 2007).

This Fact Sheet is based on the findings of that Task Group and updates recent reviews on the health effects of ELF EMF published in 2002 by the International Agency for Research on Cancer (IARC), established under the auspices of WHO, and by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 2003.

ELF field sources and residential exposures

Electric and magnetic fields exist wherever electric current flows - in power lines and cables, residential wiring and electrical appliances. **Electric** fields arise from electric charges, are measured in volts per metre (V/m) and are shielded by common materials, such as wood and metal. **Magnetic** fields arise from the motion of electric charges (i.e. a current), are expressed in tesla (T), or more commonly in millitesla (mT) or microtesla (µT). In some countries another unit called the gauss, (G), is commonly used (10,000 G = 1 T). These fields are not shielded by most common materials, and pass easily through them. Both types of fields are strongest close to the source and diminish with distance.

Most electric power operates at a frequency of 50 or 60 cycles per second, or hertz (Hz). Close to certain appliances, the magnetic field values can be of the order of a few hundred microtesla. Underneath power lines, magnetic fields can be about 20 µT and electric fields can be several thousand volts per metre. However, average residential power-frequency magnetic fields in homes are much lower - about 0.07 µT in Europe and 0.11 µT in North America. Mean values of the electric field in the home are up to several tens of volts per metre.

Task group evaluation

In October 2005, WHO convened a Task Group of scientific experts to assess any risks to health that might exist from exposure to ELF electric and magnetic fields in the frequency range >0 to 100,000 Hz (100 kHz). While IARC examined the evidence regarding cancer in 2002, this Task Group reviewed evidence for a number of health effects, and updated the evidence regarding cancer. The conclusions and recommendations of the Task Group are presented in a WHO Environmental Health Criteria (EHC) monograph (WHO, 2007).

Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF electric fields at levels generally encountered by members of the public. Thus the remainder of this fact sheet addresses predominantly the effects of exposure to ELF magnetic fields.

Short-term effects

There are established biological effects from acute exposure at high levels (well above 100 µT) that are explained by recognized biophysical mechanisms. External ELF magnetic fields induce electric fields and currents in the body which, at very high field strengths, cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system.

Potential long-term effects

Much of the scientific research examining long-term risks from ELF magnetic field exposure has focused on childhood leukaemia. In 2002, IARC published a monograph classifying ELF magnetic fields as "possibly carcinogenic to humans". This classification is used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals (other examples include coffee and welding fumes). This classification was based on pooled analyses of epidemiological studies demonstrating a consistent pattern of a two-fold increase in childhood leukaemia associated with average exposure to residential power-frequency magnetic field above 0.3 to 0.4 µT. The Task Group concluded that additional studies since then do not alter the status of this classification.

However, the epidemiological evidence is weakened by methodological problems, such as potential selection bias. In addition, there are no accepted biophysical mechanisms that would suggest that low-level exposures are involved in cancer development. Thus, if there were any effects from exposures to these low-level fields, it would have to be through a biological mechanism that is as yet unknown. Additionally, animal studies have been largely negative. Thus, on balance, the evidence related to childhood leukaemia is not strong enough to be considered causal.

Childhood leukaemia is a comparatively rare disease with a total annual number of new cases estimated to be 49,000 worldwide in 2000. Average magnetic field exposures above 0.3 µT in homes are rare: it is estimated that only between 1% and 4% of children live in such conditions. If the association between magnetic fields and childhood leukaemia is causal, the number of cases worldwide that might be attributable to magnetic field exposure is estimated to range from 100 to 2400 cases per year, based on values for the year 2000, representing 0.2 to 4.95% of the total incidence for that year. Thus, if ELF magnetic fields actually do increase the risk of the disease, when considered in a global context, the impact on public health of ELF EMF exposure would be limited.

A number of other adverse health effects have been studied for possible association with ELF magnetic field exposure. These include other childhood cancers, cancers in adults, depression, suicide, cardiovascular disorders, reproductive dysfunction, developmental disorders, immunological modifications, neurobehavioural effects and neurodegenerative disease. The WHO Task Group concluded that scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukaemia. In some instances (i.e. for cardiovascular disease or breast cancer) the evidence suggests that these fields do not cause them.

International exposure guidelines

Health effects related to short-term, high-level exposure have been established and form the basis of two international exposure limit guidelines (ICNIRP, 1998; IEEE, 2002). At present, these bodies consider the scientific evidence related to possible health effects from long-term, low-level exposure to ELF fields insufficient to justify lowering these quantitative exposure limits.

WHO's guidance

For high-level short-term exposures to EMF, adverse health effects have been scientifically established (ICNIRP, 2003). International exposure guidelines designed to protect workers and the public from these effects should be adopted by policy makers. EMF protection programs should include exposure measurements from sources where exposures might be expected to exceed limit values.

Regarding long-term effects, given the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, the benefits of exposure reduction on health are unclear. In view of this situation, the following recommendations are given:

- Government and industry should monitor science and promote research programmes to further reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure. Through the ELF risk assessment process, gaps in knowledge have been identified and these form the basis of a new research agenda.
- Member States are encouraged to establish effective and open communication programmes with all stakeholders to enable informed decision-making. These may include improving coordination and consultation among industry, local government, and citizens in the planning process for ELF EMF-emitting facilities.
- When constructing new facilities and designing new equipment, including appliances, low-cost ways of reducing exposures may be explored. Appropriate exposure reduction measures will vary from one country to another. However, policies based on the adoption of arbitrary low exposure limits are not warranted.

Further reading

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Appendix 2 – Comment on the BioInitiative Report

Background

In August 2007, an *ad hoc* group of 14 scientists and public health and policy "experts" published a report to "assess scientific evidence on health impacts from electromagnetic radiation below current public exposure limits and evaluate what changes in these limits are warranted now to reduce possible public health risks in the future" (p. 4). The individuals who comprised this group did not represent any well-established regulatory agency, nor were they convened by a recognized scientific authority. The report (hereafter referred to as the BioInitiative report) is a collection of 17 sections on various topics each authored by one to three persons from the working group. The research on both ELF and radio frequency (RF) EMF was addressed, with major portions of the report focused largely or entirely on RF research. With regard to ELF-EMF, the epidemiologic literature related to childhood cancers, Alzheimer's disease and breast cancer was discussed, as well as the experimental data for a number of mechanistic hypotheses.

Conclusions and comments

The authors of the BioInitiative Report contended that the standard procedure for developing exposure guidelines – i.e., to set guidelines where adverse health effects have been established by using a weight-of-evidence approach – is not appropriate and should be replaced by a process that sets guidelines at exposure levels where biological effects have been reported in some studies, but not substantiated in a rigorous review of the science or linked to adverse health effects.

Based on this argument, the main conclusion of the BioInitiative report was that existing standards for exposure to ELF-EMF are insufficient because "effects are now widely reported to occur at exposure levels significantly below most current national and international limits" (Table 1-1). Specifically, the authors concluded that there was strong evidence to suggest that magnetic fields were a cause of childhood leukemia based on epidemiologic findings. The report recommended the following:

> ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor … While new ELF limits are being developed and implemented, a reasonable approach

> would be a 1 mG (0.1 μT) planning limit for habitable space adjacent to all new or upgraded power lines and a 2 mG (0.2 μT) limit for all other new construction. It is also recommended that a 1 mG (0.1 μT) limit be established for existing habitable space for children and/or women who are pregnant. (p. 22)

The recommendations made in the BioInitiative report are not based on appropriate scientific methods and, therefore, do not warrant any changes to the conclusions from the numerous scientific agencies that have already considered this issue. These organizations are consistent in their conclusions that the research does not support the setting of exposure standards at these low levels of magnetic field exposure.

The World Health Organization (WHO) published the most recent weight-of-evidence review in June 2007 and concluded the following:

> Everyday, low-intensity ELF magnetic field exposure poses a possible increased risk of childhood leukaemia, but the evidence is not strong enough to be considered causal and therefore ELF magnetic fields remain classified as possibly carcinogenic. (p. 357)

The report continued:

> Given the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia and the limited potential impact on public health, the benefits of exposure reduction on health are unclear and thus the cost of reducing exposure should be very low. (p. 372)

The WHO made no recommendations for exposure standards at the magnetic field levels where an association has been reported in some epidemiologic studies of childhood leukemia. In a fact sheet created for the general public and published on their website, the WHO stated,

> When constructing new facilities and designing new equipment, including appliances, low-cost ways of reducing exposures may be explored…However, policies based on the adoption of arbitrary low exposure limits are not warranted.[20]

The conclusions in the BioInitiative report deviate substantially from those of reputable scientific organizations because they were not based on standard, scientific methods. Valid scientific conclusions are based on weight-of-evidence reviews, which entail a systematic evaluation of the entire body of scientific evidence in three areas of research (i.e., epidemiology, *in vivo* research and *in vitro* research) by a panel of experts in these relevant disciplines. The report by the BioInitiative working group does not represent a valid weight-of-evidence review for the following key reasons:

[20] http://www.who.int/mediacentre/factsheets/fs322/en/index.html

1. **Review panels should consist of a multidisciplinary team of experts that reach consensus statements by collaboratively contributing to and reviewing the final work product.** This process ensures that overall conclusions represent a valid and balanced view of each relevant area of research. The document released by the BioInitiative working group was a compilation of sections, with each authored by one to three members of the group. It does not appear that the report was developed collaboratively or reviewed in its entirety by each member.

2. **Valid conclusions about causality are based on systematic evaluations of three lines of evidence - epidemiology, *in vivo* research and *in vitro* research.** The conclusions in the BioInitiative report are not based on this multidisciplinary approach. In particular, little attention is provided to the results from whole animal *in vivo* studies on cancer and disproportionate weight is given to the results of *in vitro* studies reporting biological effects.

3. **The entire body of evidence to date should be considered when drawing conclusions regarding the strength of evidence in support of a hypothesis.** The BioInitiative report is not a comprehensive review of the cumulative evidence. Rather, results from specific studies are cited, but no rationale is provided for their inclusion relative to the many other relevant, published studies.

4. **The evidence from each study must be critically evaluated to determine its validity and the degree to which it is relevant and able to support or refute the hypothesis under question.** The significance of the results reported in any study depend on the validity of the methods used in that study, so weight-of-evidence reviews must include an evaluation of the strengths and limitations of each study. In some discussions, the report claimed to use a weight-of-evidence approach, but the individual sections of the report provide little evidence that the strengths and limitations of individual studies (e.g., the quality of exposure assessment, sample size, biases, and confounding factors) were systematically evaluated.

5. **Support for a causal relationship is based on consistent findings from methodologically sound epidemiologic studies that are coherent with the results reported from *in vivo* and *in vitro* studies**. The BioInitiative group often arrived at conclusions about causality by considering only a few studies from one discipline, with no consideration of the significance and validity of the study's results.

In summary, the authors of this report largely ignored basic scientific methods that should be followed in the review and evaluation of scientific evidence. These methods are fundamental to scientific inquiry and are not, as the BioInitiative report states, "unreasonably high."

The policy responses proposed in the report are cast as consistent with the precautionary principle, i.e., taking action in situations of scientific uncertainty before there is strong proof of harm. A central tenet of the precautionary principle is that precautionary recommendations are proportional to the perceived level of risk and that this perception is founded largely on the weight of the available scientific evidence. The BioInitiative report recommends precautionary measures on the basis of argument, rather than sound peer-reviewed scientific evidence.

Unlike the BioInitiative report, the WHO report was the product of a multidisciplinary scientific panel assembled by an established public health agency that followed appropriate scientific methods, including the systematic and critical examination of all the relevant evidence. The recommendations from the WHO report (pp. 372-373) are presented below:

- Policy-makers should establish guidelines for ELF field exposure for both the general public and workers. The best source of guidance for both exposure levels and the principles of scientific review are the international guidelines.
- Policy-makers should establish an ELF EMF protection programme that includes measurements of fields from all sources to ensure that the exposure limits are not exceeded either for the general public or workers.
- Provided that the health, social and economic benefits of electric power are not compromised, implementing very low-cost precautionary procedures to reduce exposures is reasonable and warranted.
- Policy-makers and community planners should implement very low-cost measures when constructing new facilities and designing new equipment including appliances.
- Changes to engineering practice to reduce ELF exposure from equipment or devices should be considered, provided that they yield other additional benefits, such as greater safety, or involve little or no cost.
- When changes to existing ELF sources are contemplated, ELF field reduction should be considered alongside safety, reliability and economic aspects.
- Local authorities should enforce wiring regulations to reduce unintentional ground currents when building new or rewiring existing facilities, while maintaining safety. Proactive measures to identify violations or existing problems in wiring would be expensive and unlikely to be justified.

- National authorities should implement an effective and open communication strategy to enable informed decision-making by all stakeholders; this should include information on how individuals can reduce their own exposure.

- Local authorities should improve planning of ELF EMF-emitting facilities, including better consultation between industry, local government, and citizens when siting major ELF EMF-emitting sources.

- Government and industry should promote research programmes to reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure.