Appendix D

Electric and Magnetic Fields Supporting Documentation

Appendix D.1

Connecticut Siting Council's Electric and Magnetic Fields Best Management Practices

Electric and Magnetic Fields Best Management Practices For the Construction of Electric Transmission Lines in Connecticut

Approved on December 14, 2007

I. Introduction

To address a range of concerns regarding potential health risks from exposure to transmission line electric and magnetic fields (EMF), whether from electric transmission facilities or other sources, the Connecticut Siting Council (Council) (in accordance with Public Act 04-246) issues this policy document "*Best Management Practices for the Construction of Electric Transmission Lines in Connecticut*." It references the latest information regarding scientific knowledge and consensus on EMF health concerns; it also discusses advances in transmission-facility siting and design that can affect public exposure to EMF.

Electric and magnetic fields (EMF) are two forms of energy that surround an electrical device. The strength of an electric field (EF) is proportional to the amount of electric voltage at the source, and decreases rapidly with distance from the source, diminishing even faster when interrupted by conductive materials, such as buildings and vegetation. The level of a magnetic field (MF) is proportional to the amount of electric current (not voltage) at the source, and it, too, decreases rapidly with distance from the source; but magnetic fields are not easily interrupted, as they pass through most materials. EF is often measured in units of kilovolts per meter (kV/m). MF is often measured in units of milligauss (mG).

Transmission lines are common sources of EMF, as are other substantial components of electric power infrastructure, ranging from transformers at substations to the wiring in a home. However, any piece of machinery run by electricity can be a source of EMF: household objects as familiar as electric tools, hair dryers, televisions, computers, refrigerators, and electric ovens.

In the U.S., EMF associated with electric power have a frequency of 60 cycles per second (or 60 Hz). Estimated average background levels of 60-Hz MF in most homes, away from appliances and electrical panels, range from 0.5 to 5.0 mG (NIEHS, 2002). MF near operating appliances such as an oven, fan, hair dryer, television, etc. can range from 10's to 100's of mG. Many passenger trains, trolleys, and subways run on electricity, producing MF: for instance, MF in a Metro-North Railroad car averages about 40-60 mG, increasing to 90-145 mG with acceleration (Bennett Jr., W. 1994). As a point of comparison to these common examples, the Earth itself has an MF of about 570 mG (USGS 2007). Unlike the MF associated with power lines, appliances, or computers, the Earth's MF is steady; in every other respect, however, the Earth's MF has the same characteristics as MF emanating from man-made sources.

Concerns regarding the health effects of EMF arise in the context of electric transmission lines and distribution lines, which produce time-varying EMF, sometimes called extremely-low frequency electric and magnetic fields, or ELF-EMF. As the weight of scientific evidence indicates that exposure to electric fields, beyond levels traditionally established for safety, does not cause adverse health effects, and as safety concerns for electric fields are sufficiently addressed by adherence to the National Electrical Safety Code, as amended, health concerns regarding EMF focus on MF rather than EF.

MF levels in the vicinity of transmission lines are dependent on the flow of electric current through them and fluctuate throughout the day as electrical demand increases and decreases. They can range from about 5 to 150 mG, depending on current load, height of the conductors, separation of the conductors, and distance from the lines. The level of the MF produced by a transmission line decreases with increasing distance from the conductors, becoming indistinguishable from levels found inside or outside homes (exclusive of MF emanating from sources within the home) at a distance of 100 to 300 feet, depending on the design and current loading of the line (NIEHS, 2002).

In Connecticut, existing and proposed transmission lines are designed to carry electric power at voltages of 69, 115, or 345 kilovolts (kV). Distribution lines, i.e. those lines directly servicing the consumer's building, typically operate at voltages below 69 kV and may produce levels of MF similar to those of transmission lines. The purpose of this document is to address engineering practices for proposed electric transmission lines with a design capacity of 69 kV or more and MF health concerns related to these projects, but not other sources of MF.

II. Health Concerns from Power-Line MF

While more than 40 years of scientific research has addressed many questions about EMF, the continuing question of greatest interest to public health agencies is the possibility of an association between time weighted MF exposure and demonstrated health effects. The World Health Organization (WHO) published its latest findings on this question in an Electromagnetic Fields and Public Health fact sheet, June 2007. (http://www.who.int/mediacentre/factsheets/fs322/en/index.html) The fact sheet is based on a review by a WHO Task Group of scientific experts who assessed risks associated with ELF-EMF. As part of this review, the group examined studies related to MF exposure and various health effects, including childhood cancers, cancers in adults, developmental disorders, and neurobehavioral effects, among others. Particular attention was paid to leukemia in children. The 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 leukemia". (WHO, 2007) For childhood leukemia, WHO concluded recent studies do not alter the existing position taken by the International Agency for Research on Cancer (IARC) in 2002, that ELF-MF is "possibly carcinogenic to humans."

Some epidemiology studies have reported an association between MF and childhood leukemia, while others have not. Two broad statistical analyses of these studies as a pool reported an association with estimated average exposures greater than 3 to 4 mG, but at this level of generalization it is difficult to determine whether the association is significant. In 2005, the National Cancer Institute (NCI) stated, "Among more recent studies, findings have been mixed. Some have found an association; others have not . . . . Currently, researchers conclude that there is limited evidence that magnetic fields from power lines cause childhood leukemia, and that there is inadequate evidence that these magnetic fields cause other cancers in children." The NCI stated further: "Animal studies have not found that magnetic field exposure is associated with increased risk of cancer. The absence of animal data supporting carcinogenicity makes it biologically less likely that magnetic field exposures in humans, at home or at work, are linked to increased cancer risk."

The American Medical Association characterizes the EMF health-effect literature as "inconsistent as to whether a risk exists." The National Institute of Environmental Health Sciences (NIEHS) concluded in 1999 that EMF exposure could not be recognized as "*entirely safe*" due to some statistical evidence of a link with childhood leukemia. Thus, although no public health agency has found that scientific research suggests a causal relationship between EMF and cancer, the NIEHS encourages "inexpensive and safe reductions in exposure" and suggests that the power industry continue its current practice of siting power lines to reduce exposures" rather than regulatory guidelines (NIEHS, 1999, pp. 37-38). In 2002 NIEHS restated that while this evidence was "weak" it was "still sufficient to warrant limited concern" and recommended "continued education on ways of reducing exposures" (NIEHS, 2002, p. 14).

Reviews by other study groups, including IARC (2002), the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2003), the British National Radiation Protection Board (NRPB) (2004a), and the Health Council of the Netherlands ELF Electromagnetic Fields Committee (2005), are similar to NIEHS and NCI in their uncertainty about reported associations of MF with childhood leukemia. In 2004, the view of the NRPB was:

> "[T]he epidemiological evidence that time-weighted average exposure to power frequency magnetic fields above 0.4 microtesla [4 mG] is associated with a small absolute raised risk of leukemia in children is, at present, an observation for which there is no sound scientific explanation. There is no clear evidence of a carcinogenic effect of ELF EMFS in adults and no plausible biological explanation of the association can be obtained from experiments with animals or from cellular and molecular studies. Alternative explanations for this epidemiological association are possible…Thus: any judgments developed on the assumption that the association is causal would be subject to a very high level of uncertainty." (NRPB, 2004a, p. 15)

Although IARC classified MF as "possibly carcinogenic to humans" based upon pooling of the results from several epidemiologic studies, IARC further stated that the evidence suggesting an association between childhood leukemia and residential MF levels is "limited," with "inadequate" support for a relation to any other cancers. The WHO Task Group concluded "the evidence related to childhood leukemia is not strong enough to be considered causal" (WHO, 2007).

The Connecticut Department of Public Health (DPH) has produced an EMF Health Concerns Fact Sheet (May 2007) that incorporates the conclusions of national and international health panels. The fact sheet states that while "the current scientific evidence provides no definitive answers as to whether EMF exposure can increase health risks, there is enough uncertainty that some people may want to reduce their exposure to EMF."
[http://www.dph.state.ct.us/Publications/brs/eoha/emf_2004.pdf]

In the U.S., there are no state or federal exposure standards for 60-Hz MF based on demonstrated health effects. Nor are there any such standards world-wide. Among those international agencies that provide guidelines for acceptable MF exposure to the general public, the International Commission on Non-Ionizing Radiation Protection established a level of 833 mG, based on an extrapolation from experiments involving transient neural stimulation by MF at much higher exposures. Using a similar approach, the International Committee on Electromagnetic Safety calculated a guideline of 9,040 mG for exposure to workers and the general public (ICNIRP, 1998; ICES/IEEE, 2002). This situation reflects the lack of credible scientific evidence for a causal relationship between MF exposure and adverse health effects.

III. Policy of the Connecticut Siting Council

The Council recognizes that a causal link between power-line MF exposure and demonstrated health effects has not been established, even after much scientific investigation in the U.S. and abroad. Furthermore, the Council recognizes that timely additional research is unlikely to prove the safety of power-line MF to the satisfaction of all. Therefore, the Council will continue its cautious approach to transmission line siting that has guided its Best Management Practices since 1993. This continuing policy is based on the Council's recognition of and agreement with conclusions shared by a wide range of public health consensus groups, and also, in part, on a review which the Council commissioned as to the weight of scientific evidence regarding possible links between power-line MF and adverse health effects. Under this policy, the Council will continue to advocate the use of effective no-cost and low-cost technologies and management techniques on a project-specific basis to reduce MF exposure to the public while allowing for the development of efficient and cost-effective electrical transmission projects. This approach does not imply that MF exposure will be lowered to any specific threshold or exposure limit, nor does it imply MF mitigation will be achieved with no regard to cost.

The Council will develop its precautionary guidelines in conjunction with Section 16-50p(i) of the Connecticut General Statutes, enacted by the General Assembly to call special attention to their concern for children. The Act restricts the siting of overhead 345-kV transmission lines in areas where children congregate, subject to technological feasibility. These restrictions cover transmission lines adjacent to "residential areas, public or private schools, licensed child day-care facilities, licensed youth camps, or public playgrounds."

Developing Policy Guidelines

One important way the Council seeks to update its Best Management Practices is to integrate policy with specific project development guidelines. In this effort, the Council has reviewed the actions of other states. Most states either have no specific guidelines or have established arbitrary MF levels at the edge of a right-of-way that are not based on any demonstrated health effects. California, however, established a no-cost/low-cost precautionary-based EMF policy in 1993 that was re-affirmed by the California Public Utilities Commission in 2006. California's policy aims to provide significant MF reductions at no cost or low cost, a precautionary approach consistent with the one Connecticut has itself taken since 1993, consistent with the conclusions of the major scientific reviews, and consistent with the policy recommendations of the Connecticut Department of Public Health and the WHO. Moreover, California specifies certain benchmarks integral to its policy. The benchmark for "low-cost/no-cost" is an increase in aggregate project costs of zero to four percent. The benchmark for "significant MF reduction" is an MF reduction of at least 15 percent. With a policy similar to Connecticut's, and concrete benchmarks as well, California offers the Council a useful model in developing policy guidelines.

No-Cost/Low-Cost MF Mitigation

The Council seeks to continue its precautionary policy, in place since 1993, while establishing a standard method to allocate funds for MF mitigation methods. The Council recognizes California's cost allotment strategy as an effective method to achieve MF reduction goals; thus, the Council will follow a similar strategy for no-cost/low-cost MF mitigation.

The Council directs the Applicant to initially develop a Field Management Design Plan that depicts the proposed transmission line project designed according to standard good utility practice and incorporating "no-cost" MF mitigation design features. The Applicant shall then modify the base design by adding low-cost MF mitigation design features specifically where portions of the project are adjacent to residential areas, public or private schools, licensed child day-care facilities, licensed youth camps, or public playgrounds.

The overall cost of low-cost design features are to be calculated at four percent of the initial Field Management Design Plan, including related substations. Best estimates of the total project costs during the Council proceedings should be employed, and the amounts proposed to be incurred for MF mitigation should be excluded. It is important to note that the four percent guideline is not an absolute cap, because the Council does not want to eliminate prematurely a potential measure that might be available and effective but would cost more than the four percent, or exclude arbitrarily an area adjacent to the ROW that might be suitable for MF mitigation. Nor is the four percent an absolute threshold, since the Council wants to encourage the utilities to seek effective field reduction measures costing less than four percent. In general, the Council recognizes that projects can vary widely in the extent of their impacts on statutory facilities, necessitating some variance above and below the four percent figure.

The four percent guideline for low-cost mitigation should aim at a magnetic field reduction of 15 percent or more at the edge of the utility's ROW. This 15 percent reduction should relate specifically to those portions of the project where the expenditures would be made. While experience with transmission projects in Connecticut since 1993 has shown that no-cost/low-cost designs can and do achieve reductions in MF on the order of 15 percent, the 15 percent guideline is no more absolute than the four percent one, nor must the two guidelines be correlated by rote. The nature of guidelines is to be constructive, rather than absolute.

The Council will consider minor increases above the four percent guideline if justified by unique circumstances, but not as a matter of routine. Any cost increases above the four percent guideline should result in mitigation comparably above 15 percent, and the total costs should still remain relatively low.

Undergrounding transmission lines puts MF issues out of sight, but it should not necessarily put them out of mind. With that said, soils and other fill materials do not shield MF, rather, MF is reduced by the underground cable design (refer to page 9 for further information). However, special circumstances may warrant some additional cost in order to achieve further MF mitigation for underground lines. The utilities are encouraged, prior to submitting their application to the Council, to determine whether a project involves such special circumstances. Note that the extra costs of undergrounding done for purposes other than MF mitigation should be counted in the base project cost and not as part of the four percent mitigation spending.

Additionally, the Council notes two general policies it follows in updating its EMF Best Management Practices and conducting other matters within its jurisdiction. One is a policy to support and monitor ongoing study. Accordingly, the Council, during the public hearing process for new transmission line projects, will consider and review evidence of any new developments in scientific research addressing MF and public health effects or changes in scientific consensus group positions regarding MF. The second is a policy to encourage public participation and education. The Council will continue to conduct public hearings open to all, update its website to contain the latest information regarding MF health effect research, and revise these Best Management Practices to take account of new developments in MF health effect research or in methods for achieving no-cost/low-cost MF mitigation.

The Council will also require that notices of proposed overhead transmission lines provided in utility bill enclosures pursuant to Conn. Gen. Stats. §16-50*l*(b) state the proposed line will meet the Council's Electric and Magnetic Fields Best Management Practices, specifying the design elements planned to reduce magnetic fields. The bill enclosure notice will inform residents how to obtain siting and MF information specific to the proposed line at the Council's website; this information will also be available at each respective town hall. Phone numbers for follow-up information will be made available, including those of DPH, and utility representatives. The project's final post-construction structure and conductor specifications including calculated MF levels shall also be available at the Council's website and each respective town hall.

Finally, we note that Congress has directed the Department of Energy (DOE) periodically to assess congestion along critical transmission paths or corridors and apply special designation to the most significant ones. Additionally, Congress has given the Federal Regulatory Commission supplemental siting authority in DOE designated areas. This means the Council must complete all matters in an expeditious and timely manner. Accordingly, the cooperation of all parties will be of particular importance in fulfilling the policies set forth above.

IV. MF Best Management Practices: Further Management Considerations

The Council's EMF Best Management Practices will apply to the construction of new electric transmission lines in the State, and to modifications of existing lines that require a certificate of environmental compatibility and public need. These practices are intended for use by public service utilities and the Council when considering the installation of such new or modified electric transmission lines. The practices are based on the established Council policy of reducing MF levels at the edge of a right-of-way (ROW), and in areas of particular interest, with no-cost/low-cost designs that do not compromise system reliability or worker safety, or environmental and aesthetic project goals.

Several practical engineering approaches are currently available for reducing MF, and more may be developed as technology advances. In proposing any particular methods of MF mitigation for a given project, the Applicant shall provide a detailed rationale to the Council that supports the proposed MF mitigation measures. The Council has the option to retain a consultant to confirm that the Field Management Design Plan and the proposed MF reduction strategies are consistent with these EMF Best Management Practices.

A. MF Calculations

When preparing a transmission line project, an applicant shall provide design alternatives and calculations of MF for pre-project and post-project conditions, under 1) peak load conditions at the time of the application filing, and 2) projected seasonal maximum 24-hour average current load on the line anticipated within five years after the line is placed into operation. This will allow for an evaluation of how MF levels differ between alternative power line configurations. The intent of requiring various design options is to achieve reduced MF levels when possible through practical design changes. The selection of a specific design will also be affected by other practical factors, such as the cost, system reliability, aesthetics, and environmental quality.

MF values shall be calculated from the ROW centerline out to a distance of 300 feet on each side of the centerline, at intervals of 25 feet, including at the edge of the ROW. In accordance with industry practice, the calculation shall be done at the location of maximum line sag (typically mid-span), and shall provide MF values at 1 meter above ground level, with the assumption of flat terrain and balanced currents. The calculations shall assume "all lines in" and projected load growth five years beyond the time the lines are expected to be put into operation, and shall include changes to the electric system approved by the Council and the Independent System Operator – New England.

As part of this determination, the applicant shall provide the locations of, and anticipated MF levels encompassing, residential areas, private or public schools, licensed child day care facilities, licensed youth camps, or public playgrounds within 300 feet of the proposed transmission line. The Council, at its discretion, may order the field measurement of post-construction MF values in select areas, as appropriate.

B. Buffer Zones and Limits on MF

As enacted by the General Assembly in Section 4 of Public Act No. 04-246, a buffer zone in the context of transmission line siting is deemed, at minimum, to be the distance between the proposed transmission line and the edge of the utility ROW. Buffer zone distances may also be guided by the standards presented in the National Electrical Safety Code (NESC), published by the Institute of Electrical and Electronic Engineers (IEEE). These standards provide for the safe installation, operation, and maintenance of electrical utility lines, including clearance requirements from vegetation, buildings, and other natural and man-made objects that may arise in the ROW. The safety of power-line workers and the general public are considered in the NESC standards. None of these standards include MF limits.

Since 1985, in its reviews of proposed transmission-line facilities, the Massachusetts Energy Facilities Siting Board has used an edge-of-ROW level of 85 mG as a benchmark for comparing different design alternatives. Although a ROW-edge level in excess of this value is not prohibited, it may trigger a more extensive review of alternatives.

In assessing whether a right-of-way provides a sufficient "buffer zone," the Council will emphasize compliance with its own Best Management Practices, but may also take into account approaches of other states, such as those of Florida, Massachusetts, and New York.

A number of states have general MF guidelines that are designed to maintain the 'status quo', i.e., that fields from new transmission lines not exceed those of existing transmission lines. In 1991, the New York Public Service Commission established an interim policy based on limits to MF. It required new high-voltage transmission lines to be designed so that the maximum magnetic fields at the edge of the ROW, one meter above ground, would not exceed 200 mG if the line were to operate at its highest continuous current rating. This 200 mG level represents the maximum calculated magnetic field level for 345 kV lines that were then in operation in New York State.

The Florida Environmental Regulation Commission established a maximum magnetic field limit for new transmission lines and substations in 1989. The MF limits established for the edge of 230-kV to 500-kV transmission line ROWs and the property boundaries for substations ranged from 150 mG to 250 mG, depending on the voltage of the new transmission line and whether an existing 500-kV line was already present.

Although scientific evidence to date does not warrant the establishment of MF exposure limits at the edge of a ROW, the Council will continue to monitor the ways in which states and other jurisdictions determine MF limits on new transmission lines.

C. Engineering Controls that Modify MF Levels

When considering an overhead electric transmission-line application, the Council will expect the applicant to examine the following Engineering Controls to limit MF in publicly accessible areas: distance, height, conductor separation, conductor configuration, optimum phasing, increased voltage, and underground installation. Any design change may also affect the line’s impedance, corona discharge, mechanical behavior, system performance, cost, noise levels and visual impact. The Council will consider all of these factors in relation to the MF levels achieved by any particular Engineering Control. Thus, utilities are encouraged to evaluate other possible Engineering Controls that might be applied to the entire line, or just specific segments, depending upon land use, to best minimize MF at a low or no cost.

Consistent with these Best Management Practices and absent line performance and visual impacts, the Council expects that applicants will propose no-cost/low-cost measures to reduce magnetic fields by one or more engineering controls including:

Distance

MF levels from transmission lines (or any electrical source) decrease with distance; thus, increased distance results in lower MF. Horizontal distances can be increased by purchasing wider ROWs, where available. Other distances can be increased in a variety of ways, as described below.

Height of Support Structures

Increasing the vertical distance between the conductors and the edge of the ROW will decrease MF: this can be done by increasing the height of the support structures. The main drawbacks of this approach are an increase in the cost of supporting structures, possible environmental effects from larger foundations, potential detrimental visual effects, and the modest MF reductions achieved (unless the ROW width is unusually narrow).

Conductor Separation

Decreasing the distances between individual phase conductors can reduce MF. Because at any instant in time the sum of the currents in the individual phase conductors is zero, or close to zero, moving the conductors closer together improves their partial cancellation of each other’s MF. In other words, the net MF produced by the closer conductors reduces the MF level associated with the line. Placing the conductors closer together has practical limits, however. The distance between the conductors must be sufficient to maintain adequate electric code clearance at all times, and to assure utility employees’ safety when working on energized lines. One drawback of a close conductor installation is the need for more support structures per mile (to reduce conductor sway in the wind and sag at mid-span); in turn, costs increase, and so do visual impacts.

Conductor Configuration

The arrangement of conductors influences MF. Conductors arranged in a flat, horizontal pattern at standard clearances generally have greater MF levels than conductors arranged vertically. This is due to the wider spacing between conductors found typically on H-frame structure designs, and to the closer distance between all three conductors and the ground. For single-circuit lines, a compact triangular configuration, called a “delta configuration”, generally offers the lowest MF levels. A vertical configuration may cost more and may have increased visual impact. Where the design goal is to minimize MF levels at a specific location within or beyond the ROW, conductor configurations other than vertical or delta may produce equivalent or lower fields.

Optimum Phasing

Optimum phasing applies in situations where more than one circuit exists in an overhead ROW or in a duct bank installed underground. Electric transmission circuits utilize a three-phase system with each phase carried by one conductor, or a bundle of conductors. Optimum phasing reduces MF through partial cancellation. For a ROW with more than two circuits, the phasing arrangement of the conductors of each circuit can generally be optimized to reduce MF levels under typical conditions. The amount of MF cancellation will also vary depending upon the relative loading of each circuit. For transmission lines on the same ROW, optimizing the phasing of the new line with respect to that of existing lines is usually a low-cost method of reducing MF.

MF levels can be reduced for a single circuit line by constructing it as a “split-phase” line with twice as many conductors, and arranging the conductors for optimum cancellation. Disadvantages of the split-phase design include higher cost and increased visual impact.

Increased Voltage

MF are proportional to current, so, for example, replacing a 69-kV line with a 138-kV line, which delivers the same power at half the current, will result in lower MF. This could be an expensive mitigation to address MF alone because it would require the replacement of transformers and substation equipment.

Underground Installation

Burying transmission lines in the earth does not, by itself, provide a shield against MF, since magnetic fields, unlike electric fields, can pass through soil. Instead, certain inherent features of an underground design can reduce MF. The closer proximity of the currents in the wires provides some cancellation of MF, but does not eliminate it entirely. Underground transmission lines are typically three to five feet below ground, a near distance to anyone passing above them, and MF can be quite high directly over the line. MF on either side of an underground line, however, decreases more rapidly with increased distance than the MF from an overhead line.

The greatest reduction in MF can be achieved by “pipe-type” cable installation. This type of cable has all of the wires installed inside a steel pipe, with a pressurized dielectric fluid inside for electrical insulation and cooling. Low MF is achieved through close proximity of the wires, as described above, and through partial shielding provided by the surrounding steel pipe. While this method to reduce MF is effective, system reliability and the environment can be put at risk if the cable is breached and fluid is released.

Lengthy high-voltage underground transmission lines can be problematic due to the operational limits posed by the inherent design. They also can have significantly greater environmental impacts, although visual impacts associated with overhead lines are eliminated. The Council recognizes the operational and reliability concerns associated with current underground technologies and further understands that engineering research regarding the efficiency of operating underground transmission lines is ongoing. Thus, in any new application, the Council may require updates on the feasibility and reliability of the latest technological developments in underground transmission line design.

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Appendix D.2

Field Management Design Plan

Field Management Design Plan

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1.0 Summary and Recommended Design

CL&P reviewed the development along the Preferred Route to determine if there were any areas that should receive attention in a Field Management Design Plan (“FMDP”). There are no public or private schools, licensed youth camps, licensed day-care facilities or public playgrounds along the Preferred Route, but the Council may consider an area towards the northeast end of the Preferred Route to be a residential area. CL&P examined several options to reduce magnetic fields in this area. “No-cost” options such as close phase spacing and best phase arrangement were included in the base design. Other methods were reviewed, however, none of them were “low-cost” options. CL&P therefore recommends the base design with the “no-cost” mitigation measures.

2.0 Council’s Best Management Practices for Electric and Magnetic Fields

The Connecticut Siting Council provides guidance in developing a FMDP for a proposed project. This guidance is found in the *Connecticut Siting Council’s Best Management Practices for Electric and Magnetic Fields*. In this document, the Council prescribes areas for focus in a FMDP and the following guidance for selection of “low-cost” MF management measures.

1. Focus Areas for FMDP – *“The Applicant shall then modify the base design by adding low-cost MF mitigation design features specifically where portions of the project are adjacent to residential areas, public or private schools, licensed child day-care facilities, licensed youth camps, or public playgrounds.”*
2. Low Cost Designs – *“The overall cost of low-cost design features are to be calculated at four percent of the initial project estimated costs, including related substations.”*
3. Target MF Reductions – *“The four percent guideline for low-cost mitigation should aim at a magnetic field reduction of 15 percent or more at the edge of the utility’s ROW.”*

2.1 Focus Areas for FMDP

Applicants are directed to identify any adjacent “residential areas, public or private schools, licensed child day-care facilities, licensed youth camps or public playgrounds” and to focus mitigation efforts on these areas.

2.2 Candidate “Low-Cost” Designs

Applicants are directed to examine costs associated with any field reduction strategies. The BMPs set 4% of total project costs (including substation costs) as a guideline for magnetic field management.

2.3 Target Magnetic Field Reductions

The BMPs state “low-cost” mitigation measures should aim to achieve a 15% reduction at the edge of the utility’s right-of-way. Underground transmission lines are often constructed within public ROWs such as city streets. As such, there is no edge of utility ROW. CL&P calculated fields out to 100 feet on either side of the underground transmission line to compare mitigation options.

3.0 Focus Areas Along Preferred Route

CL&P looked for areas it thought might be considered by the Council to be adjacent “residential areas”. CL&P also referred to the Connecticut Department of Consumer Protection’s online database to identify any licensed child day-care facilities or youth camps near the Preferred Route, and CL&P reviewed the City of Stamford’s website for listings of public playgrounds and all schools. No licensed youth camps, licensed child day-care facilities, schools or public playgrounds were identified within 600 feet of the Preferred Route.

CL&P also used GoogleEarth™ to look at nearby groups of residences that might be considered adjacent residential areas. Two groups of residences adjacent to each other were identified as areas of focus for a FMDP: Lincoln Avenue and Culloden Road.

3.1 Lincoln Avenue

Lincoln Avenue ends at the Glenbrook Substation. Lincoln Avenue has residences on the south side, and commercial facilities on the north side in the vicinity of the Preferred Route. There are 6 houses along a length of 450 feet. This area is highlighted in green in Figure 1 below.

Figure 1 - Focus Area on Lincoln Avenue

3.2 Culloden Road

Culloden Road parallels existing overhead transmission lines and the New York, New Haven, Hartford Railroad corridor. There are 31 residences along a section of approximately 800 feet of Culloden Road next to the Preferred Route.

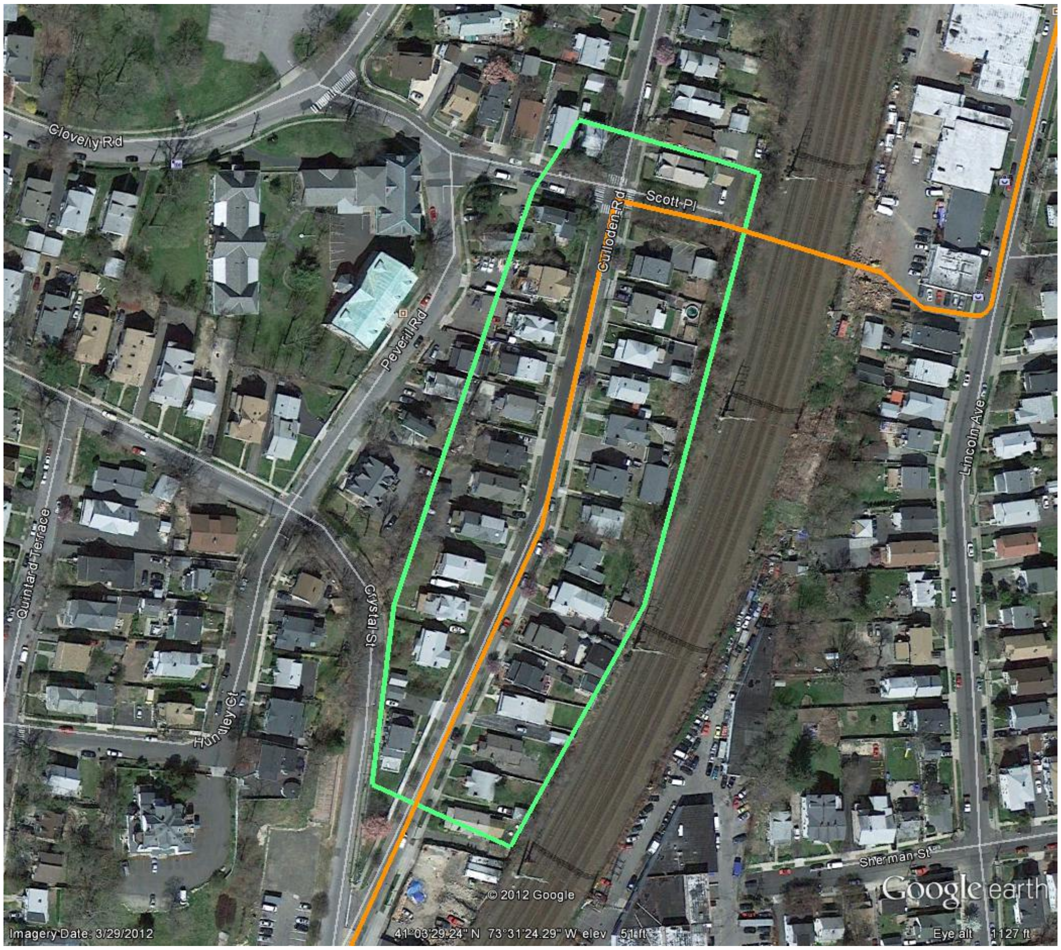


Figure 2 - Focus Area on Culloden Road

4.0 "No-Cost" Mitigation Measures

The Project's base design incorporates two "no-cost" magnetic field reduction measures. These are minimizing the spacing between the cables and arranging the phases of the underground line to achieve better cancellation with the field from the existing overhead transmission lines.

5.0 Options Considered But Dismissed

The following magnetic field management methods were considered but dismissed because of high costs, technical difficulty or limited effectiveness.

5.1 High-Pressure Fluid-Filled Cables

High-Pressure Fluid-Filled ("HPFF") cable systems (also known as "pipe-type" cables) produce lower magnetic fields than XLPE cable systems. 115-kV HPFF systems are very reliable and can operate for many years without faults. However, HPFF cables draw higher charging current than do XLPE cables. HPFF cables also have a large volume of insulating fluid which requires pumping stations and reservoirs and must be closely monitored to prevent leakage.

HPFF cables were examined as a design for the Project. Because such cables are not available with the capacity rating needed for this transmission line, any design would require two cables per phase. Because of the limited space available at the existing South End Substation, there is not enough room to accommodate the additional line position needed to bring in a second cable. Using HPFF for the portion through the focus areas is also not a viable option since HPFF cables cannot be spliced directly to XLPE cables (a transition station would be required). Therefore, the HPFF option was dismissed.

5.2 “Shielding” Plates

CL&P reviewed the use of conducting and steel “shielding” plates. Neither of these options has been implemented on large scale. These plates will tend to cause localized heating over a duct bank, reducing the capacity of the cables. It is also difficult to maintain continuous plating over a duct bank for long distances. Errors in plate welding, frost heaves, corrosion and dig in’s can beak the magnetic or electric path of plates. This will cause elevated magnetic fields in these areas due to fringe field effects. Based on these technical concerns, CL&P dismissed this mitigation option for the focus areas.

5.2.1 Conductive Shielding Plates

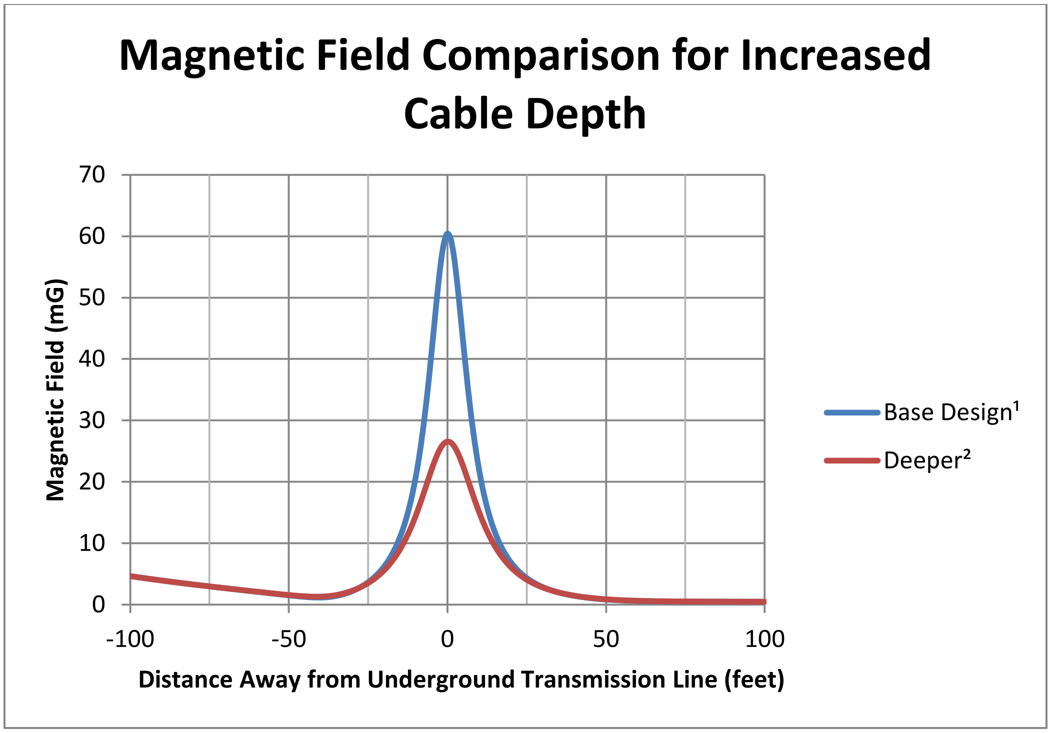
Conductive plates reduce above-ground magnetic fields because eddy currents are magnetically induced in the plate. These eddy currents produce a magnetic field which partially cancels the magnetic fields from the cables.

5.2.2 Steel Shielding Plates

Steel plates (or any relatively high permeability material) reduce above-ground magnetic fields by providing a low reluctance path for magnetic flux (similar to a low resistance path in an electric circuit). Beyond the plates, magnetic fields are thus lower.

5.3 Increased Cable Depths

Increasing the depth of the cables moves the source of the magnetic fields further below ground. Because the field diminishes with distance, this will reduce the magnetic fields above the underground transmission line. However, when moving away from the line, the reduction is lost because the distance from the source is less affected by the depth of the cables.



[1] Base design assumed a depth to the top of cable of 45”

[2] Deeper Design assumed a depth to top of cable of 93”

Figure 3 - Comparison of Calculated Fields for Base Design and Increased Cable Depth

5.4 Cancellation Loops

Cancellation loops work in a similar manner to conductive shielding plates. Cancellation loops employ two or more parallel conductors, such as ground continuity conductors (“GCCs”). The parallel conductors will have a voltage imposed on them through magnetic coupling. If the GCCs are connected together at each vault, then the voltage in this low impedance closed loop causes circulating currents to flow in the GCCs. The GCC currents will produce magnetic fields which will tend to cancel the magnetic fields from the transmission cables, reducing magnetic fields directly over the cables. The design is depicted in Figure 4 where the GCCs would be located in the two conduits for grounding.

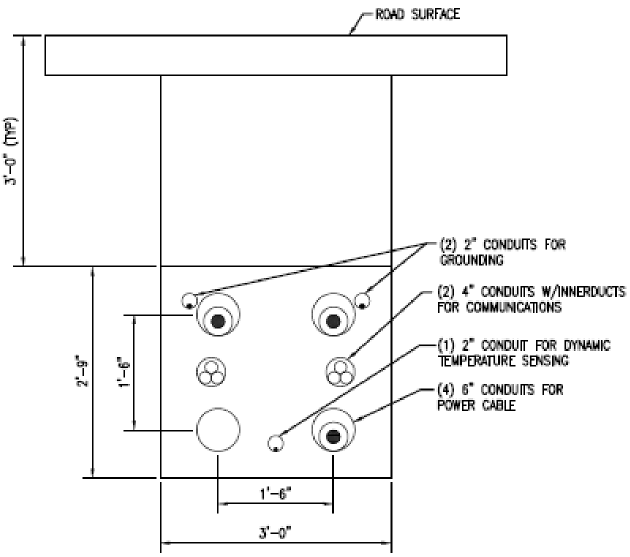


Figure 4 - Cancellation Loop Design

However, away from the cables, the magnetic fields tend to be higher than without the cancellation loop. This is shown in Figure 5 below. Because the fields away from the cables would be higher, CL&P dismissed this option.

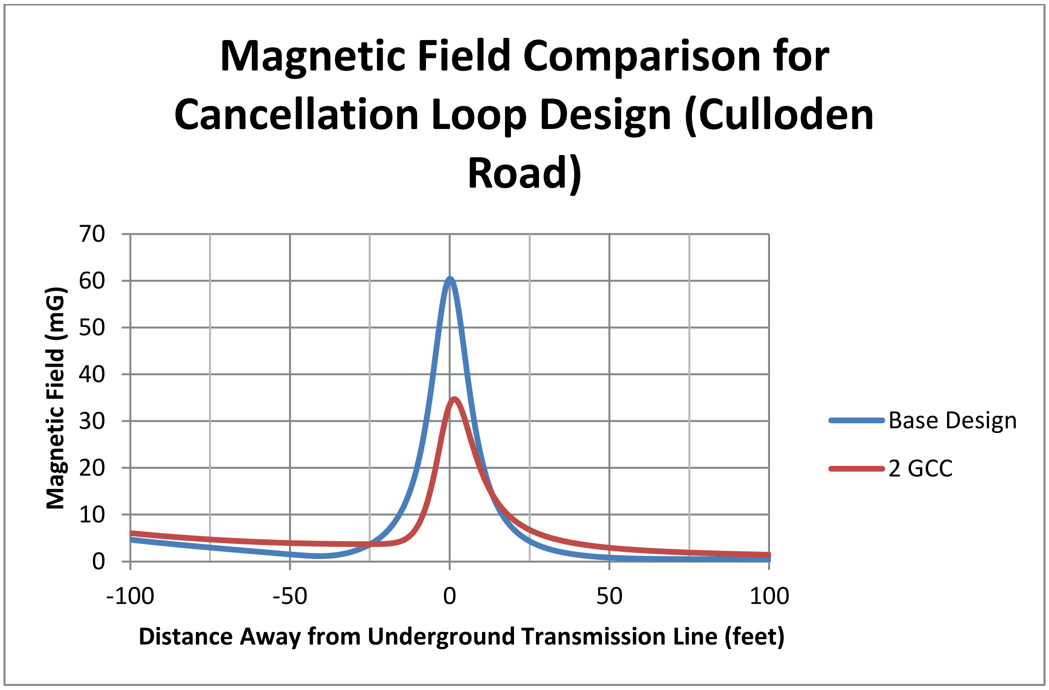


Figure 5 - Comparison of Calculated Fields for Base Design and Cancellation Loop Design

Appendix D.3

Tabulated Calculation Results of Electric and Magnetic Fields

Table 1: Magnetic Fields at Distances from the Center of the Transmission Line (feet) for Average Annual Loading

	Distance	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	225	250	275	300
Lincoln Ave	Pre-Project	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.1	1.3	1.6	1.9	2.5	3.3	4.5	6.7	10.8	19.6	39.2	57.0	40.3	18.4	12.0	12.8
	Post-Project	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.7	1.2	4.7	60.1	4.1	2.0	3.2	5.0	8.1	14.8	29.7	46.5	34.4	15.5	8.6	8.0
Culloden Rd	Pre-Project	19.6	39.2	57.0	40.3	18.4	12.0	12.8	10.8	7.6	5.3	3.8	2.8	2.2	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.6	0.5	0.4	0.4	0.4
	Post-Project	14.9	29.7	46.5	34.3	15.5	8.6	8.0	6.7	4.7	3.0	1.5	3.6	60.4	4.3	0.8	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.2
State St	Pre-Project	3.3	4.5	6.7	10.8	19.6	39.2	57.0	40.3	18.4	12.0	12.8	10.8	7.6	5.3	3.8	2.8	2.2	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.6
	Post-Project	2.5	3.4	5.1	8.2	14.9	29.7	46.6	34.4	15.5	8.7	8.0	3.7	62.7	4.6	1.8	1.5	1.2	1.0	0.9	0.7	0.6	0.5	0.5	0.4	0.4

Table 2: Magnetic Fields at Distances from the Center of the Transmission Line (feet) for Peak Day Average Loading

	Distance	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	225	250	275	300
Lincoln Ave	Pre-Project	0.6	0.7	0.8	0.8	1.0	1.1	1.2	1.4	1.6	1.9	2.3	2.8	3.5	4.5	5.9	8.2	12.1	19.5	35.5	70.8	103.2	72.8	33.3	21.6	23.0
	Post-Project	0.5	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.4	2.4	9.1	116.3	7.9	3.8	6.1	9.6	15.7	28.7	57.4	90.0	66.4	30.1	16.7	15.5
Culloden Rd	Pre-Project	35.5	70.8	103.2	72.8	33.3	21.6	23.0	19.5	13.7	9.5	6.8	5.1	3.9	3.1	2.5	2.1	1.8	1.5	1.3	1.1	1.0	0.9	0.8	0.7	0.7
	Post-Project	28.7	57.4	89.9	66.4	30.0	16.7	15.5	13.0	9.0	5.8	2.9	7.0	116.9	8.4	1.6	1.0	0.9	0.9	0.8	0.7	0.7	0.6	0.5	0.5	0.5
State St	Pre-Project	5.9	8.2	12.1	19.5	35.5	70.8	103.2	72.8	33.3	21.6	23.0	19.5	13.7	9.5	6.8	5.1	3.9	3.1	2.5	2.1	1.8	1.5	1.3	1.1	1.0
	Post-Project	4.8	6.7	9.9	15.9	28.7	57.4	90.0	66.5	30.0	16.9	15.4	7.3	121.3	9.0	3.5	2.9	2.4	2.0	1.7	1.4	1.2	1.1	0.9	0.8	0.7

Table 3: Magnetic Fields at Distances from the Center of the Transmission Line (feet) for Annual Peak Loading

	Distance	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	225	250	275	300
Lincoln Ave	Pre-Project	0.7	0.8	0.9	1.0	1.1	1.3	1.5	1.7	1.9	2.3	2.7	3.3	4.1	5.3	7.0	9.7	14.4	23.2	42.1	84.0	122.4	86.3	39.4	25.5	27.3
	Post-Project	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.2	1.3	1.6	2.8	10.8	137.7	9.4	4.5	7.3	11.3	18.6	34.0	68.0	106.6	78.7	35.6	19.8	18.4
Culloden Rd	Pre-Project	42.1	84.0	122.4	86.3	39.4	25.5	27.3	23.1	16.3	11.3	8.1	6.0	4.7	3.7	3.0	2.5	2.1	1.8	1.6	1.4	1.2	1.1	1.0	0.9	0.8
	Post-Project	34.1	68.1	106.6	78.7	35.6	19.8	18.4	15.4	10.7	6.8	3.5	8.3	138.4	10.0	1.9	1.2	1.1	1.0	0.9	0.9	0.8	0.7	0.6	0.6	0.5
State St	Pre-Project	7.0	9.7	14.4	23.2	42.1	84.0	122.4	86.3	39.4	25.5	27.3	23.1	16.3	11.3	8.1	6.0	4.7	3.7	3.0	2.5	2.1	1.8	1.6	1.4	1.2
	Post-Project	5.7	7.9	11.7	18.8	34.0	68.1	106.7	78.8	35.6	20.0	18.3	8.7	143.6	10.7	4.1	3.4	2.8	2.4	2.0	1.7	1.4	1.3	1.1	1.0	0.9

Table 4: Electric Fields at Distances from the Center of the Transmission Line (feet)

Distance	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	225	250	275	300
Lincoln Ave	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.07	0.09	0.11	0.14	0.17	0.10	0.81	2.23	0.82	0.07	0.31	0.49
Culloden Rd	0.10	0.81	2.23	0.82	0.07	0.31	0.49	0.26	0.07	0.07	0.07	0.06	0.06	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01
State St	0.09	0.11	0.14	0.17	0.10	0.81	2.23	0.82	0.07	0.31	0.49	0.26	0.07	0.07	0.07	0.06	0.06	0.05	0.04	0.03	0.03	0.03	0.02	0.02	0.02

Appendix D.4

Update on Research on Extremely Low Frequency Electric and Magnetic Fields and Health

Health Sciences Practice

Exponent®

Update of Research on Extremely Low Frequency Electric and Magnetic Fields and Health

May 1, 2011 – July 31, 2012

Stamford Reliability Cable Project

Update of Research on Extremely Low Frequency Electric and Magnetic Fields and Health

May 1, 2011 – July 31, 2012

Stamford Reliability Cable Project

Submitted to:

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August 30, 2012

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Acronyms and Abbreviations

AC	Alternating current
AD	Alzheimer’s disease
ALL	Acute lymphoblastic leukemia
ALS	Amyotrophic lateral sclerosis
AMI	Acute myocardial infarction
AML	Acute myeloid leukemia
BMP	Best Management Practices
CI	Confidence interval
CSC	Connecticut Siting Council
CVD	Cardiovascular disease
DMBA	7,12-dimethylbenz[a]anthracene
ELF	Extremely low frequency
EMF	Electric and magnetic fields (or electromagnetic fields)
EPA	Environmental Protection Agency
G	Gauss
GHz	GigaHertz
HCN	Health Council of the Netherlands
HR	Hazard ratio
HRV	Heart rate variability
Hz	Hertz
IARC	International Agency for Research on Cancer
ICNIRP	International Committee on Non-Ionizing Radiation Protection
ISCO	International Standard Classification of Occupations
JEM	Job exposure matrix
kV	Kilovolt
kV/m	Kilovolts per meter
m	Meter
mG	Milligauss
MPE	Maximum permissible exposure

NHL	Non-Hodgkin’s lymphoma
NIEHS	National Institute for Environmental and Health Sciences
NLMS	National Longitudinal Mortality Study
NRPB	National Radiation Protection Board of Great Britain
OR	Odds ratio
ROW	Right of way
RR	Relative Risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SSI	Swiss Radiation Protection Authority
TWA	Time weighted average
V/m	Volts per meter
WHO	World Health Organization

Limitations

At the request of Northeast Utilities, Exponent prepared this summary report on the status of research related to extremely low-frequency electric- and magnetic-field exposure and health. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available, through any additional work, or review of additional work performed by others.

The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

1 Executive Summary

This report was prepared to address the topic of exposure to extremely low frequency (ELF) electric and magnetic fields (EMF) and health for the Connecticut Siting Council at the request of Northeast Utilities as part of its Application for the Stamford Reliability Cable Project.

ELF EMF are invisible fields surrounding all objects that generate, use, or transmit electricity. There are also natural sources of ELF EMF, including the electric fields associated with the normal functioning of our circulatory and nervous systems. People living in developed countries are constantly exposed to ELF EMF in their environments, since electricity is fundamental part of technologically-advanced societies. Sources of man-made ELF EMF include appliances, wiring, and motors, as well as distribution and transmission lines. Section 3 of this report provides information on the nature and sources of ELF EMF, as well as typical exposure levels.

Research on EMF and health began with the goal of finding therapeutic applications and understanding biological electricity, i.e., the role of electrical potentials across cell membranes and current flows between cells in our bodies. Over the past 30 years, researchers have examined whether EMF from man-made sources can cause short- or long-term health effects in humans using a variety of study designs and techniques. Research on ELF EMF and long-term human health effects was prompted by an epidemiology study conducted in 1979 of children in Denver, Colorado, which studied the relationship of their cancers with the potential for ELF EMF exposure from nearby distribution and transmission lines. The results of that study prompted further research on childhood leukemia and other cancers. Childhood leukemia has remained the focus of ELF EMF and health research, although many other diseases have been studied, including other cancers in children and adults, neurodegenerative diseases, reproductive and developmental effects, cardiovascular diseases, and psychological and behavioral effects such as depression or suicide.

Guidance on the possible health risks of all types of exposures comes from health risk assessments, i.e., systematic weight-of-evidence evaluations of the cumulative literature, on a particular topic conducted by expert panels organized by national and international scientific organizations.

The World Health Organization (WHO) published the most recent, comprehensive health risk assessment of EMF in the extremely low frequency (ELF) range in 2007 that critically reviewed the cumulative epidemiologic and laboratory research through 2005, taking into account the strength and quality of the individual research studies. The public and policy makers should look to the conclusions of reviews such as this, since they are conducted by scientists representing the various disciplines required to understand the topic at hand using validated scientific standards and systematic methods. This WHO report was one of the health agency reviews that informed the Connecticut Siting Council when it updated its EMF Best Management Practices in 2007.In a health risk assessment of any exposure, it is essential to consider the type and strength of research studies available for evaluation. Human health studies vary in methodological rigor and, therefore, in their capacity to extrapolate findings to the population at large. Furthermore, all studies in three areas of research—epidemiologic, *in vivo* (experimental whole animal), and *in vitro* (experimental in cells and tissues)—must be evaluated to understand possible health risks.

Section 4 of this report provides a summary of the methods used to conduct a health risk assessment. Section 5 provides a summary of the WHO's conclusions with regard to various health outcomes (childhood leukemia and brain cancer, adult breast cancer, brain cancer, leukemia/lymphoma; reproductive and developmental effects; neurodegenerative disease; and cardiovascular disease). Finally, this report contains a systematic literature review and a critical evaluation of all epidemiology studies in these areas of research and *in vivo* studies of cancer published between May 1, 2011 and July 31, 2012 (Section 6).

Note that this Executive Summary provides only an outline of the material discussed in this report. Exponent's technical evaluations, analyses, conclusions, and recommendations are included in the main body of this report, which at all times the controlling document.

2 Introduction

The World Health Organization (WHO) published a health risk assessment of EMF in the extremely low frequency (ELF) range in 2007 that critically reviewed the cumulative epidemiologic and laboratory research through 2005, taking into account the strength and quality of the individual research studies. The WHO report provided the following overall conclusions:

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (WHO, 2007, p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (WHO, 2007, p. 355).

This report contains a systematic literature review and a critical evaluation of all epidemiology and *in vivo* studies published between May 1, 2011 and July 31, 2012, which updates Exponent's report prepared for Northeast Utilities' Interstate Reliability Project (IRP), "Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: Interstate Reliability Project," dated June 10, 2011. The IRP report systematically evaluated peer-reviewed research and reviews by scientific panels published between January 1, 2006 and May 1, 2011. The IRP report and this report together provide an analysis of the status of research on ELF EMF inclusive of 2006 through mid-2012.

The studies evaluated in that report and the studies evaluated here do not provide sufficient evidence to alter the basic conclusion of the WHO: the research does not support the conclusion that ELF EMF at the levels we encounter in our everyday environment are a cause of cancer or any other disease.

There are no national recommendations, guidelines, or standards in the United States to regulate ELF EMF or to reduce public exposures, although the WHO recommends adherence to the International Commission on Non-Ionizing Radiation Protection's (ICNIRP) standards for the prevention of acute health effects at high exposure levels. In light of the epidemiologic data on childhood leukemia, scientific organizations are still in agreement that only no-cost or low-cost interventions to reduce ELF EMF exposure are appropriate.

This is consistent with the Connecticut Siting Council's (CSC) recommendation for the use of effective no-cost and low-cost technologies to reduce the public's magnetic-field exposure. While the large body of existing research does not indicate any harm associated with ELF EMF, research on this topic will continue to reduce remaining uncertainty.

In response to public concerns regarding ELF EMF and health, the CSC adopted revised "EMF Best Management Practices for the Construction of Electric Transmission Lines in Connecticut" (BMP) on December 14, 2007. The BMP policy is founded on the recognition of consistent conclusions by "a wide range of public health consensus groups," as well as their own commissioned weight-of-evidence review (CSC BMP, 2007, p. 4). The CSC summarized the current scientific consensus by noting the conclusions of these public health consensus groups, including the most comprehensive review by the WHO in 2007, and earlier reviews published by the National Institute for Environmental and Health Sciences (NIEHS) in 1999, the International Agency for Research on Cancer (IARC) in 2002, the Australian Radiation Protection and Nuclear Safety Agency in 2003, the National Radiological Protection Board of Great Britain (NRPB) in 2004, and the Health Council of the Netherlands (HCN) in 2005.

The CSC summarized the current scientific consensus as follows: there is limited evidence from epidemiology studies of a statistical association between estimated, average exposures greater than 3-4 milligauss (mG) and childhood leukemia; the cumulative research, however, does not indicate that magnetic fields are a cause of childhood leukemia, since animal and other experimental studies do not suggest that magnetic fields are carcinogenic and the epidemiology studies are of limited quality. The CSC also noted the WHO's recent conclusion with respect to other diseases: "the scientific evidence supporting an association between ELF magnetic field exposure and all of these health effects is much weaker than for childhood leukemia" (CSC BMP, 2007, p. 2).

Based on this scientific consensus, the CSC concluded that proportional precautionary measures for the siting of new transmission lines in the state of Connecticut should include "the use of effective no-cost and low-cost technologies and management techniques on a project-specific basis to reduce MF [magnetic field] exposure to the public while allowing for the development of efficient and cost-effective electrical transmission projects" (CSC BMP, 2007, p. 11).

The BMP also stated that the CSC will "consider and review evidence of any new developments in scientific research addressing MF [magnetic fields] and public health effects or changes in scientific consensus group positions regarding MF" (CSC BMP, 2007, p. 5).

Since the CSC BMP policies are based largely on the conclusions of the WHO report in 2007, Exponent's report "Current Status of Research on Extremely Low Frequency Electric and Magnetic Fields and Health: Interstate Reliability Project," dated June 10, 2011, provided the CSC with an easily-referenced document that brought the WHO's conclusions up to date. As a follow-up, this current report systematically evaluates peer-reviewed research and reviews by scientific panels published between May 1, 2011 and July 31, 2012. A number of studies published in 2010 are also included because they had not yet been indexed by the Pub Med search engine at the time of Exponent's previous literature search.

3 Extremely Low Frequency Electric and Magnetic Fields: Nature, Sources, Exposure, and Known Effects

Nature of ELF EMF

Electricity is transmitted as current from generating sources to high-voltage transmission lines, substations, distribution lines, and then finally to our homes and workplaces for consumption. The vast majority of electricity is transmitted as alternating current (AC), which changes direction 60 times per second (i.e., a frequency of 60 Hertz [Hz]) in North America. EMF from these AC sources is often referred to as power-frequency or extremely low frequency (ELF) EMF.

Everything that is connected to our electrical system (i.e., power lines, appliances, and wiring) produces ELF EMF (Figure 1). Electric fields and magnetic fields are properties of the space near these electrical sources. Forces are experienced by objects capable of interacting with these fields; electric charges are subject to a force in an electric field, and moving charges experience a force in a magnetic field.

- **Electric fields** are the result of voltages applied to electrical conductors and equipment. The electric field is expressed in measurement units of volts per meter (V/m) or kilovolts per meter (kV/m), where 1 kV/m = 1,000 V/m. Conducting objects including fences, buildings, and our own skin and muscle easily block electric fields. Therefore, certain appliances within homes and workplaces are the major source of electric fields indoors, while power lines are the major source of electric fields outdoors.

- **Magnetic fields** are produced by the flow of electric currents. Unlike electric fields, however, most materials (including the earth) do not readily block magnetic fields. The strength of a magnetic field is expressed as magnetic flux density in units of gauss (G) or milligauss (mG), where 1 G = 1,000 mG.[1] The strength of the magnetic field at any point depends on characteristics of the source, including (in the case of power lines) the arrangement of conductors, the amount of current flow, and distance from the conductors.

Sources and exposure

The intensity of both electric fields and magnetic fields diminishes with increasing distance from the source. For example, higher EMF levels are measured close to the conductors of distribution and transmission lines and decrease rapidly with increasing distance from the conductors. Transmission line EMF generally decreases with distance from the conductors in proportion to the square of the distance, creating a bell-shaped curve of field strength.

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[1] Scientists also refer to magnetic flux density at these levels in units of microtesla (μT). Magnetic flux density in mG units can be converted to μT by dividing by 10, i.e., 1 mG = 0.1 μT.

Since electricity is such an integral part of our infrastructure (e.g., transportation systems, homes, and businesses), people living in modern communities literally are surrounded by these fields (Figure 1). While EMF levels decrease with distance from the source, any home, school, or office tends to have a "background" EMF level as a result of the combined effect of the numerous EMF sources.

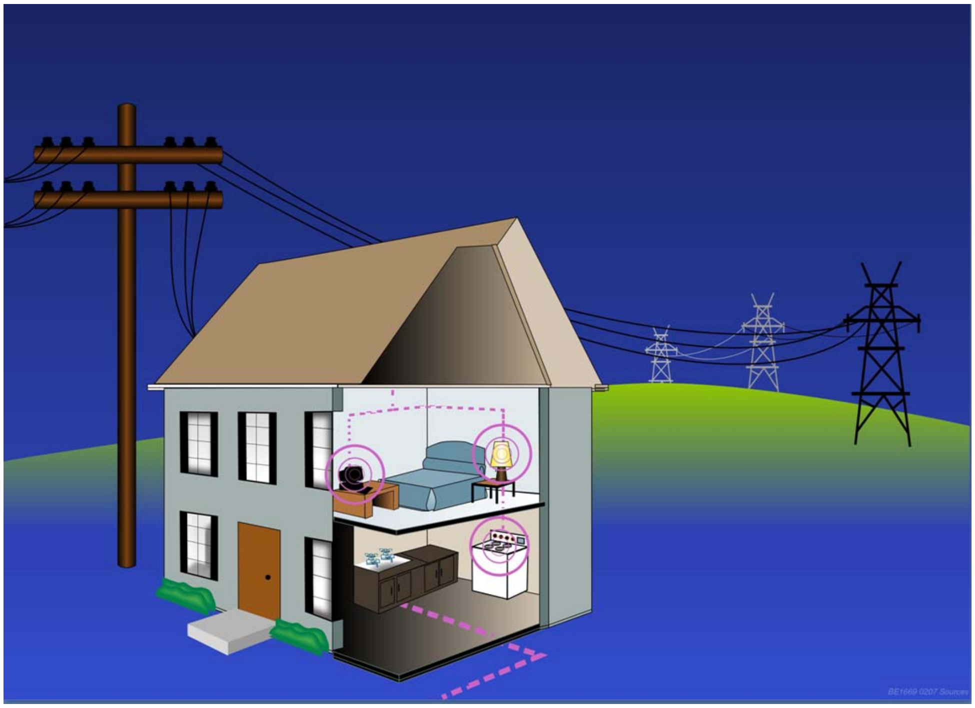

Figure 1. Common sources of ELF EMF in the home (appliances, wiring, currents running on water pipes, and nearby distribution and transmission lines)

Figure 2 outlines typical EMF levels measured in residential settings and occupational environments (all of which contribute to a person's background EMF level) compared to typical EMF levels measured at a typical transmission line's ROW. The fields from underground transmission lines are not included in this figure, as they are a rare source of EMF exposure. The magnetic field over buried conductors can be as high, or even higher, than an overhead line but the magnetic field will diminish more quickly with distance. No electric field will be produced above ground by underground cables. In general, the background magnetic-field level as estimated from the average of measurements throughout a house away from appliances may range up to 5 mG, while levels can be hundreds of mG in close proximity to appliances. Background levels of electric fields range from 0.01-0.02 kV/m, while appliances produce levels up to several tens of V/m (WHO, 1984).

Experiments have yet to show which aspect of ELF EMF exposure, if any, may be relevant to biological systems. The current standard of EMF exposure for health research is long-term, average personal exposure, which is the average of all exposures to the varied electrical sources encountered in the many places we spend our days and nights. As expected, this exposure is different for every person and is difficult to approximate. Exposure assessment is a source of uncertainty in studies of ELF EMF and health (WHO, 2007). Some basic conclusions drawn from surveys of the general public's exposure to magnetic fields are:

- *Residential sources of magnetic-field exposure:*
  - Residential magnetic-field levels are caused by currents carried by nearby transmission and distribution systems, pipes or other conductive paths, and electrical appliances (Zaffanella, 1993).
  - The highest magnetic-field levels are typically found directly next to appliances (Zaffanella, 1993). For example, Gauger (1985) reported the maximum AC magnetic field at 3 centimeters from a sampling of appliances as 3,000 mG (can opener), 2,000 mG (hair dryer), 5 mG (oven), and 0.7 mG (refrigerator).
  - Several parameters affect personal magnetic-field exposures at home: residence type, residence size, type of water line, and proximity to overhead power lines. Persons living in small homes, apartments, homes with metallic piping, and homes close to three-phase electric power distribution and transmission lines tended to have higher at-home magnetic-field levels (Zaffanella and Kalton, 1998).
- *Personal magnetic-field exposure:*
  - A survey of 1,000 randomly selected persons in the United States who wore a magnetic field meter that recorded the magnetic field twice each second reports that the average of all measurements taken over 24-hours, i.e., their time-weighted average (TWA) exposure, is less than 2 mG for the vast majority of persons (Zaffanella and Kalton, 1998).[2]
  - In general, personal magnetic-field exposure is greatest at work and when traveling (Zaffanella and Kalton, 1998).
- *Workplace magnetic-field exposure*
  - Some occupations (e.g., electric utility workers, sewing machine operators, telecommunication workers, industrial welders) have higher exposures due to work near equipment with high ELF EMF levels.[3]
- *Power-line magnetic-field exposure*
  - The EMF levels associated with power lines vary substantially depending on their configuration and current load, among other factors. At a distance of 300 feet and during average electricity demand, however, the magnetic field levels from many

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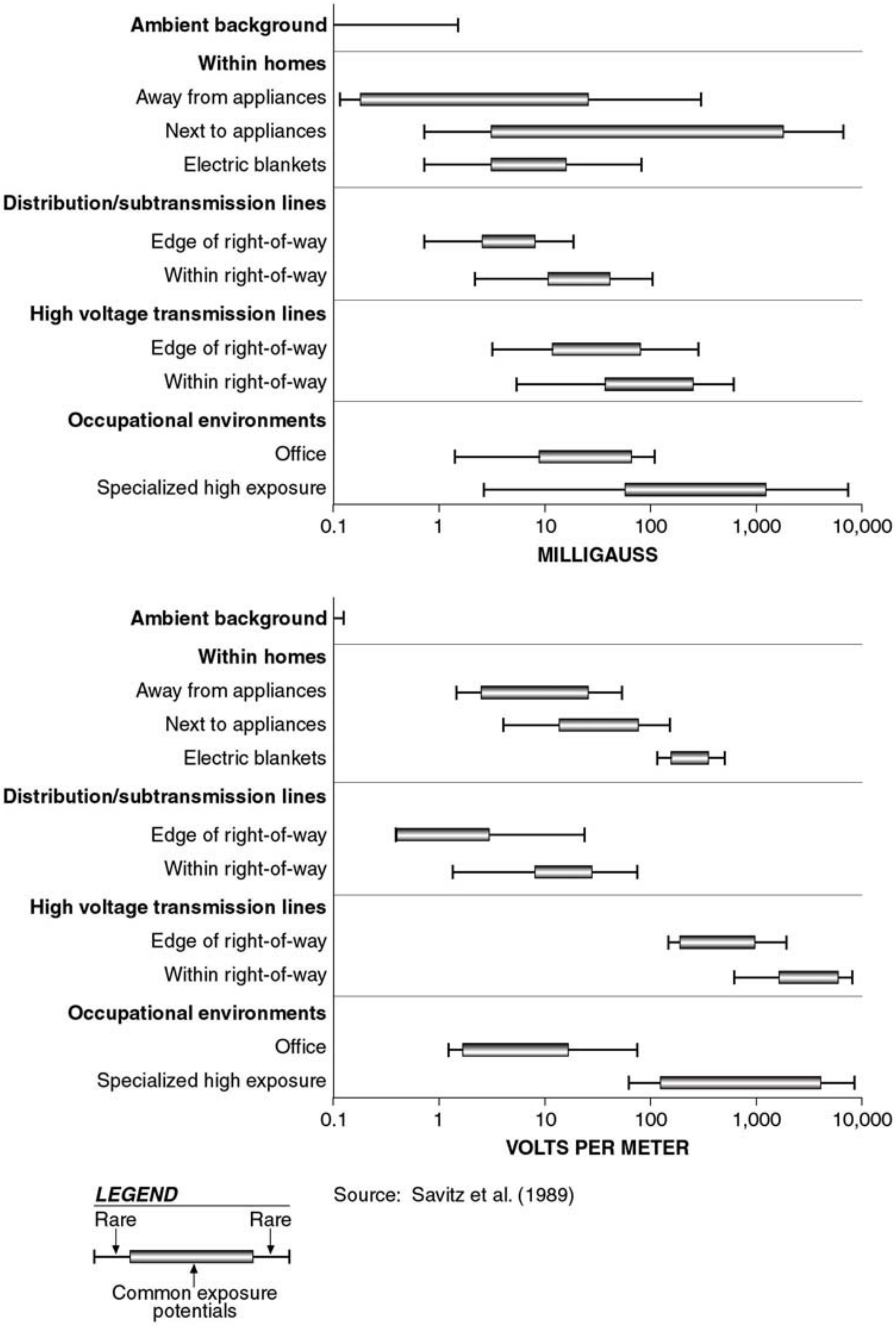
[2] TWA is the average exposure over a given specified time period (i.e., an 8-hour workday or a 24-hour day) of a person's exposure to a chemical or physical agent. The average is determined by sampling the exposure of interest throughout the time period.

[3] http://www.niehs.nih.gov/health/assets/docs_p_z/emf-02.pdf

transmission lines are often similar to the background levels found in most homes (Figure 2).



Source: Savitz et al. (1989)

Figure 2. Magnetic and electric field levels in the environment

Known effects

There is a greater opportunity for long-term exposure to magnetic fields since electric fields are effectively blocked by common objects. For this reason, among others, research on long-term health effects has focused on magnetic fields rather than electric fields. In addition, magnetic fields can induce electric currents in other materials, while electric fields cannot.

Like virtually any exposure, adverse effects can be expected from exposure to very high levels of ELF EMF. If the current density or electric field induced by an extremely strong magnetic field exceeds a certain threshold, excitation of muscles and nerves is possible. Also, strong electric fields can induce charges on the surface of the body or ungrounded objects that can lead to small shocks, i.e., micro shocks. These effects have no long-term damage or health consequences. Limits for the general public and workplace have been set to prevent these effects, but there are no real-life situations where these levels are exceeded on a regular basis.

Two international scientific organizations, ICNIRP and the International Committee on Electromagnetic Safety (ICES), have published guidelines for limiting public exposure to ELF EMF to protect against these acute effects (ICES, 2002; ICNIRP, 2010). These guidelines were developed following weight-of-evidence reviews of the literature, including epidemiologic and experimental evidence related to both short-term and long-term exposure.[4] Both reviews concluded that the stimulation of nerves and the central nervous system could occur at very high exposure levels immediately upon exposure, but that the research did not suggest any long-term health effects.

The ICNIRP guideline states that exposure to magnetic fields should be below 2,000 mG for the general public and 4,200 mG for workers "[to] provide protection against all established adverse health effects" (ICNIRP, 2010). The ICES recommends a maximum permissible magnetic-field exposure of 9,040 mG for the general public (ICES, 2002). For reference, in a survey by Zaffanella and Kalton (1998), only about 1.6% of the general public experienced exposure to magnetic fields of at least 1,000 mG during a 24-hour period.

The ICNIRP's screening value for exposure to 60-Hz electric fields for the general public is 4.2 kV/m and the ICES screening value is 5 kV/m. Both organizations allow higher exposures if it can be demonstrated that exposures do not produce electric fields within tissues that exceed basic restrictions on internal electric fields.

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[4] Valberg et al. (2011) provides a listing of guidelines provided by health and safety organizations.

Table 1. Reference levels for whole body exposure to 60-Hz fields: general public

Organization recommending limit	Magnetic fields	Electric fields
ICNIRP restriction level	2,000 mG	4.2 kV/m
ICES maximum permissible exposure (MPE)	9,040 mG	5 kV/m 10 kV/m[a]

[a] This is an exception within transmission line ROWs because people do not spend a substantial amount of time in ROWs and very specific conditions are needed before a response is likely to occur (i.e., a person must be well insulated from ground and must contact a grounded conductor) (ICES, 2002, p. 27).

The recent literature includes a number of studies of workers with the potential for high field exposures that characterize occupational exposure and evaluate compliance with standards. They include a study of spot measurements of EMF during work tasks at 110-kV switching and transforming stations in Finland to evaluate compliance with ICNIRP reference levels (Korpinen et al., 2011a) and a study of occupational electric field exposure at the same 110-kV switching station that evaluated compliance with the European Union's Directive 2004/40/EC (Korpinen et al., 2012); 3-hour TWA magnetic-field measurements of dentists and spot measurements near dental equipment in Taiwan (Huang et al., 2011); spot measurements and personal monitoring of magnetic fields in hospital personnel in Spain (Ubeda et al., 2011); spot measurements and personal monitoring of magnetic fields in railway workers in Italy (Contessa et al., 2010); and a study of electric fields, current densities, and contact currents at a 400-kV substation in Finland (Korpinen et al., 2011b). In general, the measured magnetic fields were below the occupational reference values of ICNIRP in these studies. At some locations within substations, worker exposure to electric fields could exceed the reference level (Korpinen et al., 2011b, 2012), but the induced current density in the central nervous system did not exceed the ICNIRP basic restriction value.

Methods for Evaluating Scientific Research

Science is more than a collection of facts. It is a method of obtaining information and of reasoning to ensure that the information and conclusions are accurate and correctly describe physical and biological phenomena. Many misconceptions in human reasoning occur when people casually interpret their observations and experience. Therefore, scientists use systematic methods to conduct and evaluate scientific research and assess the potential impact of a specific agent on human health. This process is designed to ensure that more weight is given to those studies of better quality and studies with a given result are not selected out from all of the studies available to advocate or suppress a preconceived idea of an adverse effect. Scientists and scientific agencies and organizations use these standard methods to draw conclusions about the many exposures in our environment.

Weight-of-evidence reviews

The scientific process entails looking at *all* the evidence on a particular issue in a systematic and thorough manner to evaluate if the overall data presents a logically coherent and consistent picture. This is often referred to as a weight-of-evidence review, in which all studies are considered together, giving more weight to studies of higher quality and using an established analytic framework to arrive at a conclusion about a possible causal relationship. Weight-of-evidence reviews are typically conducted within the larger framework of health risk assessments or evaluations of particular exposures or exposure circumstances that qualitatively and quantitatively define health risks. Weight-of-evidence and health risk assessment methods have been described by several agencies, including the IARC, which routinely evaluates substances such as drugs, chemicals, and physical agents for their ability to cause cancer; the WHO International Programme for Chemical Safety; and the US Environmental Protection Agency (EPA), which set guidance for public exposures (WHO, 1994; USEPA, 1993; USEPA, 1996). Two steps precede a weight-of-evidence evaluation: a systematic review to identify the relevant literature and an evaluation of each study to determine its strengths and weaknesses.

The following sections discuss important considerations in the evaluation of human health studies of ELF EMF in a weight-of-evidence review, including exposure considerations, study design, methods for estimating risk, bias, and the process of causal inference. The purpose of discussing these considerations here is to provide context for the later weight-of-evidence evaluations.

EMF exposure considerations

Exposure methods range widely in studies of EMF, including: the classification of residences based on the relative capacity of nearby power lines to produce magnetic fields (i.e., wire code categories); occupational titles; calculated magnetic-field levels based on job histories (a job-exposure matrix [JEM]); residential distance from nearby power lines; spot measurements of magnetic-field levels inside or outside residences; 24-hour and 48-hour measurements of magnetic fields in a particular location in the house, e.g., a child's bedroom; calculated magnetic-field levels based on the characteristics of nearby power installations; and, finally, personal 24-hour and 48-hour magnetic-field measurements.

Each of these methods has strengths and limitations (Kheifets and Oksuzyan, 2008). Since magnetic-field exposures are ubiquitous and vary over a lifetime as the places we frequent and the sources of EMF in those places change, making valid estimates of personal magnetic-field exposure is challenging. Furthermore, without a biological basis to define a relevant exposure metric (average, peak, etc.) and a defined critical period for exposure (*in utero*, shortly before diagnosis, etc.), relevant and valid assessments of exposure are problematic. Exposure misclassification is one of the most significant concerns in studies of ELF EMF.

In general, long-term personal measurements are the metrics selected by epidemiologists. Other methods are generally weaker because they may not be strong predictors of long-term exposure and do not take into account all magnetic-field sources. EMF can be estimated indirectly by assigning an estimated amount of EMF exposure to an individual based on calculations considering nearby power installations or a person's job title. For example, a relative estimate of exposure could be assigned to all machine operators based on historical information on the magnitude of the magnetic field produced by the machine. Indirect measurements are not as accurate as direct measurements because they do not contain information specific to that person or the exposure situation. In the example of machine operators, the indirect measurement may not account for how much time any one individual spends working at that machine or any potential variability in magnetic fields produced by the machines over time, and occupational measurements do not take into account the worker's residential magnetic-field exposures.

While an advance over earlier methods, JEMs still have some important limitations, as highlighted in a review by Kheifets et al. (2009) summarizing an expert panel's findings.[5] A person's occupation provides some relative indication of the overall magnitude of his or her occupational magnetic-field exposure, but 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. This was highlighted in a study of 48-hour magnetic-field measurements of 543 workers in Italy in a variety of occupational settings, including: ceramics, mechanical engineering, textiles, graphics, retail, food, wood and biomedical industries (Gobba et al., 2011). There was significant variation in this study between the measured TWA magnetic-field levels for workers in many of the International Standard Classification of Occupations' (ISCO) job categories, which the authors attributed to variation in industry within the task-defined ISCO categories.

Types of health research studies

Research studies can be broadly classified into two groups: 1) epidemiologic observations of people and 2) experimental studies on animals, humans, cells, and tissues in laboratory settings. Epidemiology studies investigate how disease is distributed in populations and what factors influence or determine this disease distribution (Gordis, 2000). Epidemiology studies attempt to establish causes for human disease while observing people as they go about their normal, daily lives. Such studies are designed to quantify and evaluate the associations between disease and reported exposures to environmental factors.

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

Experimental studies are designed to test specific hypotheses under controlled conditions and are vital to assessing cause-and-effect relationships. An example of a human experimental study relevant to this area of research would be a study that measures the impact of magnetic-field

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

exposure on acute biological responses in humans, such as hormone levels. These studies are conducted in laboratories under controlled conditions.

In vivo and *in vitro* experimental studies are also conducted under controlled conditions in laboratories. *In vivo* studies expose laboratory animals to very high levels of a chemical or physical agent to determine whether exposed animals develop cancer or other effects at higher rates than unexposed animals, while attempting to control other factors that could possibly affect disease rates (e.g., diet and genetics). *In vitro* studies of isolated cells and tissues are also important because they can help scientists understand biological mechanisms as they relate to the same exposure in intact humans and animals.

The results of experimental studies of animals, and particularly those of isolated tissues or cells, however, may not always be directly extrapolated to human populations. In the case of *in vitro* studies, the responses of cells and tissues outside the body may not reflect the response of those same cells if maintained in a living system, so their relevance cannot be assumed. Therefore, it is both necessary and desirable to explore agents that could present a potential health threat in epidemiology studies as well.

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

Estimating risk

Epidemiologists measure the statistical association between exposures and disease in order to estimate risk. In this context, risk simply refers to an exposure that is associated with a health event and does not imply that a causal relationship has been established.[6] This brief summary of risk is included to provide a foundation for understanding and interpreting statistical associations in epidemiology studies as risk estimates.

Two common types of risk estimates are absolute risk and relative risk (RR). Absolute risk, also known as incidence, is the amount of new disease that occurs in a given period of time. For example, the absolute risk of invasive childhood cancer in children ages 0-19 years for 2004 was 14.8 per 100,000 children (Ries et al., 2007). RR estimates are calculated to evaluate whether a particular exposure or inherent quality (e.g., EMF, diet, genetics, race) is associated with a disease outcome. This is calculated by looking at the absolute risk in one group relative to a comparison group. For example, white children in the 0-19 year age range had an estimated

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[6] The following definition is provided of "risk" in a dictionary of epidemiology terms: "…an aspect of personal behavior or lifestyle, an environmental exposure, or an inborn or inherited characteristic, that, on the basis of epidemiological evidence, is known to be associated with health-related condition(s) considered important to prevent" (Last, 1991).

absolute risk of childhood cancer of 15.4 per 100,000 in 2004, and African American children had an estimated absolute risk of 13.3 per 100,000 in the same year. By dividing the absolute risk of white children by the absolute risk of African American children, we obtain a RR estimate of 1.16. This RR estimate can be interpreted to mean that white children have a risk of childhood cancer that is 16% greater than the risk of African American children. Additional statistical analysis is needed to evaluate whether this association is statistically significant, as defined in the following sub-section.

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

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

Statistical significance

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

Confidence intervals (CI) are typically reported along with RR and OR values. A CI is a range of values for an estimate of effect that has a specified probability (e.g., 95%) of including the "true" estimate of effect; CIs evaluate statistical significance, but do not address the role of bias, as described further below. A 95% CI indicates that, if the study were conducted a very large number of times, 95% of the measured estimates would be within the upper and lower confidence limits.

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

Meta-analysis and pooled analysis

In epidemiologic research, the results of studies with a smaller number of participants may be difficult to distinguish from normal, random variation. This is also the case for sub-group analyses where few cases are estimated to have high exposure levels, e.g., in case-control studies of childhood leukemia and TWA magnetic-field exposure greater than 3-4 mG. Meta-analysis is an analytic technique that combines the published results from a group of studies into one summary result. A pooled analysis, on the other hand, combines the raw, individual-level data from the original studies and analyzes all of the data from the studies together. These methods are valuable because they increase the number of individuals in the analysis, which allows for a more robust and stable estimate of association. Meta- and pooled analyses are also an important tool for qualitatively synthesizing the results of a large group of studies.

The disadvantage of meta- and pooled analyses is that they can convey a false sense of consistency across studies if *only* the combined estimate of effect is considered (Rothman and Greenland, 1998). These analyses typically combine data from studies with different study populations, methods for measuring and defining exposure, and disease definitions. This is particularly true for analyses that combine data from case-control studies, which often use very different methods for the selection of cases and controls and exposure assessment. Therefore, in addition to the synthesis or combining of data, meta- and pooled analyses should be used to understand what factors cause the results of the studies to vary (publication date, study design, possibility of selection bias, etc.), and how these factors affect the associations calculated from the data of all the studies combined (Rothman and Greenland, 1998).

Meta- and pooled analyses are a valuable technique in epidemiology; however, in addition to calculating a summary RR, they should follow standard techniques (Stroup et al., 2001) and analyze the factors that contribute to any heterogeneity between the studies.

Bias in epidemiologic studies

One key reason that results of epidemiology studies cannot directly provide evidence for cause-and-effect is the presence of bias. Bias is defined as "any systematic error in the design, conduct or analysis of a study that results in a mistaken estimate of an exposure's effect on the risk of disease" (Gordis, 2000, p. 204). In other words, sources of bias are factors or research situations that can mask a true association or cause an association that does not truly exist. As a result, the extent of bias, as well as its types and sources, is one of the most important considerations in the interpretation of epidemiology studies. Since it is not possible to fully control human populations, perfectly measure their exposures, or control for the effects of all other risk factors, bias will exist in some form in all epidemiology studies of human health. Experimental studies, on the other hand, more effectively manage bias because of the tight control the researchers have over most study variables.

One important source of bias occurs when a third variable confuses the relationship between the exposure and disease of interest because of its relationship to both. Consider an example of a researcher whose study finds that people who exercise have a lower risk of diabetes compared to people who do not exercise. It is known that people who exercise more also tend to consume healthier diets and healthier diets may lower the risk of diabetes. If the researcher does not control for the impact of diet, it is not possible to say with certainty that the lower risk of diabetes is due to exercise and not to a healthier diet. In this example, diet is the confounding variable.

Cause vs. association and evaluating evidence regarding causal associations

Epidemiology studies can help suggest factors that may contribute to the risk of disease, but they are not used as the sole basis for drawing inferences about cause-and-effect relationships. Since epidemiologists do not have control over the many other factors to which people are exposed in their studies (e.g., chemicals, pollution, infections) and diseases can be caused by a complex interaction of many factors, the results of epidemiology studies must be interpreted with caution. A single epidemiology study is rarely unequivocally supportive or non-supportive of causation; rather, a weight is assigned to the study based on the validity of its methods and all studies (epidemiology, *in vivo*, and *in vitro*) must be considered together in a weight-of-evidence review to arrive at a conclusion about possible causality between an exposure and disease.

In 1964, the Surgeon General of the United States published a landmark report on smoking-related diseases (HEW, 1964). As part of this report, nine criteria for evaluating epidemiology studies (along with experimental data) for causality were outlined. In a more recent version of this report, these criteria have been reorganized into seven criteria. In the earlier version, coherence, plausibility, and analogy were considered as distinct items, but are now summarized together because they have been treated in practice as essentially reflecting one concept (HHS, 2004). Table 2 provides a listing and brief description of each criterion.

Table 2. Criteria for evaluating whether an association is causal

Criteria	Description
Consistency	Repeated observation of an association between exposure and disease in multiple studies of adequate statistical power, in different populations, and at different times.
Strength of the association	The larger (stronger) the magnitude and statistical strength of an association is between exposure and disease, the less likely such an effect is the result of chance or unmeasured confounding.
Specificity	The exposure is the single (or one of a few) cause of disease.
Temporality	The exposure occurs prior to the onset of disease.

Criteria	Description
Coherence, plausibility, and analogy	The association cannot violate known scientific principles and the association must be consistent with experimentally demonstrated biologic mechanisms.
Biologic gradient	This is also known as a dose-response relationship, i.e., the observation that the stronger or greater the exposure is, the stronger or greater the effect.
Experiment	Observations that result from situations in which natural conditions imitate experimental conditions. Also stated as a change in disease outcome in response to a non-experimental change in exposure patterns in population.

Source: Department of Health and Human Services, 2004

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

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

Biological response vs. disease in human health

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

4 The WHO 2007 Report: Methods and Conclusions

The WHO is a scientific organization within the United Nations system whose mandate includes providing leadership on global health matters, shaping health research agendas, and setting norms and standards. The WHO established the International EMF Project in 1996, in response to public concerns about exposures to EMF and possible adverse health outcomes. The project's membership includes 8 international organizations, 8 collaborating institutions, and over 54 national authorities. The overall purpose of the Project is to assess health and environmental effects of exposure to static and time-varying fields in the frequency range 0-300 Gigahertz (GHz). A key objective of the EMF Project was to evaluate the scientific literature and make a status report on health effects to be used as the basis for a coherent international response, including the identification of important research gaps and the development of internationally acceptable standards for EMF exposure.

Methods

As part of their Environmental Health Criteria Programme, the WHO published a Monograph in June 2007 summarizing health research on exposures in the ELF range. The Monograph used standard scientific procedures, as outlined in its Preamble and described above in Section 4, to conduct the review. The Task Group responsible for the report's overall conclusions consisted of 21 scientists from around the world with expertise in a wide range of disciplines. The Task Group relied on the conclusions of previous weight-of-evidence reviews,[7] where possible, and mainly focused on evaluating studies published after an IARC review of ELF EMF (with regard to cancer) in 2002 .

The WHO Task Group and IARC use specific terms to describe the strength of the evidence in support of causality between specific agents and cancer. These categories are described here because, while they are meaningful to scientists who are familiar with the IARC process, they can create an undue level of concern with the general public.

Sufficient evidence of carcinogenicity is assigned to a body of epidemiologic research if a positive association has been observed in studies in which chance, bias, and confounding can be ruled out with reasonable confidence. *Limited evidence of carcinogenicity* describes a body of epidemiologic research where the findings are inconsistent or there are outstanding questions about study design or other methodological issues that preclude making a conclusion. *Inadequate evidence of carcinogenicity* describes a body of epidemiologic 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. A similar classification system is used for evaluating *in vivo* studies and mechanistic data for carcinogenicity.

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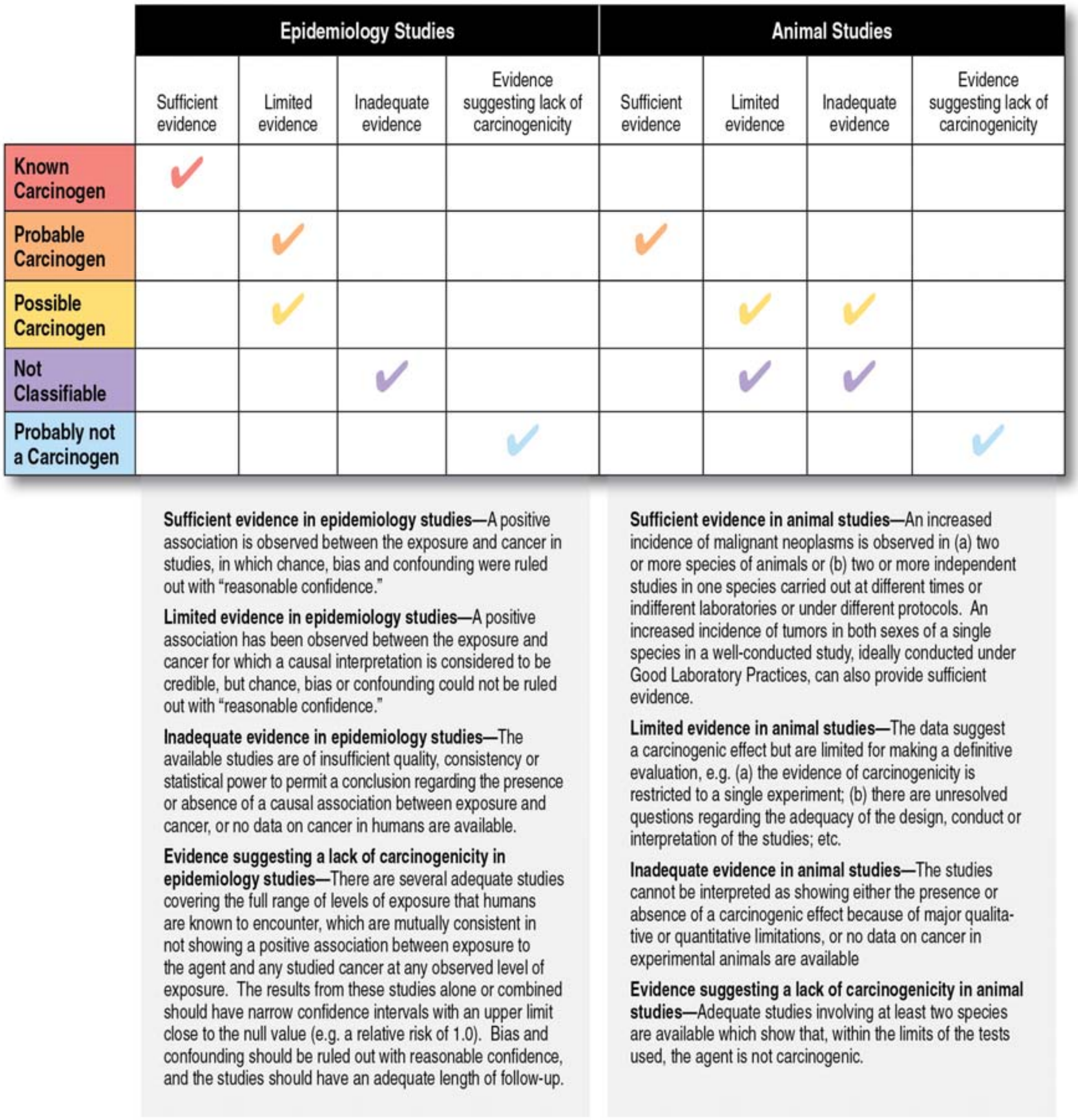
[7] The term "weight-of-evidence review" is used in this report to denote a systematic review process by a multidisciplinary, scientific panel involving experimental and epidemiologic research to arrive at conclusions about possible health risks. The WHO Monograph on EMF does not specifically describe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

Summary categories are assigned by considering the conclusions of each body of evidence (epidemiologic, *in vivo*, and *in vitro*) together (Figure 3). *In vitro* research is not described in Figure 3 because it provides ancillary information and, therefore, is used to a lesser degree in evaluating carcinogenicity and is classified simply as strong, moderate, or weak. Categories include (from highest to lowest risk): carcinogenic to humans, probably carcinogenic to humans, possibly carcinogenic to humans, unclassifiable, and probably not carcinogenic to humans. These categories are intentionally meant to err on the side of caution, giving more weight to the possibility that the exposure is truly carcinogenic and less weight to the possibility that the exposure is not carcinogenic. The category "possibly carcinogenic to humans" denotes exposures for which there is limited evidence of carcinogenicity in epidemiology studies and less than sufficient evidence of carcinogenicity in studies of experimental animals.



	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 3. Basic IARC method for classifying exposures based on potential carcinogenicity

The IARC has reviewed over 900 substances and exposure circumstances to evaluate their potential carcinogenicity. Over 80% of exposures fall in the categories possible carcinogen (27%) or non-classifiable (55%). This occurs because 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. Throughout the history of the IARC, only one agent has been classified as probably not a carcinogen, which illustrates the conservatism of the evaluations and the difficulty in proving the absence of an effect beyond all doubt.

Conclusions

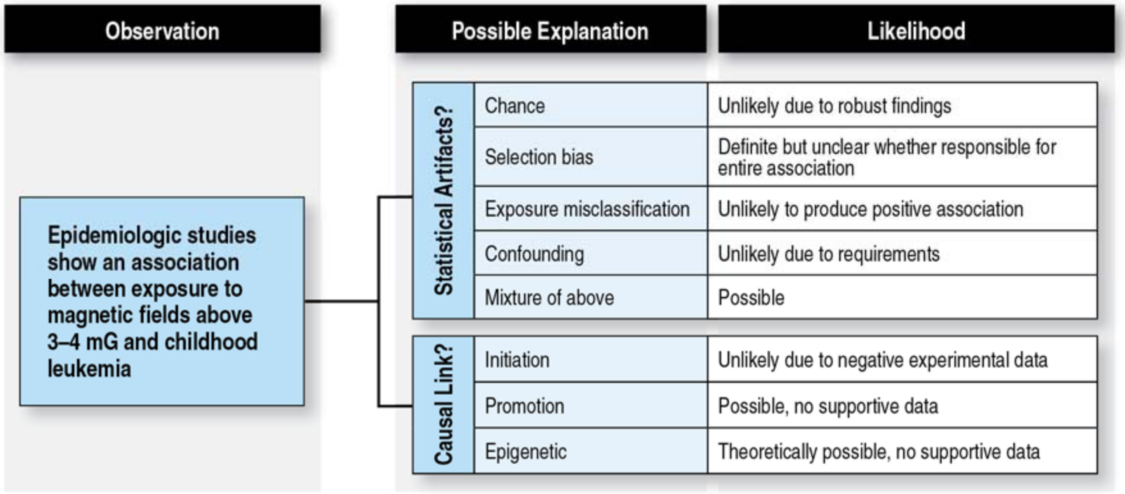
The WHO report provided the following overall conclusions with regard to ELF EMF:

> New human, animal, and in vitro studies published since the 2002 IARC Monograph, 2002 [*sic*] do not change the overall classification of ELF as a possible human carcinogen (WHO, 2007, p. 347).
>
> Acute biological effects [i.e., short-term, transient health effects such as a small shock] have been established for exposure to ELF electric and magnetic fields in the frequency range up to 100 kHz that may have adverse consequences on health. Therefore, exposure limits are needed. International guidelines exist that have addressed this issue. Compliance with these guidelines provides adequate protection. Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukaemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted (WHO, 2007, p. 355).

With regard to specific diseases, the WHO concluded the following:

Childhood cancers. The WHO report paid particular attention to childhood leukemia because the most consistent epidemiologic association in the area of ELF EMF and health research has been reported between this disease and TWA exposure to high, magnetic-field levels. Two pooled analyses reported an association between childhood leukemia and TWA magnetic-field exposure >3-4 mG (Ahlbom et al., 2000; Greenland et al., 2000); it is this data, categorized as limited epidemiologic evidence, that resulted in the classification of magnetic fields as possibly carcinogenic by the IARC in 2002.

The WHO report systematically evaluated several factors that might be partially, or fully, responsible for the consistent association, including: chance, misclassification of magnetic-field exposure, confounding from hypothesized or unknown risk factors, and selection bias (Figure 4). The authors concluded that chance is an unlikely explanation since the pooled analyses had a large sample size and decreased variability. Control selection bias probably occurs to some extent in these studies and would result in an overestimate of the true association, but would not explain the entire observed association. It is less likely that confounding occurs, although the possibility that some yet-to-be identified confounder is responsible for the association cannot be fully excluded. Finally, exposure misclassification would likely result in an underestimate of the true association, although that may not always be the case. The WHO concluded that reconciling the epidemiologic data on childhood leukemia and the negative experimental findings (i.e., no hazard or risk observed) 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 likely be minimal, if the association was determined to be causal.



Observation		Possible Explanation	Likelihood
Epidemiologic studies show an association between exposure to magnetic fields above 3–4 mG and childhood leukemia	Statistical Artifacts?	Chance	Unlikely due to robust findings
		Selection bias	Definite but unclear whether responsible for entire association
		Exposure misclassification	Unlikely to produce positive association
		Confounding	Unlikely due to requirements
		Mixture of above	Possible
	Causal Link?	Initiation	Unlikely due to negative experimental data
		Promotion	Possible, no supportive data
		Epigenetic	Theoretically possible, no supportive data

Source: Adapted from Schüz and Ahlbom (2008)

Figure 4. Possible explanations for the observed association between magnetic fields and childhood leukemia

Fewer studies have been published on magnetic fields and childhood brain cancer compared to studies of childhood leukemia. The WHO Task Group described the results of these studies as inconsistent and limited by small sample sizes and recommended a meta-analysis to clarify the research findings.

Breast cancer. The WHO concluded that recently published studies on breast cancer and ELF EMF exposure were higher in quality compared with previous studies, and for that reason, they provide strong support to previous consensus statements that magnetic-field exposure does not influence the risk of breast cancer. In summary, the WHO stated "[w]ith these [recent] studies, the evidence for an association between ELF magnetic-field exposure and the risk of female breast cancer is weakened considerably and does not support an association of this kind" (WHO, 2007, p. 9). The WHO recommended no further research with respect to breast cancer and magnetic-field exposure.

Adult leukemia and brain cancer. 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 diseases remains inadequate" (WHO, 2007, p. 307). The WHO panel recommended updating the existing cohorts of occupationally-exposed individuals in Europe and pooling the epidemiologic data on brain cancer and adult leukemia to confirm the absence of an association.

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

In vitro research on carcinogenesis. The WHO concluded that magnetic-field exposure below 50,000 mG was not associated with genotoxicity *in vitro*. There was some evidence, however, to suggest that magnetic fields above these levels might interact with other genotoxic agents to induce damage. Evidence for an association between magnetic fields and altered apoptosis or expression of genes controlling cell cycle progression was considered inadequate.

Reproductive and developmental effects. The WHO concluded that, overall, the body of research does not suggest that maternal or paternal exposures to ELF EMF cause adverse reproductive or developmental outcomes. The evidence from epidemiology studies on miscarriage was described as inadequate and further research on this possible association was recommended, although it was designated as low priority.

In vivo research on reproductive and developmental effects. The WHO Task Group concluded that the available *in vivo* studies were inadequate for drawing conclusions regarding the potential effects of magnetic fields on the reproductive system. Furthermore, the Task Group concluded that studies conducted in mammalian models showed no adverse developmental effects associated with magnetic-field exposure.

Neurodegenerative disease. The WHO reported that the majority of epidemiology studies have reported associations between occupational magnetic-field exposure and mortality from Alzheimer's disease (AD) and amyotrophic lateral sclerosis (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). The WHO concluded that there is inadequate data in support of an association between magnetic fields and AD or ALS. The panel highly recommended that further studies be conducted in this area, particularly studies where the association between magnetic fields and ALS is estimated while controlling for the possible confounding effect of electric shocks.

In vivo research on neurological effects. The WHO stated that various animal models were used to investigate possible field-induced effects on brain function and behavior. Few brief, transient responses had been identified.

Cardiovascular disease. It has been hypothesized that magnetic-field exposure reduces heart rate variability (HRV), which in turn increases the risk for acute myocardial infarction (AMI). With one exception (Savitz et al., 1999), however, none of the studies of cardiovascular disease morbidity and mortality has shown an association with exposure. Whether a specific association exists between exposure and altered autonomic control of the heart remains speculative and the overall evidence does not support an association. Experimental studies of both short- and long-term exposure indicate that, while electric shock is an obvious health hazard, other hazardous cardiovascular effects associated with ELF EMF are unlikely to occur at exposure levels commonly encountered environmentally or occupationally.

5 Current Scientific Consensus

The following sections identify and describe epidemiology and *in vivo* studies related to ELF EMF and health published from May 1, 2011 through July 31, 2012. The purpose of this section is to evaluate whether the findings of these recent studies alter the conclusions published by the WHO in their 2007 report, as described in Section 5.

Literature search methodology

A structured literature search was conducted using PubMed, a search engine provided by the National Library of Medicine and the National Institutes of Health that includes over 15 million up-to-date citations from MEDLINE and other life science journals for biomedical articles (http://www.pubmed.gov). A well-defined search strategy was used to identify literature indexed May 1, 2011 through July 31, 2012.[8] While PubMed contains an extensive database of publications, some studies are indexed well after their publication date. For that reason, there are several studies included in this report that were published prior to May 1, 2011, but indexed after that date. In addition, for the health outcomes for which no new studies have been published since May 1, 2011, we have included the summary from our 2011 update to provide the most recent conclusions on this topic, so a number of studies published prior to May 1, 2011 are included in those topics as well.

All fields (title, abstract, etc.) were searched with various search strings that referenced the exposure[9] and diseases of interest,[10] as well as authors that regularly publish in this field. A scientist with experience in this area reviewed the titles and abstracts of these publications for inclusion in this evaluation. Only peer-reviewed, epidemiology studies, pooled- or meta-analyses, and human experimental studies of 50-Hz or 60-Hz AC ELF EMF and recognized disease entities are included. *In vivo* animal studies of 50-Hz or 60-Hz AC ELF EMF are also included, but only on the topic of cancer.

The following specific inclusion criteria were applied:

1. **Outcome**. Included studies evaluated one of the following diseases: cancer; reproductive and developmental effects; neurodegenerative diseases; or cardiovascular disease. Research on other outcomes is not included (psychological effects, behavioral effects, hypersensitivity). Few studies are available in these research areas and, as such, research

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[8] While extensive efforts were made to identify relevant studies, it is possible that some studies reporting on the association between a disease and some measure of EMF exposure were missed. Many occupational and environmental case-control studies of cancer are published, some of which examine a large number of possible exposures; if no reference to EMF is made in the abstract, title, or keywords, for example, these studies may not have been identified using our search strategy. The most informative studies in this field, however, will be identified by our search strategy.

[9] EMF, magnetic fields, electric fields, or electromagnetic.

[10] Cancer (cancer, leukemia, lymphoma, carcinogenesis), neurodegenerative disease (neurodegenerative disease, Alzheimer's disease, amyotrophic lateral sclerosis, or Lou Gehrig's disease), cardiovascular effects (cardiovascular or heart rate), or reproductive outcomes (miscarriage, reproduction, or development).

evolves more slowly.

2. **Exposure**. The study must have evaluated 50-Hz or 60-Hz AC ELF EMF.
3. **Exposure assessment methods**. To be included in this report, exposure must have been evaluated beyond self-report of an activity or occupation. Included studies estimated exposure through various methods including: calculated EMF levels using distance from power lines; time-weighted average EMF exposures; and average exposures estimated from JEMs.
4. **Study design**. Epidemiology, human experimental, and *in vivo* studies were included. *In vitro* studies were not systematically evaluated, since this field of study is less informative to the risk assessment process (IARC, 2002). We rely on the conclusions of the WHO report (as described in Section 5) with regard to mechanistic data from *in vitro* studies. Furthermore, only *in vivo* studies of carcinogenicity were evaluated in this review; the review relies on the conclusions of the WHO with regard to *in vivo* studies in the areas of reproduction, development, neurology, and cardiology.
5. **Peer-review**. The study must have been peer-reviewed and published in English. Therefore, no foreign language studies, conference proceedings, abstracts, or on-line material was included.

Methodological research is now being pursued in many areas of ELF EMF research to identify the possible impact of certain aspects of study design or biases on the studies' results. Therefore, articles evaluating the impact of methodological aspects of epidemiology studies in this field are discussed, where appropriate. Systematic review articles of relevant topics are also noted, where appropriate. Studies published prior to the scope of this update are noted in certain circumstances to provide context.

Epidemiology and human experimental studies are evaluated below by outcome (childhood cancer; adult cancer; reproductive or developmental effects; neurodegenerative diseases; and cardiovascular effects), followed by an evaluation of *in vivo* research in the field of cancer. Tables 3-10 list the relevant studies in these areas, including the study's first author and the title of the article.

Health outcomes

Childhood leukemia

In 2002, the IARC assembled and reviewed research related to ELF EMF to evaluate the strength of the evidence in support of carcinogenicity. The IARC expert panel noted that, when studies with the relevant information were combined in a pooled analysis, a statistically significant two-fold association was observed between childhood leukemia and estimated exposure to high, average levels of magnetic fields (i.e., greater than 3-4 mG of average 24- and 48-hour exposure). This evidence was classified as "limited evidence" in support of carcinogenicity, falling short of "sufficient evidence" because chance, bias, and confounding could not be ruled out with “reasonable confidence.” Largely as a result of the findings related to childhood leukemia, the IARC classified magnetic fields as “possibly carcinogenic,” a category that describes exposures with limited epidemiologic evidence and inadequate evidence from *in vivo* studies. The classification “possibly carcinogenic” was confirmed by the WHO in June 2007.

Recent studies

Three studies have evaluated the association between childhood leukemia and magnetic fields since our previous review—two case-control studies and one pooled analysis. An additional study provides a quantitative analysis of the dose-response risk threshold of magnetic field exposure levels.

Wünsch-Filho et al. (2011) conducted a case-control study in the State of São Paolo, Brazil, which included 162 cases of childhood acute lymphoblastic leukemia recruited from eight hospitals between 2003 and 2009. Controls (n=565) were selected from the São Paolo birth registry and matched to gender, age, and city of birth.

A strength of this study was its exposure assessment that utilized two approaches to measure ELF magnetic fields. First, the researchers took 3-minute magnetic field measurements in every room in the house and outside the door to the home, although the authors do not indicate at what time of day or what time of year these outdoor measurements were taken.[11] They also took a 24-hour measurement in the child’s bedroom. These measurements were categorized into four groups: < 1 mG, 1 mG - ≤ 3 mG, ≥ 3 mG – 4 mG, and > 4 mG. Second, the distance between each household to the closest power line of various capacities (88 kV, 138 kV, 230 kV, 345 kV, and 440 kV) was determined for cases and controls in the Metropolitan Region, since it is the only area in the state for which electric grid maps are available.

In addition to the exposure assessment methods, the study is noteworthy because of the relatively large number of cases with estimated exposure $\geq$ 3 mG (11 cases, i.e., 7%). Prior to publication of the Wünsch Filho study, a pooled analysis (Kheifets et al., 2010a, discussed in the previous update) used their raw data to calculate an OR equal to 1.26 (95% CI=0.61-2.62) for 24-hour residential exposure $\geq$ 3 mG, but Wünsch-Filho et al. (2011) actually reported a lower OR of 1.09 (95% CI=0.33-3.61) for the same exposure level.[12] The authors concluded that although their results do not support an association between childhood leukemia and magnetic fields, this conclusion carries less weight because of the study’s weaknesses. The strengths of this study are undercut by poor participation rates, small sample sizes, and a hospital-based design. The most significant limitation was selection bias that may have artificially reduced the OR (i.e., low participation rates and some evidence that the excluded controls had higher magnetic-field exposures).

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[11] Since loads on power lines vary throughout the day and at different times of the year, spot measurements around the perimeter of a home are only a moderately good proxy for actual magnetic-field exposure levels (Armstrong et al., 2001).

[12] Pooled analyses often report results that differ substantially from those reported in the underlying studies because of differences in inclusion/exclusion criteria.

Studies have also investigated whether magnetic-field exposure of parents either prior to conception or during pregnancy may be relevant to the risk of childhood leukemia. A small body of literature is available on this topic with inconsistent findings, including a study by Hug et al. (2010) that was discussed in the previous update and a new case-control study by Reid et al. (2011) that used advanced JEMs to compare the occupational exposure of the parents of children with leukemia to the exposure of parents of healthy children. As with the earlier study (Hug et al., 2010), Reid et al. (2011) found no statistically significant association with maternal or paternal magnetic-field exposure measured in several time periods: any time before birth, up to 2 years before birth, up to 1 year before birth, and 1 year after birth.

Recent research has evaluated the possible confounding effects of contact currents and investigations of childhood leukemia (Does et al., 2011, discussed in the previous update). Contact currents occur when the water line provides the ground for the home's electrical system. The hypothesis is that a child may experience a contact current from touching surfaces at different potentials while bathing, and these contact currents may be responsible for the association between magnetic fields and childhood leukemia. Two criteria must be fulfilled for contact currents to have this confounding effect. First, there must be an independent causal relationship between contact currents and childhood leukemia, and second, there must be a strong association between residential magnetic fields and the voltage between bathtub plumbing fixtures and drains.

A pooled-analysis by Kavet et al. (2011) suggests that the second criterion is met. The authors combined data from the Northern California Childhood Leukemia Study for over 500 case and control residences (n=>500) with data from other measurement studies conducted in Pittsfield, Massachusetts (n= 22), Denver, Colorado (n=191), and San Jose, California (n=15). The authors reported an OR of 15.1 (95% CI 3.6-6.1) for the association between contact currents and magnetic fields and concluded that the data could "support the possibility that contact current could be responsible for the association of childhood leukemia with magnetic fields." Since only one epidemiology study has been conducted on this subject (Does et al., 2011), further research should be conducted in study populations with a greater potential for elevated contact current and magnetic-field exposure and with information available on the frequency of contact-current exposure. The prevalence of contact currents, however, in buildings is declining rapidly with the increased use of non-conductive plastic plumbing.

Kheifets et al. (2011) conducted a quantitative analysis to examine the widely-accepted conclusion that the dose-response threshold for exposure to magnetic fields for childhood leukemia is >3 mG – 4 mG. The authors suggest that the data best fits a model assuming cases of childhood leukemia could occur below the 3-4 mG range if a true relationship existed, although there were many limitations to their analysis.

In addition to these new studies, several other recent publications on magnetic fields and childhood leukemia warrant mention. One editorial questioned whether studies of childhood leukemia and magnetic fields have exhausted the methods available to this field and stated that "better insights into this association cannot be expected" (Schmiedel and Blettner, 2010). Several areas of inquiry, however, may provide additional clarity. For example, an ongoing international epidemiologic study is being conducted on children with high magnetic-field exposure from residence above internal transformer stations in apartment buildings, which provides a more stable estimate of the association in upper exposure categories with less concerns of selection bias (Hareuveny et al., 2011). Agreement on the relevant exposure metric and window has not been reached. In addition, further work on prenatal exposure is warranted since research suggests that the first genetic changes linked to leukemia occur as part of fetal development (Eden, 2010).

Assessment

In summary, the association between childhood leukemia and magnetic fields remains unexplained. Wünsch Filho et al. (2011) has provided some evidence of an association with elevated magnetic field levels, but the results are undercut a number of limitations, the most significant of which was selection bias.

Although Reid et al. (2011) utilized advanced JEM methods in their study, when all the literature in this area is considered, small sample sizes, exposure uncertainties, and potential confounding with electromagnetic energy of different frequencies (as well as other occupational exposures, e.g., chemicals) prevent firm conclusions from being drawn. More research is required with improved exposure techniques.

Thus, the results of these studies do not change the classification of the epidemiologic data as limited. This conclusion is supported by recent reviews (Calvente et al., 2010; Eden, 2010; Miller and Green, 2010) and conclusions from scientific organizations (SSM, 2010; EFHRAN, 2010a).

It should be noted that magnetic fields are just one area in the large body of research on the possible causes of childhood leukemia. There are many other hypotheses under investigation that point to possible genetic, environmental, and infectious explanations for childhood leukemia, which have similar or stronger support in epidemiology studies (Ries et al., 1999; McNally and Parker, 2006; Belson et al., 2007; Rossig and Juergens, 2008; Eden 2010).

Table 3. Relevant studies of childhood leukemia

Author	Year	Study Title
Kheifets et al.	2011	Exploring exposure-response for magnetic fields and childhood leukemia
Reid et al.	2011	Risk of childhood lymphoblastic leukaemia following parental occupational exposure to extremely low frequency electromagnetic fields
Wünch-Filho et al.	2011	Exposure to magnetic fields and acute lymphocytic leukemia in São Paulo, Brazil

Childhood brain cancer

Compared to the research on magnetic fields and childhood leukemia, there have been fewer studies of childhood brain cancer. The data are less consistent and limited by even smaller numbers of exposed cases than studies of childhood leukemia. The WHO review 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 (WHO, 2007, p. 18).

Recent studies

There have been no new studies of childhood brain cancer published since May 1, 2011. In light of this, the following summary from our 2011 update provides the most recent conclusions on this topic.

In response to the WHO recommendation above, both a meta- and pooled analysis of studies on childhood brain tumors and residential magnetic-field exposure were conducted by Mezei et al. (2008) and Kheifets et al. (2010b), respectively. In Mezei et al. (2008), 13 epidemiologic studies were identified that used various proxies of residential magnetic-field exposure (distance, wire codes, calculated magnetic fields, and measured magnetic fields). 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 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.

The pooled analysis by Kheifets et al. (2010b) provides stronger data compared to the meta-analysis described above because original data were used, various sub-group analyses were conducted, and there was adjustment for possible confounding variables (e.g., socioeconomic status and mobility). The pooled analysis included data from 10 studies published from 1979-2010 of childhood brain or central nervous system cancer with long-term measurements, calculated fields, or spot measurements of residential magnetic-field exposure. Similar to childhood leukemia, few cases of childhood brain cancer had estimated magnetic-field exposures greater than 3-4 mG. None of the analyses showed statistically significant increases and, while some categories of high exposure had an OR ≥1.0, the overall patterns were not consistent with an association and no dose-response patterns were apparent. The authors concluded that their results provide little evidence for an association between magnetic fields and childhood brain tumors.

The pooled analysis included two case-control studies published after the WHO 2007 review (Kroll et al., 2010; Saito et al., 2010). Nearly 80% of the childhood brain cancer cases in the pooled analysis were contributed by Kroll et al. (2010), which evaluated 47 childhood brain cancer cases diagnosed over a 33-year period in the United Kingdom with their birth address within 400 m of a high-voltage transmission line. No associations with calculated magnetic-field exposure from nearby transmission lines were reported in any analysis of brain cancer in this large study, including calculated magnetic fields ≥1-2 mG, 2-4 mG, and 4mG.

In a case-control study of 55 cases of childhood brain cancer, Saito et al. (2010) reported that children with brain cancer were more likely to have average magnetic-field exposure levels greater than 4 mG, compared to children without brain cancer.[13] The association was based on three cases and one control; interpretations of the data were, therefore, limited by small numbers in the upper exposure category. The study was also limited by very poor participation rates among study subjects; poor participation rates introduce the possibility of selection bias, among other biases. The strength of this study was its exposure assessment. Measurements were taken continuously over a weeklong period in the child's bedroom approximately 1 year post-diagnosis.

In a recent 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 offspring. Associations were reported between childhood brain cancer and average magnetic-field exposures greater than approximately 3 mG for exposure during the 2 years prior to conception and during conception; no associations were found using the cumulative and peak exposure metrics. Previous studies of parental occupational magnetic-field exposure and childhood brain tumors have produced inconsistent results. More research is required in this area.

Assessment

Overall, recent studies were inconsistent, but the weight of the recent data does not support an association between magnetic-field exposures and the development of childhood brain cancer. The larger and more methodologically advanced work (Kheifets et al., 2010b; Kroll et al., 2010) does not support an association. The recent data do not alter the classification of the epidemiologic data in this field as inadequate.

Table 4. Relevant studies of childhood brain cancer

Authors	Year	Study Title
Kheifets et al.	2010b	A pooled analysis of extremely low-frequency magnetic fields and childhood brain tumors
Kroll et al.	2010	Childhood cancer and magnetic fields from high-voltage power lines in England and Wales: A case-control 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.	2008	Residential magnetic field exposure and childhood brain cancer: A meta-analysis
Saito et al.	2010	Power frequency magnetic fields and childhood brain tumors: A case-control study in Japan

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[13] The unpublished results of this study were included in Mezei et al. (2008).

Breast cancer

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. The WHO concluded that the recent body of research on this topic was less susceptible to bias compared with previous studies, and, as a result, it provided strong support to previous consensus statements that magnetic-field exposure does not influence the risk of breast cancer. Specifically, the WHO stated:

> 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 (WHO, 2007, p. 307).

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

Recent studies

As in the case of new studies of childhood brain cancer, there have been no new studies of breast cancer and ELF EMF since May 1, 2011. In order to provide the most recent conclusions on this topic, the following is the summary from Exponent's 2011 update.

Two case-control studies (McElroy et al., 2007; Ray et al., 2007) and one cohort study (Johansen et al., 2007) have recently been published in this field, all of which evaluated occupational magnetic-field exposure.[14] In addition, a meta-analysis of 15 studies of breast cancer and magnetic-field exposure was published (Chen et al., 2010), which included one of the recent case-control studies (McElroy et al., 2007).

Chen et al. (2010) meta-analyzed 15 studies published from 2000-2009 that examined residential or occupational magnetic-field exposure or electric blanket usage. The authors crudely re-categorized data from the original studies to reflect a common comparison of <2 mG and >2 mG and reported an overall OR of 0.99 (95% CI=0.90–1.1). The advantage of this meta-analysis is its very large size (24,338 cases and 60,628 controls). Its main limitation, however, is that data from a wide range of exposure definitions and cut-points were combined.

Ray et al. (2007) was a case-control study nested in a cohort of approximately 250,000 female 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

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[14] In addition to the studies described in the text, 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 this report because no qualitative or quantitative estimates of magnetic-field exposure were made, beyond occupation and industry titles.

between breast cancer and estimates of high magnetic-field exposure. A large cohort study of utility workers in Denmark also reported that women exposed to higher occupational magnetic-field levels did not have higher rates of breast cancer (Johansen et al., 2007).

Recent methodological work for adult cancers

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 JEM). The latter method, while advanced, still has some important limitations, as highlighted recently in a review by Kheifets et al. (2009) summarizing an expert panel's findings.[15] 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.

The expert panel concluded the following:

> Inconsistent results for many of the outcomes [related to occupational EMF exposure] may be attributable to numerous shortcomings in the studies, most notably in exposure assessment. There is, however, no obvious correlation between exposure assessment quality and observed associations … To better assess exposure, we call for the development of a more complete job-exposure matrix that combines job title, work environment and task, and an index of exposure to electric fields, magnetic fields, spark discharge, contact current, and other chemical and physical agents (quoted in Kheifets et al., 2009)

Mee et al. (2009) measured the personal magnetic-field exposures of a proportion of their study participants in an ongoing case-control study of brain cancer in the United Kingdom (the UK Adult Brain Tumour Study). Personal magnetic-field measurements were taken for a minimum of 3 days by 317 persons (cases, controls, or proxies of either), and statistical analyses were performed to establish whether crude occupational classifications, which are traditionally employed in JEM, accounted for the observed variation in measured occupational magnetic-field exposures. The analysis confirmed that JEMs could be improved by linking occupational classifications with industry or information on participation in certain tasks of interest (e.g., use of welding equipment or work near power lines). Similarly, a recent study of the 48-hour exposure of 543 workers in Italy found that JEMs were a poor indicator of actual occupational,

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

magnetic-field exposure levels; half of the occupations classified in the same JEM categories included significantly different individual TWAs (Gobba et al., 2011).

Assessment

These studies, particularly the meta-analysis and the large cohort of utility workers, add to growing support against a causal role for magnetic fields in breast cancer. These studies should receive weight in the overall assessment because of their large size, but the studies are still limited by deficiencies in exposure measures. Recent review papers (Feychting and Forssén 2006; Hulka and Moorman, 2008) and expert groups (SCENIHR, 2009) support the conclusion that magnetic-field exposure does not influence the risk of breast cancer.

Table 5. Relevant studies of breast cancer

Authors	Year	Study Title
Chen et al.	2010	Extremely low-frequency electromagnetic fields exposure and female breast cancer risk: A meta-analysis based on 24,338 cases and 60,628 controls
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

Adult brain cancer

Brain cancer was studied along with leukemia in many of the occupational studies of EMF. The findings were inconsistent, and there was no pattern of stronger findings in studies with more advanced methods, although a small association could not be ruled out. The WHO classified the epidemiologic data on adult brain cancer as inadequate 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.

The WHO stated the following:

> 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 (WHO 2007, p. 307).

Recent studies

One study of adult brain cancer and magnetic-field exposure has been published since May 1, 2011. A group of researchers from the University of São Paulo in Brazil conducted a case-control study based on death certificate data from two different databases (both the city and State of São Paolo's official mortality databases) for deaths between 2002 and 2005 in the Metropolitan Region of São Paulo (Marcilio et al., 2011). They identified deaths from brain cancer among adults in this large, urban area (population of approximately 20 million) that has a high demographic density and extensive overhead high-voltage power lines throughout the area. The researchers found no association between brain cancer mortality and living near a transmission line at death or calculated magnetic-field levels from these transmission lines. Their analyses were not done by histological subtype.

The strengths of this study include the relatively large sample size (n=2,357). In addition, the assessment of distance from transmission lines to the residence was performed without knowledge of subjects' case or control status and the selection of cases and controls did not entail voluntary participation, so there was no possibility of selection or recall bias.

Limitations of this study include the use of cancer deaths rather than incident cases, which limits generalizations to subtypes with a higher mortality rate. In addition, the authors only evaluated exposure at the address where participants lived at time of death and did not evaluate information on occupational exposures, both of which preclude an accurate assessment of overall TWA exposure. Finally, proximity to transmission lines appears to be a poor surrogate of magnetic-field exposure (Maslanyj et al., 2009).

Assessment

While an association still cannot be ruled out *entirely* because of remaining deficiencies in exposure assessment methods, there is no strong evidence in support of a relationship between magnetic fields and brain cancer. The data remain inadequate (EFHRAN, 2010a).

Table 6. Relevant studies of adult brain cancer

Authors	Year	Study Title
Marcilio et al.	2011	Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil

Adult leukemia and lymphoma

There is a vast amount of literature on adult leukemia and EMF, most of which is related to occupational exposures. Overall, the findings of these studies are inconsistent—with some studies reporting a positive association between measures of EMF and leukemia and other studies showing no association. No pattern has been identified whereby studies of higher quality or design are more likely to produce positive or negative associations. The WHO subsequently classified the epidemiologic evidence for adult leukemia as "inadequate." They recommended updating the existing occupationally-exposed cohorts in Europe and updating a meta-analysis on occupational magnetic-field exposure.

Recent studies

One study has been published on adult leukemia since May 1, 2011. The Brazilian case-control study discussed above also evaluated adult leukemia deaths (Marcilio et al., 2011). A statistically significant association was found between residence at death within 50 meters of a transmission line, but it was unclear how to interpret this association because it was restricted to lower voltage lines. In addition, proximity is a poor predictor of magnetic-field exposure. A positive association was also found with calculated exposures greater than 3 mG from these transmission lines, but the association was not statistically significant (OR=1.61, 95% CI=0.91-2.86). No analyses were conducted by leukemia subtypes.

Assessment

This study did not provide strong evidence in support of an association. While the possibility that there is a relationship between adult lymphohematopoietic malignancies and magnetic-field exposure still cannot be entirely ruled out, because of the remaining deficiencies in study methods, the current database of studies provides weak evidence. The data remain inadequate (EFHRAN, 2010a).

Table 7. Relevant studies of adult leukemia/lymphoma

Authors	Year	StudyTitle
Marcilio et al.	2011	Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil

Reproductive/developmental effects

Beginning a decade ago, 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). The Li et al. study was criticized by the NRPB *inter alia* because of the potential for selection bias, a low compliance rate, measurement of exposure after miscarriages, and the selection of exposure categories after inspection of the data (NRPB, 2002).

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 women who had miscarriages reported in the cohort by Li et al.

(2002) had magnetic-field measurements taken after miscarriage occurred, when changes in physical activity may have already occurred, and all measurements in Lee et al. (2002) 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, 2007). The WHO concluded, “There is some evidence for increased risk of miscarriage associated with measured maternal magnetic-field exposure, but this evidence is inadequate” (WHO, 2007, p. 254) and recommended further epidemiologic research.

Recent studies

While no new original studies on magnetic-field exposure and miscarriage have been conducted, six studies have been published recently on reproductive and developmental effects (Table 5). Three of these studies by the same lead investigator considered novel hypotheses regarding magnetic-field exposure and reproductive and developmental effects in the areas of sperm quality, asthma in offspring, and childhood obesity (Li et al., 2010; Li et al., 2011; Li et al., 2012).

Li et al. (2010) conducted the first investigation of measured magnetic-field levels and semen abnormalities in a population-based, case-control study derived from healthy sperm donors in Shanghai, China. A two-fold, statistically significant association was reported between high magnetic-field exposure (90th percentile of 24-hour measurements ≥ 1.6mG) and poor sperm quality. The relationship exhibited a dose-response pattern, i.e., the association increased in strength as estimated exposure increased, and other features associated with a valid relationship. The main strength of the study was the use of actual personal magnetic-field measurements. The authors note, however, that their study had limitations. They were only able to measure magnetic-field exposure for one 24-hour time period for each participant, and it is unclear how this 24-hour measurement reflects true magnetic-field exposure during spermatogenesis. In addition, except for a control for occupation, no control for chemical exposures, e.g., smoking, were considered (Fariello et al., 2012).

Li et al. (2011) also were the first to evaluate the association between magnetic-field exposure *in utero* and subsequent asthma in offspring. The researchers analyzed data from a prospective cohort study of 626 pregnant women collected a decade earlier in the San Francisco area (Li et al., 2002). In this study, the authors found that asthmatic children were more likely to have mothers with median, personally-recorded exposures to magnetic fields > 2 mG during pregnancy, compared to the magnetic-field exposures of mothers of healthy children (hazard ratio [HR]=3.52, 95% CI=1.68-7.35). The association was strong and indicated a dose-response pattern.

The design and methods of this study appear relatively strong, although similar to their study of sperm quality, the participants wore a magnetic-field meter for only one 24-hour period during the first or second trimester. In addition, it is possible that an unknown confounder is responsible for the observed association. The authors did not adjust for family income in their analysis, although family income of subjects with medium and high exposure was significantly below that of the low magnetic-field exposure subjects. This association of an indicator of low socio-economic status with higher magnetic-field exposure suggests the possibility that the association is confounded by socioeconomic factors that play a role in the development of childhood asthma directly or as a surrogate of environmental risk factors such as indoor mold, allergen exposure, and outdoor pollution (Rona, 2000). Additional limitations of this study (including residual confounding from indoor air quality and other risk factors for asthma) and comments on the authors' interpretation of the results have been published by several scientists (Brain et al., 2012; Villeneuve, 2012). Further studies on this topic with more detailed information on risk factors for childhood asthma are required.

Using the same cohort of pregnant women as in their previous studies, Li et al. (2012) published another analysis of *in utero* magnetic-field exposure, in this case, on the risk of childhood obesity. The magnetic-field exposure of the mothers during pregnancy was related to the weight of their children up to 13 years of age. The children of mothers with TWA magnetic-field exposures >1.5 mG were significantly more likely to be over the 97.5 percentile of age-specific weight than children of mothers with exposures ≤ 1.5 mG. A significant trend for higher weight with increasing magnetic-field exposure was also reported.

In both recent Li et al. studies (2011, 2012) mothers with higher magnetic-field exposures had significantly lower family incomes. Given this association and the complicated interrelationships between socioeconomic status and risk factors for childhood obesity, residual confounding is a distinct possibility (Brain et al., 2012; Villeneuve, 2012). Although adjustment was carried out for some socioeconomic risk factors and eight other potential confounding variables, income itself was not included as an adjustment factor. Curiously, pre-existing diabetes and gestational diabetes were treated as a single risk factor although each deserves separate treatment. By not characterizing the exposure groups by the prevalence of pre-existing diabetes of the mothers, one does not know whether the reported results are related to magnetic-field exposure or simply to more persons in the higher exposure group with a possibly hereditary risk factor for diabetes.

Most of the same concerns raised during the original publication of this cohort apply to both the Li et al. (2011) and Li et al (2012) studies, including the potential for selection bias, a low compliance rate, and the apparent selection of exposure categories after inspection of the data (NRPB, 2002). In the original Li et al. (2002) study of miscarriage, exposure was defined *a priori* as the average magnetic-field level recorded over 24 hours, for which no significant association with miscarriage was reported. The authors reported an association with magnetic-field exposures above a peak value of 16 mG, however, this was based on apparent *post hoc* inspection of the data. In the study of asthma, magnetic-field exposures were categorized into three groups, all apparently set *post hoc* as < 10 percentile, > 10 to 90th percentile, and > 90th percentile. In the study of obesity, on the other hand, only exposures in the 90th percentile were considered. No explanation was provided by the authors for the differing exposure categories between studies. This raises the question as to whether different exposure categories were chosen after review of the results to maximize the strength of the reported association. This and the other limitations of the study diminish the weight of the reported results.

Malagoli et al. (2012) investigated maternal exposure to magnetic fields from high-voltage power lines in a population-based, case-control study of birth defects in northern Italy between

1998 and 2006. The authors matched 228 newborns with congenital malformations with a control group of healthy newborns by year of birth, the mothers' age, and hospital of birth. Maternal residence during the first trimester was identified using GIS to determine if the residence was within a "geocoded" exposure corridor near high-voltage power lines (≥ 132 kV) with calculated magnetic-field levels > 1 mG. Only one case and five controls resided within the exposure corridor, and the study did not find an association between birth defects and magnetic-field exposure (RR = 0.7, 95% CI = 0.1-8.1 in the highest exposure category (≥ 4 µT). The authors concluded that the results do not support the hypothesis that *in utero* exposure to magnetic fields are related to birth defects, although the study is limited by the small number of participants and low statistical power.

The final study models internal electric fields and current density as a function of electric and magnetic field exposure in pregnant women and fetuses at different stages of gestation. The modeled internal fields indicate that compliance with the ICNIRP Reference Levels for public exposure will produce internal electric fields and current densities in the mother and fetus substantially below the Basic Restriction values (Dimbylow and Findlay, 2010).

Assessment

The three, new epidemiology studies in this research area do not change the classification of the data from earlier studies as inadequate (EFHRAN, 2010a). The three studies by Li et al. (2010, 2011, 2012) report associations between varies personal magnetic field exposure categories and semen abnormalities, childhood asthma, and childhood obesity, respectively, but further research is required to address the limitations of these studies and to establish consistency.

Table 8. Relevant studies of reproductive and developmental effects

Authors	Year	Study Title
Dimbylow and Findlay	2010	The effects of body posture, anatomy, age, and pregnancy on the calculation of induced current densities at 50 Hz
Li et al.	2010	Exposure to magnetic fields and the risk of poor sperm quality
Li et al.	2011	Maternal exposure to magnetic fields during pregnancy in relation to the risk of asthma in offspring
Li et al.	2012	A prospective study of in-utero exposure to magnetic fields and the risk of childhood obesity
Malagoli et al	2012	Maternal exposure to magnetic fields from high voltage power lines and the risk of birth defects

Neurodegenerative diseases

Research into the possible effect of magnetic fields on the development of neurodegenerative diseases began in 1995, and the majority of research since then has focused on AD and a specific type of motor neuron disease called ALS, also known as Lou Gehrig's disease. 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 AD 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 disease. The WHO panel concluded that there is "inadequate" data in support of an association between magnetic fields and AD or ALS. The panel recommended more research in this area using better methods; in particular, studies that enrolled incident AD cases (rather than ascertaining cases from death certificates) and studies that estimated electrical shock history in ALS cases were recommended. Specifically, the WHO 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" (WHO, 2007, p. 194) and "overall, the evidence for an association between ELF exposure and ALS is considered inadequate" (WHO, 2007, p. 206).

Recent studies

The only recent study of magnetic-field exposure and Alzheimer's disease (Andel et al., 2010) was included in Exponent's earlier report. Two epidemiology studies of motor neuron disease, however, have been published recently (Table 9). The researchers who investigated adult mortality from leukemia and brain cancer, discussed above, also investigated the association between magnetic-field exposure from overhead transmission lines and ALS (Marcilio et al., 2011). Their study included 367 adult (age 40 or older) cases of ALS and 308 controls. The authors estimated risk for four different distances from power lines and found no increase in risk in any of the categories, which were adjusted for race, education, and marital status.

The second epidemiology study, a large cohort of the general population in the United assembled from five census surveys, also did not provide evidence that any type of motor neuron disease (ALS makes up 90% of all motor neuron disease) is associated with occupational magnetic-field exposure (Partlett et al., 2011). The cohort of nearly 300,000 persons was followed for a maximum of 9 years, and 40 deaths due to motor neuron disease were identified. The incidence of motor neuron disease was compared for different magnetic-field exposure categories based on the job reported at the time of the census. The population-based nature and large size of the study adds strength to the conclusions, but the analysis is limited by the generic JEM that did not allow for direct or individual measurement of occupational exposure to magnetic fields, did not take into account variability of exposure within job categories, and did not consider specific job tasks within categories.

In its 2007 review, the WHO recommended that studies of the effects of magnetic fields on the performance of mentally demanding tasks by human volunteers be conducted. One meta-analysis and two human experimental studies of EMF exposure in relation to neurological endpoints are included in the recent body of research on neurodegenerative disease (Table 9). The meta-analysis quantitatively summarized the results of seven human experimental studies on the cognitive performance of 445 subjects (Barth et al., 2010). The authors concluded that, in aggregate, the studies provided little evidence for any effects of magnetic fields on cognitive function.

In an attempt to add to the sparse research on the effects of exposure to high-level magnetic fields in occupations such as power line worker and industrial welder, Corbacio et al. (2011) evaluated the impact of a 60 Hz, 30,000 mG magnetic field on cognitive function. The researchers found that magnetic field at such a high level had no effect on the speed and accuracy of performance on nine cognitive tasks in 99 healthy human subjects (Corbacio et al., 2011). Volunteer adult participants (mean age 23.5) were assigned to two consecutive exposure conditions: sham/sham, exposure/sham, or sham/exposure, and also blinded to the examiners. This study does not support the notion that magnetic-field exposure affects cognitive functions.

Another study examined the effects of magnetic-field exposure on electrical activity of the brain. Carrubba et al. (2010) reported that 60-Hz magnetic fields of 10 and 50 mG did not produce delayed evoked potentials in human subjects, as recorded from the scalp with onset or offset of the field. Magnetic-field stimuli, however, produced changes in brain electrical activity, suggesting that the fields were detected in a manner similar to that of other sensory events. This study was not reported to have implemented methods to ensure that the analyses were conducted in a blinded manner.

A final study addressed the WHO's recommendation that additional dosimetry to better estimate the electric-field levels induced in tissues is needed. Hirata et al. (2011) used an advanced numerical dosimetry method to calculate the levels of electric fields produced in the brain and retina of human subjects exposed to an 81,000 mG, 20-Hz magnetic field, an exposure reported to stimulate visual phosphenes. The induced field levels were similar to those assumed by ICES and ICNIRP in previous modeling as a threshold for stimulation of the central nervous system. It should be noted, however, that both ICES and ICNIRP estimate that the threshold for stimulation would be considerably higher at 50-Hz or 60-Hz power frequencies.

Assessment

The two recent epidemiology studies do not alter the conclusion that there is "inadequate" data on motor neuron disease (Marcilio et al., 2011; Partlett et al., 2011). As evidenced by these two studies that relied on death certificate data and the lack of any new research on Alzheimer's disease, little new progress has been made to clarify these associations or address the WHO's recommendations. In addition, no recent work has addressed the possible confounding effect of electrical shocks. The recent studies continue to be limited by uncertainties about the estimates of occupational magnetic-field exposure—both Marcilio et al. (2011) and Partlett et al. (2011) relied on generic JEMs that did not incorporate job tasks or reflect cumulative occupational magnetic-field exposure. Further research in this area will be needed to address the limitations of research to date on neurodegenerative disease (Kheifets et al., 2008; EFHRAN, 2010a; SSM, 2010).

Recent neurobiological studies of magnetic fields, like those reviewed by the WHO in 2007 report, found no responses in humans to magnetic-field stimulation at levels below those that lead overt nerve stimulation. The exception is evidence of non-specific changes in electrical activity that are not indicative of harm. These findings are consistent with dosimetric estimates of the field strength required to stimulate magnetophosphenes, which are widely regarded as the biological response with the lowest threshold. Some evidence for Alzheimer's disease might be judged as limited, but all other neurobiological studies (including studies of ALS, other neurodegenerative diseases, and subjective symptoms) was judged inadequate and had weak biological plausibility (EFHRAN, 2010a; 2010b).

Table 9. Relevant studies of neurodegenerative disease

Authors	Year	Study Title
Barth et al.	2010	Effects of extremely low frequency magnetic field exposure on cognitive functions: results of a meta-analysis
Corbacio et al.	2011	Human cognitive performance in a 3 mT power-line frequency magnetic field
Carrubba et al.	2010	Numerical analysis of recurrence plots to detect effect of environmental strength magnetic fields on human brain electrical activity
Hirata et al.	2011	An electric field induced in the retina and brain at threshold magnetic flux density causing magnetophosphenes
Marcilio et al.	2011	Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil
Parlett et al.	2011	Evaluation of occupational exposure to magnetic fields and motor neuron disease mortality in a population-based cohort

Cardiovascular disease

It has been hypothesized that magnetic-field exposure reduces heart rate variability, which in turn is a marker of increased susceptibility for AMI. In a large cohort of utility workers, Savitz et al. (1999) reported an increased risk of arrhythmia-related deaths and deaths due to AMI. Previous and subsequent studies did not report a statistically significant increase in cardiovascular disease (CVD) mortality or incidence related to occupational magnetic-field exposure (WHO, 2007). The WHO concluded, "Overall, the evidence does not support an association between ELF exposure and cardiovascular disease." (WHO, 2007, p. 220)

Recent studies

No new studies on cardiovascular disease have been published since the last update. Therefore, as with several other sections above, we have included the discussion of cardiovascular disease and magnetic field exposure from the June, 2011 update.

The recent literature includes a cohort representative of the general working population in the United States that was assembled from a census-derived database (the National Longitudinal Mortality Study [NLMS]) and linked to the National Death Index for follow-up of death due to CVD through 1989 (Cooper et al., 2009). The NLMS includes persons selected from the United States census 1979–1981 and their last or current job title, which was linked to an average occupational magnetic-field exposure based on a JEM. No increase in CVD mortality overall, or for specific CVD types, was reported with indirect control for smoking and some demographic risk factors.

The study by Cooper et al. (2009) is limited by incomplete information in the NLMS (e.g., a full occupational history and potential confounding variables), as well as a crude JEM. Although limited, the study's findings are consistent with the WHO conclusion that the evidence does not support an association. A recent systematic review by McNamee et al. (2009) also noted that the epidemiologic literature does not support an association, although future research is still needed given the limitations of the existing literature.

Another recent study by McNamee et al. (2011) evaluated whether magnetic fields affect human heart rate and heart rate variability. Forty-eight study participants were exposed for 1 hour to an 18,000 mG magnetic field in a controlled fashion, and no effects on cardiovascular parameters were observed.

Assessment

Recent studies, while limited, are consistent with the conclusion that there is no association between magnetic fields and CVD or cardiovascular parameters related to CVD.

Table 10. Relevant studies of cardiovascular disease

Authors	Year	Study Title
Cooper et al.	2009	A population-based cohort study of occupational exposure to magnetic fields and cardiovascular disease mortality
McNamee et al.	2011	The response of the human circulatory system to an acute 200-μT, 60-Hz magnetic field exposure

In vivo studies of carcinogenesis

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 the animals' 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 review 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, 1999b; 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 predisposed transgenic mice to ELF magnetic fields did not report an increased incidence of this lymphoma type (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, ultraviolet radiation, or other chemicals. No effects were observed for studies on chemically-induced preneoplastic liver lesions, leukemia or 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; Mevissen et al., 1993a,1993b, 1996a, 1996b, 1998; Baum et al., 1995; Löscher and Mevissen, 1995), suggesting that magnetic-field exposure increased the proliferation of mammary tumor cells. These results were not replicated in a subsequent series of experiments in a laboratory in the United States (Anderson et al., 1999; Boorman et al.1999a, 1999b), 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.[16]

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" (WHO, 2007, p. 322). 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.

Recent studies

Eleven studies indexed by Pub Med since Exponent's 2011 update investigated effects of magnetic-field exposures on carcinogenic processes in animals (Table 10). In an effort to determine why certain strains of rats develop breast cancer in response to magnetic-field exposure following initiation with DMBA while others do not, Fedrowitz and Löscher (2010) examined gene expression in the mammary gland following magnetic-field exposure. Fischer 344 rats (magnetic-field susceptible) and Lewis rats (magnetic-field resistant) were continuously exposed to a 1,000 mG magnetic field for 2 weeks, after which gene expression in the mammary tissue was analyzed using a whole-genome microarray. Only 22 out of >31,100 genes were altered by magnetic-field exposure and only one of these genes was altered in both strains of rats (albeit in different directions). Genes showing the greatest fold-change in F344 rats were those for α-amylase and parotid secretory protein. More research is still needed to determine the potential role of these genes breast cancer. This study was conducted using sham exposures and blinded analyses.

A number of these new studies involved the direct injection of cancerous cells into mice and their subsequent exposure to magnetic fields to assess whether such exposures reduced tumor size or increased animal survival. These studies were conducted to evaluate the hypothesis that magnetic-field exposure may preferentially kill tumor cells or augment the apoptotic effects of

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[16] 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).

X-irradiation. Berg and colleagues (2010) reported that either treatment with bleomycin (an antibiotic used as an anti-cancer treatment) or exposure to a 200,000 mG, 50-Hz magnetic field reduced mean tumor size; combined treatment had an even greater effect. Likewise, Wen and colleagues (2011) reported that exposure to a 7,000 mG, 100-Hz magnetic field reduced tumor size and increased mean survival time of mice injected with hepatocellular carcinoma cells and subsequently treated with x-rays; a dose-response relationship was observed (i.e., the parameters were directly affected by the number of magnetic-field applications). Finally, Jiménez-Garcia et al. (2010) reported that exposure to a 45,000 mG, 120 Hz magnetic field (50 minutes per day for 32 days) inhibited development of pre-neoplastic lesions in rats initiated via treatment with N-diethylnitrosamine, 2-acetylaminofluorene, and partial hepatectomy. These studies used few animals per group and none reported to have been conducted in a blinded manner. Nevertheless, these findings suggest a possible ameliorative role of magnetic-field exposure in cancer treatment.

Other studies investigated the role of magnetic-field exposures in the development of oxidative stress. Akdag et al. (2010) found that certain oxidative stress indices and markers of oxidative stress (catalase and malondialdehyde levels), but not others (myeloperoxidase levels), were altered in the brains of rats after exposure to a 5,000 mG magnetic field for 2 hours per day for 10 months. Chu et al. (2011) also reported differential effects on oxidative stress markers in the brains of mice after acute (3-hour) exposure to a 23,000 mG (60-Hz) magnetic field, with certain markers showing altered expression (malondialdehyde, hydroxyl radical, superoxide dismutase, ascorbic acid) and others being unaffected by treatment (glutathione peroxidase, glutathione). Exposure to a 70,000 mG (40-Hz) magnetic field for 60 minutes per day for 10 days significantly increased the concentration of free sulfydryl groups in the brains of rats and the concentration of thiobarbituric acid reactive substances (TBARs; a lipid peroxidation marker) was increased after both 30- and 60-minute exposures (Ciejka et al., 2011); hydrogen peroxide concentrations, however, were not significantly affected. Similarly, Goraca et al. (2010) reported that exposure to a 70,000 mG (40 Hz) magnetic field for 60 minutes per day for 2 weeks increased expression of lipid peroxidation markers in the hearts of rats and reduced plasma antioxidant capacity; no effect was observed when the exposures were reduced to only 30 minutes per day. Martínez-Sámano et al. (2010), on the other hand, found that certain oxidative stress markers (glutathione levels and superoxide dismutase activity), but not markers of lipid peroxidation, were altered in the livers of rats following an acute 2-hour exposure to a 24,000 mG (60 Hz) magnetic field; physical restraint of the rats produced a similar response. Only the study by Akdag et al. (2010) reported using methods to ensure that analyses were conducted blind.

Finally, several studies explored the role of magnetic-field exposure in DNA damage. Mariucci et al. (2010) reported that DNA damage was increased in all examined brain regions in CD-1 mice exposed to a 10,000 mG (50 Hz) magnetic field for 1 or 7 days. This damage was evident when animals were sacrificed immediately after exposure, but not if animals were sacrificed after a 24-hour recovery period, suggesting that the findings may be reversible. In another study (Okudan et al., 2010), continuous exposure to much lower magnetic-field strengths of 10-50 mG (50 Hz) for 40 days did not cause a genotoxic response in Swiss albino mice. This latter study reported the use of procedures to blind the analyses.

Table 11. Relevant *in vivo* studies of carcinogenesis

Authors	Year	Study Title
Akdag et al.	2010	Effects of extremely low-frequency magnetic field on caspase activities and oxidative stress values in rat brain
Berg et al.	2010	Bioelectromagnetic field effects on cancer cells and mice tumors
Chu et al.	2011	Extremely low frequency magnetic field induces oxidative stress in mouse cerebellum
Ciejka et al.	2011	Effects of extremely low frequency magnetic field on oxidative balance in brain of rats
Fedrowitz and Löscher	2010	Gene expression in the mammary gland tissue of female Fischer 344 and Lewis rats after magnetic field exposure (50 Hz, 100 μT) for 2 weeks
Goraca et al.	2010	Effects of extremely low frequency magnetic field on the parameters of oxidative stress in heart
Jiménez-Garcia	2010	Anti-proliferative effect of extremely low frequency electromagnetic field on preneoplastic lesions formation in the rat liver
Mariucci et al.	2010	Brain DNA damage and 70-kDa heat shock protein expression in CD1 mice exposed to extremely low frequency magnetic fields
Martínez-Sámano	2010	Effects of acute electromagnetic field exposure and movement restraint on antioxidant system in liver, heart, kidney and plasma of Wistar rats: A preliminary report
Okudan et al.	2010	Effects of long-term 50 Hz magnetic field exposure on the micro nucleated polychromatic erythrocyte and blood lymphocyte frequency and argyrophilic nucleolar organizer regions in lymphocytes of mice
Wen et al.	2011	The effect of 100 Hz magnetic field combined with X-ray on hepatoma-implanted mice

Assessment

Three studies reported that magnetic fields at intensities ranging from 7,000 mG to 200,000 mG alone or in conjunction with chemical agents exhibited therapeutic properties for cancer. Other studies focused on biological measures (gene expression and oxidative processes) with only indirect and hypothetical relevance to the development of cancer. At the relatively high exposures studied, no effect or increases in various measures of oxidative processes were reported. Two studies measured DNA damage; the study of 40-50 mG magnetic-field intensity reported no effect, which adds to the list of studies that have failed to replicate several earlier studies at similar intensities that had been reviewed by the WHO in 2007; the study at 10,000 mG reported changes in an indicator of DNA damage but the response disappeared within 24 hours. Most of the *in vivo* studies did not employ blinding to protect against systematic bias in the collection and analysis of the data. Reviewers for the European Health Risk Assessment Network on Electromagnetic Fields Exposure (EFHRAN) concluded that the *in vivo* research published up to July 2010 indicated a "lack of effect" of magnetic fields in cancer studies. For other *in vivo* studies, EFHRAN suggested that the evidence for effects on behavior or memory was "limited" while the hematology evidence was "inadequate" (EFHRAN, 2010b).

6 Reviews by Scientific Organizations

National and international scientific organizations have published a substantial number of reports or scientific statements with regard to the possible health effects of ELF EMF over the past 5 years. Although none of these documents represents a cumulative weight-of-evidence review of the caliber of the WHO review published in June 2007, their conclusions are of relevance. In general, the conclusions of these reviews are consistent with the scientific consensus articulated in Section 5.

The WHO and other scientific organizations have not found any *consistent* associations with regard to ELF EMF exposure and any type of cancer or disease, except childhood leukemia, nor have they concluded that there is a cause-and-effect link with any health effect, including childhood leukemia (WHO, 2007; HPA, 2009; SCENIHR, 2009; EFHRAN, 2010a, 2010b; ICNIRP, 2010; SSM, 2010).

Although some research questions remain, the epidemiologic evidence does not support a cause-and-effect relationship between magnetic fields and adult leukemia/lymphoma or brain cancer, with the data being described as inadequate or weak (WHO, 2007; SCENIHR, 2009; EFHRAN, 2010a). Scientific organizations have concluded that there is strong evidence in support of *no* relationship between magnetic fields and breast cancer or cardiovascular disease (WHO, 2007; SSI, 2008; ICNIRP, 2010; EFHRAN, 2010a, 2010b; SSM, 2010). Although two epidemiology studies reported a statistical association between peak magnetic-field exposure and miscarriage a decade ago, a serious bias in how these studies were conducted was identified and various scientific panels concluded that these biases preclude making any conclusions about associations between magnetic-field exposure and miscarriage (WHO, 2007; ICNIRP, 2010). Similar issues arise in the consideration of more recent studies of sperm quality, childhood asthma, and childhood obesity by the same lead investigator. While an association between some neurodegenerative diseases (i.e., Alzheimer's disease and amyotrophic lateral sclerosis (also known as Lou Gehrig's disease) and estimates of higher average occupational magnetic-field exposure has been reported, scientific panels have described this research as weak and inadequate and recommended more research in this area (SCENIHR, 2007; WHO, 2007; SCENIHR, 2009; HCN, 2009a; ICNIRP, 2010; EFHRAN, 2010a, 2010b; SSM, 2010).

In summary, over the past twenty years, reviews published by scientific organizations using weight-of-evidence methods have concluded that the cumulative body of research to date does not support the hypothesis that ELF EMF causes any long-term adverse health effects at the levels we encounter in our everyday environments. An evaluation of current research does not point to better quality or stronger evidence that would change these assessments.

The following list indicates the scientific organization and a link to the online reports or statements.

- **The European Health Risk Assessment Network on Electromagnetic Fields Exposure**
    - http://efhran.polimi.it/docs/EFHRAN_D2_final.pdf (EFHRAN, 2010a)

  - http://efhran.polimi.it/docs/IMS-EFHRAN_09072010.pdf (EFHRAN, 2010b)

- **The Health Council of Netherlands**
  - http://www.gezondheidsraad.nl/en/publications/advisory-letter-power-lines-and-alzheimer-s-disease (HCN, 2009a)
  - http://www.gezondheidsraad.nl/sites/default/files/200902.pdf (HCN, 2009b)

- **The International Commission on Non-Ionizing Radiation Protection**
  - http://www.icnirp.de/documents/LFgdl.pdf (ICNIRP, 2010)

- **The Scientific Committee on Emerging and Newly Identified Health Risks (European Union)**
  - http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_007.pdf (SCENIHR, 2007)
  - http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_022.pdf (SCENIHR, 2009)

The Swedish Radiation Protection Authority

  - http://www.who.int/peh-emf/publications/reports/SWEDENssi_rapp_2006.pdf (SSI, 2007)
  - http://www.who.int/peh-emf/publications/reports/SWEDENssi_rapp_2007.pdf (SSI, 2008)

- **The Swedish Radiation Safety Authority**
  - http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2009/SSM-Rapport-2009-36.pdf (SSM, 2009)
  - http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2010/SSM-Rapport-2010-44.pdf (SSM, 2010)

7 Summary

A number of epidemiology and *in vivo* studies have been published on EMF and health since Exponent's 2011 update. The weak statistical association between high, average magnetic fields and childhood leukemia remains largely unexplained and unsupported by the experimental data. The recent *in vivo* studies confirm the lack of experimental data supporting a leukemogenic risk associated with magnetic-field exposure.

Overall, the current body of research supports the conclusion that there is no association between magnetic fields and adult cancer or cardiovascular disease, although future research is needed that improves upon exposure estimations. Recent literature suggested an association with magnetic fields and AD, but firm no conclusions can be drawn from this literature set regarding causation.

In conclusion, no recent studies provide evidence to alter the conclusion that the research suggests EMF exposure is not the cause of cancer or any other disease process at the levels we encounter in our everyday environment.

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