

**DRAFT**  
**Electric and Magnetic Field Best Management Practices**  
**For the Construction of Electric Transmission Lines in Connecticut**

November 5, 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 [strength] level of a magnetic field (MF) is proportional to the amount of electric current 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).

**Comment [Companies1]:** "Level" is the technically correct term for magnetic fields measured in milligauss and is used consistently elsewhere throughout the Draft.

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 demand for electric current 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 [voltage] of the line under typical loading conditions (NIEHS, 2002).

Comment [Companies2]: See sec. I ¶2 and Sec. IV C¶1 of this Draft.

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 MF 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. 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).

Comment [Companies3]: Open quote is missing. Should be before "continue."

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)

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](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, [when necessary], 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.

**Comment [Companies4]:**  
"Necessary" is inconsistent with precautionary approach, which is not based on necessity.

The Council will develop its precautionary guidelines in conjunction with Section 16-50p(i) of the Connecticut General Statutes [Public Act 04-246], enacted by the General Assembly to call special attention to their concern for children. The Act restricts the siting of overhead 345kV 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"

**Comment [Companies5]:** The referenced section of PA 04-346 has been codified as §16-50p(i). Reference to that section of the general statutes also captures amendments that have been made since the original passage of the Public Act.

### 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 without regard for MF mitigation. The Applicant shall then modify the base design by adding no-cost/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 no-cost/low-cost design features should be calculated at of 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 high-priority land uses, necessitating some variance above and below the four percent figure.

**Comment [Companies6]:** "high-priority land uses" presumably refers to "residential areas, public or private schools, licensed child day-care facilities, licensed youth camps, or public playgrounds". Suggest that for clarity, either the list be repeated here, or when the list is first stated (p.4, just above heading "Developing Policy Guidelines") it be made a defined term, such as "Statutory Facilities" or even "High-Priority Land Uses," and then repeat that defined term here.

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 or more, 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. 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 by continuing to conduct hearings open to all, periodically updating the Council's website to contain the latest information regarding MF health effect research, and to revise these Best Management Practices when deemed necessary either by new developments in MF health effect research or by development of new methods to achieve 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(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 Energy 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 [ROW-edge] MF levels at the edge of ROW, and in areas of particular interest (or, if defined term is used elsewhere, "Statutory Facilities" or "High Priority Land Uses"), with no-cost/low-cost designs that do not compromise system reliability or worker safety, or environmental and aesthetic project goals.

**Comment [Companies7]:** The Council has demonstrated interest in reducing fields not just at ROW edge. Where "statutory facilities" adjoin the ROW, the Council has investigated MF levels at the inhabited portions of the facilities. To capture this thought a revision such as that suggested here may be considered.

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 M[m]anagement 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, 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 by the Independent System Operator – New England.

**Comment [Companies8]:** The "all lines in" provision was in the Council's May 22, 2007 Draft, and seems to have been inadvertently omitted here.

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 low or no-cost measures to reduce magnetic fields by one or more measures 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 magnetic field 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 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 (except those related to transition stations, which are above ground) 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.

## V. References

American Medical Association (AMA). 2003. "Effects of Electric and Magnetic Fields."  
<http://www.ama-assn.org/ama/pub/category/13682.html>

Australian Radiation Protection and Nuclear Safety Agency (ARPNSA). 2003. The Controversy Over Electromagnetic Fields and Possible Adverse Health Effects: Fact Sheet.  
[http://www.arpansa.gov.au/is\\_emf.htm](http://www.arpansa.gov.au/is_emf.htm)

Bennett, Jr., W., Health and Low Frequency Electromagnetic Fields, Yale University Press, 1994.

British National Radiation Protection Board (NRPB) (now Health Protection Agency or HPA). 2004a. Advice on Limiting Exposure to Electromagnetic Fields (0-300 GHz). Documents of the NRPB. 15(2)  
[http://www.hpa.org.uk/radiation/publications/documents\\_of\\_nrpb/abstracts/absd15-2.htm](http://www.hpa.org.uk/radiation/publications/documents_of_nrpb/abstracts/absd15-2.htm)

British National Radiation Protection Board (NRPB) (now Health Protection Agency or HPA). 2004b. Review of the Scientific Evidence for Limiting Exposure to (0 to 300 GHz) Electromagnetic Fields. Documents of the NRPB. 15(3)  
[http://www.hpa.org.uk/radiation/publications/documents\\_of\\_nrpb/abstracts/absd15-3.htm](http://www.hpa.org.uk/radiation/publications/documents_of_nrpb/abstracts/absd15-3.htm)

California Public Utilities Commission. Order Instituting Investigation on the Commission's Own Motion to Develop Policies and Procedures for Addressing the Potential Health Effects of Electric and Magnetic Fields of Utility Facilities. Decision No. 93-11-013, Investigation No. 91-01-012 (Filed January 15, 1991). November 2, 1993. San Francisco, CA.

California Public Utilities Commission. Order Instituting Rulemaking to update the Commission's policies and procedures related to electromagnetic fields emanating from regulated utility facilities. Decision 06-01-042 (Filed August 19, 2004). January 26, 2006. San Francisco, CA.  
[http://www.cpuc.ca.gov/PUBLISHED/FINAL\\_DECISION/53181.htm](http://www.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/53181.htm).

California Public Utilities Commission. EMF Design Guidelines for Electrical Facilities. July 21, 2006.  
<http://www.cpuc.ca.gov/static/energy/environment/electromagnetic+fields/california+guidelines+for+electrical+facilities+072106+published.pdf>

Commonwealth Associates, Inc. and IIT Research Institute, Electric and Magnetic Fields (EMF) RAPID Program Engineering Project 8: FINAL REPORT, Evaluation of Field Reduction Technologies, Volume 1 (Report) and Volume 2 (Appendices), 1997.

Connecticut Department of Public Health (DPH). 2004. EMF Health Concerns Fact Sheet.  
[http://www.dph.state.ct.us/Publications/brs/eoha/emf\\_2004.pdf](http://www.dph.state.ct.us/Publications/brs/eoha/emf_2004.pdf)

Health Council of the Netherlands: ELF Electromagnetic Fields Committee. Electromagnetic fields: Annual Update 2001, 2003, 2004, 2005. <http://www.gr.nl/pdf.php?ID=1281&p=1>

Institute of Electrical and Electronics Engineers (IEEE). 2002. "C95.6-2002 IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz", Prepared by Subcommittee 3, Safety Levels with Respect to Human Exposure ISBN 0-7381-3389-2, 2002.

Institute of Electrical and Electronics Engineers (IEEE). 2002. "C2-2002 National Electric Safety Code", American National Standards Institute, 2002.

International Committee on Electromagnetic Safety (ICES) / International Agency for Research on Cancer (IARC). 2002. Static and Extremely Low-Frequency Electric and Magnetic Fields: <http://www-cie.iarc.fr/htdocs/monographs/vol80/80.html>

International Commission on Non-ionizing Radiation Protection (ICNIRP). 1998. "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz). <http://www.icnirp.org/documents/emfqdl.pdf>

Johnson, G.B., Power Research Engineering, Field Management Technologies, EMF Engineering Symposium, 1998.

Minnesota State Interagency Working Group on EMF Issues, A White Paper of Electric and Magnetic Field (EMF) Policy and Mitigation Options, 2002.

National Cancer Institute. Magnetic Field Exposures and Cancer: Questions and Answers. April 21, 2005. <http://www.cancer.gov/cancertopics/factsheet/Risk/magnetic-fields>

National Institute of Environmental Health Sciences. 2002. EMF Questions and Answers. EMF RAPID Program. <http://www.niehs.nih.gov/emfrapid/booklet/home.htm>

National Institute of Environmental Health Sciences, Report on Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields, 1999. [http://www.niehs.nih.gov/emfrapid/html/EMF\\_DIR\\_RPT/NIEHS\\_Report.pdf](http://www.niehs.nih.gov/emfrapid/html/EMF_DIR_RPT/NIEHS_Report.pdf)

National Research Council. 1999. Research on Power Frequency Fields Completed Under the Energy Policy Act of 1992. <http://www.nap.edu/catalog/9587.html>

Public Service Commission of Wisconsin. 2001. EMF – Electric and Magnetic Fields Brochure. <http://psc.wi.gov/consumerinfo/brochures/electric/6002b.pdf>

United States Geological Survey (2007). <http://geomag.usgs.gov/intro.php>

World Health Organization (2007) Fact Sheet N322, Electromagnetic Fields and Public Health, Exposure to extremely low frequency fields. <http://www.who.int/mediacentre/factsheets/fs322/en/index.html>