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Electric and Magnetic Field Best Management Practices For the Construction of Electric Transmission Facilities in Connecticut

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I. Introduction

The Connecticut Siting Council (Council) recognizes that the potential for adverse health effects from exposure to power-line electric and magnetic fields (EMF) is a matter of public concern Studies conducted from the late 1970's to date have addressed a range of concerns regarding potential health risks from exposure to EMF, whether from electric transmission facilities or other sources. To address these concerns, the Council (in accordance with Public Act 04-246) issues this policy document "*Best Management Practices for the Construction of Electric Transmission Facilities 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 fields are proportional to electric voltage, decrease rapidly with distance from the source, and are interrupted by conductive materials such as buildings and vegetation. Magnetic fields (MF) are proportional to electric current and also decrease with distance from the source, but are not interrupted by most materials. In addition to power lines, common sources of EMF include substations, transformers, household electrical wiring, electric tools, and household appliances such as hair dryers, televisions, and electric ovens. Grounding currents contribute to power line MF. Estimated average background levels of 60-Hz magnetic fields in most homes, away from appliances and electrical panels, range from 0.5 to 5 milligauss (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. As a point of comparison, the Earth has a magnetic field of about 570 mG.[1] Aside from the difference in time variation, the Earth's steady magnetic field has the same characteristics as magnetic fields associated with alternating current.

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. In the U.S., EMF associated with electric power have a frequency of 60 cycles per second (or 60 Hz). Health concerns regarding EMF are focused on magnetic fields rather than electric fields, since the weight of scientific evidence indicates that exposure to electric fields, beyond levels traditionally established for safety, does not cause adverse health effects. Safety concerns for electric fields are sufficiently addressed by adherence to the National Electrical Safety Code, as amended.

MF levels under transmission lines vary greatly, increasing and decreasing throughout the day as the demand for electric current in the lines increases and decreases. MF levels in the vicinity of transmission lines can range from about 5 to 150 mG, depending on electric-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 drops off with distance from the conductors, becoming indistinguishable from levels typically found inside or outside homes (away from operating appliances) at distances beyond approximately 300 feet (The National Institute of Environmental

1. United States Geological Survey: http://geomag.usgs.gov/intro.html

Health Sciences, 2002). For some transmission lines and typical loading conditions, the drop off to typical levels found inside or outside homes can occur over distances of less than 200 feet.

In Connecticut, existing and proposed transmission lines are designed to carry electric power at voltages of 69, 115, or 345 kilovolts (kV). Distribution lines 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 MF guidelines and engineering practices for proposed electric transmission lines with a design capacity of 69 kV or more, but not other sources of MF.

II. Health Effects from Power-Line MF

While scientific research has addressed many questions about EMF, the question of greatest interest to public health agencies is the possibility of an association between MF and leukemia in children. Some epidemiology studies have reported an association, while others have not. Two pooled analyses of these studies reported an association with estimated average exposures greater than 3 to 4 milligauss but it is difficult to determine if this level of risk represents a real increase. In 2005, the National Cancer Institute 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 that the "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 determined that a causal association has been established from EMF research, 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 the International Agency for Research on Cancer (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), have reached conclusions similar to NIEHS and NCI regarding the difficulty of making firm conclusions as to the basis for reported associations of MF with childhood leukemia. 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. 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 μT [4 mG] is associated with a small absolute raised risk of leukaemia 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 judgements developed on the

assumption that the association is causal would be subject to a very high level of uncertainty." (NRPB, 2004a, p. 15)

DPH has produced an EMF Health Concerns Fact Sheet (January 2004) 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." (p. 3).

[http://www.dph.state.ct.us/Publications/brs/eoha/emf_2004.pdf]

There are no state or federal health-based exposure standards for 60-Hz MF. Among those agencies that provide guidelines for acceptable, continuous-exposure, general-public MF levels, the International Commission on Non-Ionizing Radiation Protection established a general-public MF exposure guideline of 833 mG based on known adverse effects of high field exposures. The International Committee on Electromagnetic Safety adopted a similar, scientifically based general-public and worker MF exposure standard of 9,040 mG (ICNIRP, 1998; ICES / IEEE, 2002). Worldwide, aside from the guidelines just mentioned, no health-based exposure standards have been set. This situation reflects the scientific uncertainty regarding the presence or absence of 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 adverse health effects has not been established from the scientific investigation in the U.S. and abroad. While it is desirable to look to additional research to resolve the question about childhood leukemia, the Council recognizes that additional research may not be forthcoming in the near future to adequately resolve this question. Since the Council is uncertain as to whether there is any public health risk, it seeks to focus its policy of "prudent avoidance" that has guided its Best Management Practices since 1993. The Council has adopted a cautious approach in revising and updating these Best Management Practices. These practices are intended to recognize the latest information as well as effective technologies and management techniques on a project-specific basis to protect the public and maximize the efficiency of the electric generation, transformation, and transmission industry.

The California Experience

Like the Connecticut Siting Council, the California Public Utilities Commission adopted an EMF policy applicable to the construction of new transmission and upgraded facilities in 1993 (CPUC Decision 93-11-013). In 2006, following a multi-year review process, the CPUC updated its EMF Policy in Decision 06-01-042 (California 2006 Decision;)[2]; and the CPUC has provided detailed guidance for the application of that policy in its "EMF Design Guidelines for Electrical Facilities"[3]. The California 2006 Decision "re-affirmed that health hazards from exposures to EMF have not been established and that state and federal health regulatory agencies have determined that setting numeric exposure limits is not appropriate." (California Guidelines, at 1) The CPUC also re-affirmed that its existing no-cost and low-cost precautionary-based EMF policy should be continued. Unlike Connecticut's 1993 policy, the California policy provides a quantitative "benchmark" for "low cost" measures, which it defined as aggregate costs up to 4% of the total project cost, that would achieve a magnetic field reduction of 15% or more.

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2 http://www.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/53181.htm)

3 http://www.cpuc.ca.gov/static/energy/environment/electromagnetic+fields/california+guidelines+for+electrical+facilities+072106+published.pdf

The CPUC has explained its 4% "benchmark" as follows:

> "We direct the utilities to use 4 percent as a benchmark in developing their EMF mitigation guidelines. We will not establish 4 percent as an absolute cap at this time because we do not want to arbitrarily eliminate a potential measure that might be available but costs more than the 4 percent figure. Conversely, the utilities are encouraged to use effective measures that cost less than 4 percent."[4]

> "[W]e would consider minor increases above the 4% benchmark if justified under unique circumstances, but not as a routine application in utility design guidelines. We add the additional distinction that any EMF mitigation cost increases above the 4% benchmark should result in significant EMF mitigation to be justified, and the total costs should be relatively low." (California 2006 Decision, at 7)

> "As a guideline for accomplishing this task, we expect that EMF reductions will be 15% or greater at the utility ROW." (California 2006 decision at 10)

The "total project cost" on which the 4% benchmark is calculated includes both lines and related substations. (California 2006 Decision, at 7). MF reduction measures will "normally" not be required for underground lines; however, the CPUC recognized that "special circumstances [may] warrant some additional cost in order to achieve significant further EMF mitigation" beyond that achieved by undergrounding. (California 2006 Decision, at 12)

The CPUC also stated that in its future proceedings on transmission facility applications, "EMF concerns…should be limited to the utility's compliance with the Commission's low-cost and no-cost policies." *Id.*, at 21.

Developing a Benchmark for Connecticut

The California experience provides a useful model for Connecticut's EMF policy going forward. It is consistent with the approach that 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 World Health Organization. The California policy has significant advantages as compared to Connecticut's 1993 Policy, in that it provides more concrete and detailed guidance for achieving significant EMF reductions at low cost. Accordingly, we agree with the California rationale and recommend following the California framework in updating Connecticut's EMF Best Management Practices policy. We refer to the California 2006 Decision and generally adopt the California EMF Design Guidelines for Electrical Facilities (July 21, 2006) in implementing the Connecticut policy. However, since this is Connecticut's policy, not California's, we are following the guidance of Connecticut Public Act 04-246 in our land use prioritization of the expenditure of "low cost" funds, as follows:

1. private or public schools, licensed child day care facilities, licensed youth camps or public playgrounds

2. residential

3. recreational

4. commercial / industrial

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4 CPUC Decision 93-11-013, §3.3.2, p. 10; California Guidelines, at 1.

5. agricultural

6. undeveloped land

The Council directs the utilities to develop a Field Management Plan for power line projects that is consistent with the Council's Best Management Practices and the priority areas outlined above. This plan shall use 4% of the total projected cost of lines and related substations as a benchmark in developing EMF mitigation for new transmission lines. The 4% should be calculated as a percentage of the best estimate of the total costs during the Certificate proceeding, excluding from the base the amounts proposed to be incurred for MF mitigation. The 4% benchmark is not an absolute cap, because we do not want to arbitrarily eliminate a potential measure that might be available and effective but costs more than the 4% figure. This 4% is also not an absolute minimum, because we want to encourage the utilities to seek effective field reduction measures that cost less than 4 percent. The 4% benchmark for "low cost" measures assumes that the expenditure of costs would achieve a magnetic field reduction of 15% or more at the edge of the utility's ROW. The anticipated reductions in magnetic field of at least 15% should relate to those portions of the project where the expenditures would be made.

The Council will consider minor increases above the 4% benchmark if justified under unique circumstances, but not as a routine application. Any EMF mitigation cost increases above the 4% benchmark should result in significant EMF mitigation to be justified, and the total costs should still remain be relatively low.

MF reduction measures will not routinely be required for underground lines. However, special circumstances may warrant some additional cost in order to achieve significant further MF mitigation beyond that achieved by undergrounding. The utilities are encouraged, prior to submitting their application to the Council, to determine whether there are instances of such special circumstances in the project for which approval is sought. It should be noted 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 4% mitigation spending.

In addition, 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 will periodically request an update on changes in public-health consensus-group positions on EMF, and on any research that identifies adverse health effects from exposure to power-line electrical and magnetic fields. The second is to encourage public participation and education. The Council will continue to improve the accessibility of its open hearings and meetings, its website, <http://www.ct.gov/csc>, its numerous reports and findings—particularly this one—and the many other proceedings or documents through which it carries out its mission. The Council will also require that notices of proposed overhead transmission lines in bill enclosures provided pursuant to Conn. Gen. Stats. §16-50*l*(b) include a statement that the proposed line will meet the Council's Electric and Magnetic Field Best Management Practices, including the design of the line to reduce magnetic fields. The bill enclosure notice will inform residents how to obtain siting and EMF information specific to the proposed line at the Council's website; this information will also be available at town hall. Phone numbers for follow-up information should be made available, including those of local health, DPH, and utility representatives. The project's final post-construction specifications including EMF estimates should also be available at the Council's website and town hall.

IV. MF Best Management Practices: Further Considerations

The Council's 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. Such practices are based on the established Council policy of reducing ROW-edge MF levels with low-cost and practical engineering approaches that do not compromise system reliability or worker safety, or environmental and aesthetic project goals. For the purpose of evaluating MF levels of proposed new construction, the Council will require calculation of post-construction, in-operation MF levels (*i.e.*, "all lines in"), with MF being projected at the seasonal maximum 24-hour average current load on the line anticipated within five years after the line is placed into operation.

The initial base proposal shall involve good engineering designs that the Applicant would propose consistent with expectations of statutes, reliability criteria, and safety codes, with no specific consideration given to MF management, but which are readily amenable to design changes to lower MF. The Applicant will then evaluate and propose cost-effective changes to this base design to lower MF levels consistent with the policies described in Section III above. The Council has the option to retain a consultant to confirm that such initial base proposal and the proposed MF reduction strategies are consistent with these Best Management Practices. The cost of this third party review would be borne by the Applicant.

A. Pre- and Post-Construction MF Calculations

When preparing a transmission line project, an applicant shall provide design alternatives and pre-construction calculations of MF resulting from each alternative, 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 design's cost, effects on system reliability, visual, and environmental impacts.

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 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.

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.

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.

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 a ROW. 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 will 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, MF can be reduced by certain inherent features of an underground design. The closer proximity of the currents in the conductors 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, decrease 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 conductors 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 conductors, as described above, and through partial shielding provided by the surrounding steel pipe.

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 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 latest technological developments in underground transmission line design.

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