STATE OF CONNECTICUT

DEPARTMENT OF PUBLIC HEALTH

MEMORANDUM

TO: Pamela B. Katz, Chair, Connecticut Siting Council

FROM: Gary Ginsberg, Ph.D., Toxicologist, CT Department of Public Health

RE: CT Department of Public Health Testimony regarding EMF

DATE: May 6, 2004

In response to CT Siting Council requests stemming from CT DPH testimony on March 25, 2004, a number of materials are enclosed and briefly described below. Please let me know if you need further information in any of these areas.

1) Request for EMF fact sheets from other states: CT DPH has searched state health department websites for fact sheets on EMF. CT DPH searched websites from selected states representing the various regions of the country. Fact sheets on EMF from the following states were collected and reviewed by CT DPH: Wisconsin, Minnesota, California, New Jersey, Virginia and New York. The following state websites were searched but EMF information was not located: Texas, Washington, Pennsylvania, Florida, South Carolina, Louisiana, Arkansas, Alaska and North Carolina.

   CT DPH's review of these other state EMF fact sheets finds that the main message is generally similar across these fact sheets: that there is some evidence of a link to childhood leukemia but that the evidence is weak and inconclusive and that prudent avoidance is recommended. These messages are nuanced slightly differently from state to state but overall, they are similar to what is contained in the CT DPH fact sheet.

   Fact sheets reviewed by CT DPH are attached.

2) Request for a copy of the letter from Amey Marella, first Selectwoman from Woodbridge, requesting a meeting with CT DPH commissioner Robert Galvin. This letter was faxed to Derek Phelps on April 2, 2004, but is also included in the current submission.

3) Email Correspondence between parties to this siting process and CTDPH: Dr. Ginsberg received emails from two participants in this process, Dr. Peter Rabinowitz on 3/24/04 and from David Schaefer on 3/18/04. These emails provided information to CT DPH regarding materials that were already on the record for this case. The emails and their attachments have been printed out and attached, although the

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attachment from Mr. Schaefer was not printed out in entirety due to its length and since it is already on the record.

4) Web Site Describing Ongoing EMF Research: At the 3/25 hearing, a question came up regarding whether there is a substantial amount of new EMF health effects research. This question arose from a statement in the NYS EMF fact sheet alluding to such ongoing research. While the NYS statement appears to be dated (CT DPH has not contacted NYS on this point), we did find a useful website from the World Health Organization which describes an international research agenda for EMF and related energy fields. The attachment to this letter contains this research agenda and pages from the website that briefly describe ongoing EMF research (their database last updated 1/14/04). This research includes new epidemiology studies, controlled human exposure studies, animal toxicology studies, and cell culture studies, with the studies being conducted in Germany, Japan, Italy, Malaysia and Saudi Arabia. Our search did not find a comparable listing of studies ongoing or planned in the U.S., but our search was not exhaustive.

5) Childhood Leukemia in Connecticut: A question arose at the 3/25 hearing as to whether there are elevations in this type of cancer in Connecticut. CT DPH maintains a cancer surveillance system that is organized by year, town, type of tumor, and age group. We also are notified of and respond to cancer cluster inquiries on a regular basis, with the infrequent inquiry rising to the level of a formal cancer cluster investigation. Our department is not aware of any childhood leukemia clusters in Connecticut. The CT DPH website lists a number of Tumor Registry publications (www.dph.state.ct.us/publications/publications.htm). While these summary data report on childhood leukemia rates statewide, these rates are not analyzed by town, in part, because of the small number of such cases in a town in a given time frame. However, a request to CT DPH's Tumor Registry could be made to compile these data. Since such rates would not be analyzed in relation to EMF or other environmental exposure sources which may affect cancer rates, they would have limited utility for the current siting process.

Letter Requesting Meeting with CT DPH Commissioner

3/22 - 1:00PM -

TOWN OF WOODBRIDGE
11 MEETINGHOUSE LANE
WOODBRIDGE, CONNECTICUT 06525

Telephone: (203) 389-3401
FAX: (203) 389-3480
E-mail: amarrella@ci.woodbridge.ct.us

AMEY W. MARRELLA
FIRST SELECTMAN

March 8, 2004

OFFICE ...
MAR 10 2004

Via Facsimile and First Class Mail

Commissioner J. Robert Galvin, M.D., M.P.H.
Connecticut Department of Public Health
410 Capitol Avenue
Hartford, CT 06134-0308

Re: **Request for Meeting**

Dear Commissioner Galvin:

I am contacting you on behalf of the 24 towns potentially impacted by the "Phase II" proposal to install seventy miles of new 345-kV electric transmission line in southwestern Connecticut. This proposal is currently pending before the Connecticut Siting Council, and is known as docket no. 272.

Many of our residents have raised concerns about the potential health effects of the electro-magnetic field generated by higher voltage electric transmission lines. We would welcome the opportunity to meet with you in order to learn the views of the Department of Public Health regarding this important public health matter. In turn, we would like to share with you some of the information that our residents have provided to us regarding the potential health effects of EMF.

We respectfully request a meeting with you in the near future to share information and ideas. We would be happy to meet with you at your office, to save your travel time. Mr. Joseph Lamartine, who has been hired by the Phase II Towns to assist us with coordination, will contact your office in the hope of arranging a meeting. Once we identify a mutually agreeable time, Mr. Lamartine will inform the Phase II Town Mayors and First Selectmen.

Thank you for your consideration of this request.

Sincerely,

Amey W. Marrella

Amey W. Marrella
First Selectman

cc: Joseph Lamartine

EMF Fact Sheets From Other States

Electromagnetic Fields

What are electromagnetic fields?

Electric and magnetic fields surround anything that uses or carries electricity. These lines of force are called electromagnetic fields (EMF).

The magnetic component of EMF is measured in milligauss. Background levels (the levels we are all commonly exposed to) usually range between 0.1 and 4 milligauss.

How can I be exposed to electromagnetic fields?

Functioning electrical appliances and power lines, produce EMF. Even the earth produces small amounts of EMF. Therefore, everyone is exposed to this form of energy. The highest EMF exposure can occur using appliances such as electric blankets, microwave ovens, and hair dryers.

Moving a short distance away from an appliance or power line will greatly reduce the strength of the electromagnetic field. For example, the EMF strength of an electric can opener at 6 inches is about 600 milligauss, but at 4 feet away, it's only 2 milligauss.

What are the effects of exposure to electromagnetic fields?

The effects of electromagnetic fields on human health are not well understood. Some studies show a relationship between exposure to EMF and the development of cancer, while other studies do not.

When scientists investigated the relationship between EMF and other effects on humans (e.g., miscarriage), their results were also mixed. A panel of experts recently reviewed all of the studies on EMF; they concluded there is not enough evidence to prove that EMF cause health problems other than a possible association with cancer.

Until more is known about the effects of EMF, prudent avoidance is advised.

How can I avoid being exposed to electromagnetic fields?

- Standing a short distance away from appliances while they are in use can significantly reduce EMF exposure. Move clocks and radios a few feet away from your bed. The strength of the EMF decreases dramatically when you increase the distance between you and the appliance.

- One way to reduce your exposure from an electric blanket is to warm the bed prior to getting in, and turning it off before going to sleep.

- Have electrical wiring checked and don't allow children to play around transformers or power lines.

- Allow your hair to air dry for a few minutes before using a hair dryer. This will reduce the time needed to dry it.

What should I do if I suspect a problem?

If you suspect that you are being exposed to high levels of EMF, limit your exposure. Follow the suggested guidelines above to reduce your EMF exposure. Contact your public utility company or local health department to find out how to measure the EMF in and around your home. EMF detectors are available from some electronic stores.

For more information

- Contact the Wisconsin Division of Public Health, Bureau of Environmental Health, PO Box 2659, Madison, WI 53701-2659, (608) 266-1120; or
- Visit the department's website, www.dhfs.state.wi.us/eh

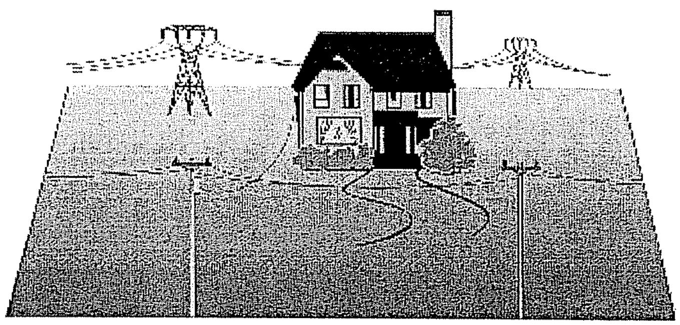
DHFS

Developed by the Wisconsin Division of Public Health,
Bureau of Environmental Health
1 West Wilson, Madison WI 53701
PPH 7103 (revised 11/00)

Electric and Magnetic Fields (EMF)

Many people have questions and concerns about electric and magnetic fields (EMF) from power lines. The information below was prepared by the Minnesota Department of Health to answer some common questions.

- Does EMF cause cancer or any other adverse health effects?
- What are typical residential EMF exposure levels?
- Is there a safe level of EMF exposure?
- How can I limit my exposures to EMF?
- How can I find more information?



The Minnesota Department of Health (MDH) regularly tracks EMF health effects research and consults with leading EMF scientists from international and federal health agencies. For information about EMF, see the links below or contact Timothy Donakowski, Radiation Control at 651-643-2128 or timothy.donakowski@health.state.mn.us

- Frequently Asked Questions (FAQs)
- Conclusions of Scientific EMF Review Committees
- Diagram of Basic Electric Power System
- White Paper On Electric And Magnetic Field

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(EMF) Policy And Mitigation Options
(September 2002) (PDF: 408KB/50 pages)

Frequently Asked Questions (FAQs)

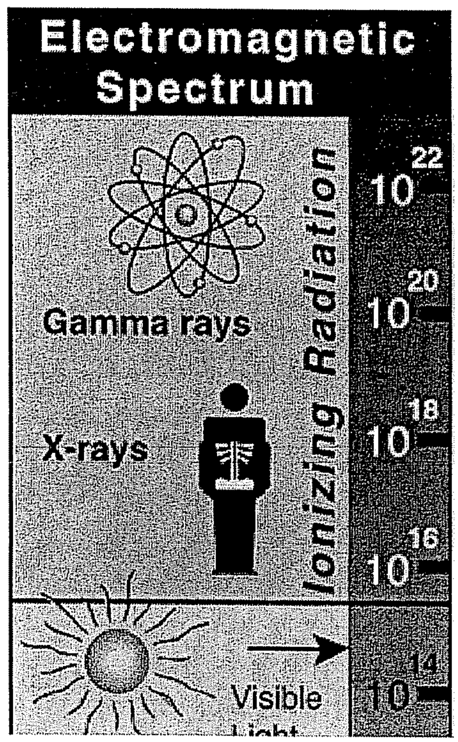
Select a topic. Go

What is EMF?

EMF refers to electric and magnetic fields which are invisible lines of force that surround any electrical device, such as a power line, electrical wiring, or an appliance. Electric fields are produced by voltage and these fields are easily shielded by objects (e.g., trees, buildings, and skin). In contrast, magnetic fields are produced by current and these fields pass through most materials. Both electric and magnetic fields weaken with increasing distance from the source.

Even though electric and magnetic fields are present around appliances and power lines, more recent interest has focused on the potential health effects of magnetic fields. This is because some epidemiological studies have suggested that there may be an association between increased cancer risks and magnetic fields.

The term "EMF" in this summary refers to 60 hertz fields associated with electrical power. These fields operate at extremely low frequencies, and are distinct from other types of fields associated with the electromagnetic spectrum, such as AM/FM radio, television, cell phones, sun light (See electromagnetic spectrum, right). For



questions about fields associated with cell phones and cell phone base stations, see Cell Phone Facts.

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How may I be exposed to EMF?

People may be exposed to EMF at work, at home, and any place where electrical power is generated, distributed, or used. Magnetic field levels vary depending on the amount of current in a power line (note this cannot be predicted from the voltage of the line). Fields are typically highest during warm summer months, when electric consumption is the highest (i.e., due to the use of air conditioners and other appliances that consume high amounts of electricity).

For estimates of typical EMF levels from transmission lines, see Figure 1. Note that the magnetic field level drops quickly from the power line (by the inverse square of distance from the line). In fact, levels at distances of 200-300 feet are often comparable or lower than levels from internal sources (e.g., appliances, wiring) in many homes. To compare levels from appliances and transmission sources, see Figure 2.

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Are there health risks from EMF?

Some epidemiological studies have reported a statistical association between surrogate indicators of residential magnetic field exposure (e.g., wire coding) and two to three fold increases in leukemia risk. More recent studies have used direct measurements to estimate magnetic field exposures. These studies show mixed results - i.e., some have reported no association and others have reported a weak association.

The inconsistencies in the epidemiological research have raised questions and concerns about whether there is a true "cause and effect" relationship between magnetic fields and leukemia (or any other adverse health effects).

Scientists generally have agreed that the epidemiological studies, by themselves, cannot establish a cause and effect relationship, and that additional evidence (e.g., laboratory studies) is needed to determine if there is a true relationship between magnetic fields and adverse effects.

In recent years there have been several laboratory studies in animals conducted under controlled experimental conditions. These studies have failed to provide any support for a relationship between magnetic fields and adverse human health effects (even at high exposure levels). In addition, studies of isolated cells (in vitro) have failed to establish a biological mechanism of action for how magnetic fields may cause cancer. These factors have raised considerable doubt in the scientific community about what relationship, if any, exists between magnetic field exposure and childhood leukemia or any other adverse health effect.

Many researchers have determined that important elements to confirm causality are currently lacking for EMF and human disease, including strength of association, consistency and specificity of observations, appropriate temporal relationship, dose response relationship, biological plausibility, and experimental verification.

Researchers also have widely acknowledged the limitations of EMF epidemiological studies, including the use of surrogate indicators (e.g., wiring code configurations) to estimate (rather than measure) magnetic field levels; the small number of cases or subjects - particularly in high exposure categories; and the potential for bias due to factors related to selection, misclassification, recall, and confounding.

While some researchers have different views on EMF, scientists agree that EMF associated with power frequencies is extremely low (60 hertz) relative to other types of fields commonly found in our environment (i.e., AM/FM radio, television, cellular phone frequencies).

They also know that low frequency EMF is not capable of causing heating or direct DNA damage (e.g., mutations) caused by higher frequency fields (e.g., ultraviolet light from the sun, cosmic rays).

Researchers continue to investigate possible mechanisms for how EMF may cause effects; however, there is limited evidence to indicate that magnetic fields cause cancer or any other adverse health effects in animals (even at high exposure levels).

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Are there exposure standards for magnetic fields?

Currently there are no federal or state *health-based* exposure standards for magnetic fields. This is due to the fact that there is inadequate scientific evidence to develop a health-based standard. References to safe/unsafe magnetic field levels in studies are not health-based standards; they are arbitrary exposure cut off points used by researchers, and they provide no scientific basis to evaluate or estimate potential health risks.

While there is currently no "safe" level determined for EMF, people may obtain measurements in their home and use information about typical magnetic field exposures to determine if their exposures are likely to be higher than, comparable to, or lower than the levels in other residential settings.

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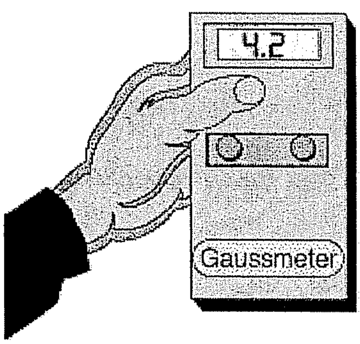

How can I measure for magnetic fields in my home?

Milligauss (mG) is the common unit of measurement for magnetic fields. These fields are measured using an instrument called a gauss meter. [Microtesla, another unit of measurement for magnetic fields, is often used in international settings and research papers. One microtesla (uT) is one-millionth of a tesla and is equal to 10 mg]

Since magnetic field levels vary depending on the current and configuration of the line, personal exposures to fields also vary at different times of the day and at different locations. Direct measurements using a gauss meter provide the most accurate and reliable estimates.

Most Minnesota electrical utilities will measure (upon request) magnetic fields (if your area is serviced by Xcel Energy, contact the EMF answer line at 612-330-6548). For other areas, contact your local utility company to request a magnetic field measurement.

Individuals also may take their own measurements by purchasing a gauss meter or by hiring an electrical consultant (companies which sell gauss meters may be identified by searching the Internet or by contacting an electrical consultant).

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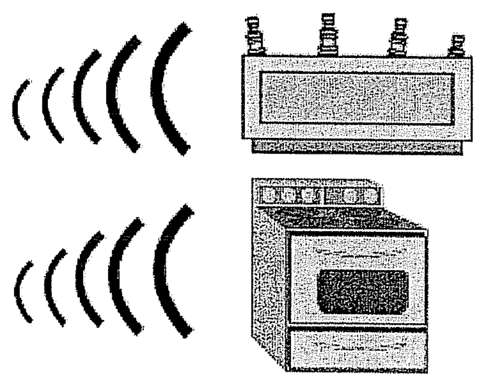
What are typical residential magnetic field exposures?



Magnetic field exposure levels vary depending on many different factors, including the amount of current and the proximity to an EMF source. Levels near appliances or a wall, for example, will typically be higher than an average mid-room reading.

In a study conducted by the Electrical Power Research Institute, spot measurements in 992 homes throughout the US showed that half (50%) of the homes studied had magnetic field measurements of 0.6 milligauss or less, when the average of measurements from all the rooms in the homes were calculated. Only 15% of the homes had mean magnetic fields greater than 2.1 milligauss. These measurements were made away from electrical appliances, and they primarily reflect the fields from internal household wiring, electrical grounding sources, and power lines. Exposures in occupational settings (e.g., near a computer or a machine/tool) are typically much higher than residential settings.

In 1998 a nationwide random survey of 1000 individuals was conducted to measure 24 hour time weighted average exposures to magnetic fields. The mean for this survey was 0.9 milligauss. Approximately 15% of the population was estimated to have exposures exceeding 2 milligauss; 2.4% had exposures exceeding 5 milligauss, and 0.4% had exposures exceeding 10 milligauss.

The last value indicates that about 1 million people in the US have an average 24 hour exposure greater than 10 milligauss. Peak exposures at a single point in time are often considerably higher due to peoples' exposures to appliances, wiring, and other sources. About 0.5% of the population had an estimated maximum (peak) exposure to magnetic fields of 1000 milligauss.

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What can be done to limit magnetic field exposures?

There are a number of ways to reduce exposures to EMF. Some are as easy as standing back from an appliance when it is in use. Remember that magnetic fields from appliances drop off dramatically in strength with increasing distance from the source.

Other EMF reduction steps, such as correcting a household wiring problem, are worth doing anyway for safety reasons. But what about more costly actions, such as burying power lines or moving out of a home?

Because scientists are still debating whether EMF is a hazard, it is not clear how much should be done at this time to reduce exposures. Some EMF reduction measures may create other problems. For instance, compacting power lines to reduce EMF can increase the danger of accidental electrocution for line workers.

If you would like to limit your exposure to EMF, you may take simple steps, such as:

- Increase the distance between yourself and the EMF source - sit at arm's length from your computer terminal.
- Avoid unnecessary proximity to high EMF sources -- such as appliances and electric blankets.
- Reduce time spent in the field - turn off your computer monitor and other electrical appliances when you aren't using them.

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What conclusions can be made about EMF?

The Minnesota Department of Health has concluded that the current body of evidence is insufficient to establish a cause and effect relationship between EMF and adverse health effects. While some epidemiological studies have reported a weak association between leukemia with increasing exposure to magnetic fields, other studies have reported no association. Epidemological studies alone are considered insufficient for concluding that a cause and effect relationship exists, and must be supplemented by data from laboratory studies. Existing laboratory studies have not substantiated this relationship (even at high exposure levels).

These conclusions are similar to the conclusions of scientific committees convened by the US Congress, and other international and national health agencies (see Conclusions of Scientific EMF Review Committees).

As with many other environmental health issues, the possibility of a health risk from EMF cannot be entirely dismissed. The MDH considers it prudent public health policy to continue to monitor the EMF research and to support prudent avoidance measures, including providing information to the public regarding EMF sources and exposures.

MDH and other state agencies are also working together to provide guidance for a consistent science-based EMF policy, including the identification of low cost no cost measures to mitigate EMF exposures.

For more information, see the EMF White Paper on Electric and Magnetic Field (EMF) Policy and Mitigation Options (September 2002) PDF (408KB / 50 pages).

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What about new EMF research initiatives and programs?

EMF research is continuing in the US and abroad, as new methods for studies are developed to improve exposure assessment; to control for confounding and other types of bias; and to investigate possible biological mechanisms. The National Institute of Environmental Health Sciences supports some limited EMF research; however, their 5-year EMF RAPID Program has concluded, and there do not appear to be any plans to expand EMF (60 hertz) federal research at this time. Federal research in related areas appears to be directed toward higher frequency fields associated with radiofrequencies and cellular phones (see Cellular Phone Facts).

In 2001 the California Department of Health Services released a draft EMF Risk Evaluation Report. For a link to the report and MDH's assessment, see the California EMF Evaluation — 2001 Draft Report.

In 2002 the World Health Organization (WHO) International EMF Project is expected to complete an assessment of EMF health risks. This project works in collaboration with international agencies and organizations to pool resources and knowledge about EMF; to identify gaps in knowledge; recommend focused research programs; conduct updated critical reviews of the scientific literature; and develop materials for risk communication. Note that WHO defines EMF broadly to include static, extremely low, intermediate, and radiofrequency fields (up to 300 gigahertz).

MDH continues to monitor important EMF health effects research, and consults with leading EMF scientists affiliated with the National Institute of Environmental Health Sciences, National Toxicology Program, and US Environmental Protection Agency.

MDH and other state agencies, including the Public Utilities Commission, Department of Commerce, Pollution Control Agency, and Environmental Quality Board also are working together to support consistent EMF policy and low/no cost measures to mitigate EMF exposures in Minnesota (where possible).

For more information, see the EMF White Paper on Electric and Magnetic Field (EMF) Policy and Mitigation Options (September 2002) PDF (408KB / 50 pages).

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Where can I find more information?

For more information about EMF research and health risks, see the web sites or contact Timothy Donakowski, Minnesota Department of Health, Radiation Unit, by phone 651-643-2128 or e-mail timothy.donakowski@health.state.mn.us. For information about other state agencies who regulate or participate in decision-making about power lines and EMF, see Contacts.

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Images are courtesy of National Institutes of Environmental Health Sciences and U.S. Department of Energy

For questions about this page, please contact our Environmental Health Division: ehweb@health.state.mn.us

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Updated Wednesday, 31-Mar-04 13:52:05

Gray Davis
Governor
State of California

Grantland Johnson
Secretary
Health and Human Services Agency

Diana M. Bontá, R.N., Dr.P.H
Director

Department of Health Services

SHORT FACTSHEET ON EMF

The use of electricity is taken for granted, but people are still concerned about whether powerlines and appliances are safe or unsafe. Here are answers to some common questions about electric and magnetic fields. See also our Web site at http://www.dhs.ca.gov/ps/deodc/ehib/.

What are electric and magnetic fields and why are people concerned about them?

Electric and magnetic fields are a basic force of nature (like gravity), generated by electricity. They are found almost everywhere. Electric and magnetic fields are found in nature, where they are created by such things as lightning and static electricity. Man-made fields are found wherever people use electricity, such as near powerlines and electrical appliances. Like sound, electric and magnetic fields are made of a mixture of components and so can be described in many different ways. Both have wave-like properties such as strength and "frequency" (how often they cycle back and forth). Sound can be loud (strong) or soft (weak), high or low pitched (different frequencies), suddenly loud or constant in tone, and pure or jarring. Similarly, electric and magnetic fields are a mixture of components. They can be strong or weak, have a high or low frequency, have sudden increases in strength ("transients") or a constant strength, and consist of one pure frequency or several (called "harmonics"). For example, the *strength* of a field can be weak and constant, as in most nighttime home environments, or it can be strong and vary from high to low every few seconds, as from an electric blanket set on high.

Powerlines and wiring in buildings and appliances generate 50 and 60 Hertz fields, sometimes referred to as "power frequency" fields. Hertz is the unit for measuring the frequency of fields in the number of wave cycles each second. The lower the frequency of a field, the lower its energy. Power frequency fields are low frequency fields and have low energy levels. Microwave and x-ray fields are high frequency fields and have high energy levels.

Early scientific studies found a link between increased rates of cancer and closeness to certain kinds of powerlines that can cause strong magnetic fields. Over the last two decades concern about the health effects of electric and magnetic fields has increased.

Where does EMF come from?

We are exposed to EMF from many sources, including high voltage transmission lines (usually on metal towers) carrying electricity from generating plants to communities, and distribution lines (usually on wooden telephone poles) that bring electricity to our homes, schools and workplaces. We are also exposed to magnetic fields from wiring in buildings and from all our electric appliances, like TV sets, radios, hair dryers, electric blankets and electric tools.

Most of the fields we experience in a day come from sources other than powerlines, such as wiring and appliances in homes or workplaces. The strength of both electric and magnetic fields decreases as you move away from their source, just as the heat from a campfire decreases with distance. For both electric and magnetic fields strength decreases more quickly with distance from "point" sources like appliances than from "line" sources such as powerlines. For example, the magnetic field is down to "background levels" (the naturally occurring amounts) at 3 or 4 feet away from an appliance (*table 1*). It reaches background levels around 60 to 200 feet from a distribution line and about 300 to 1000 feet from a transmission line.

In spite of these similarities, electric fields and magnetic fields have somewhat different properties and possibly different ways of influencing our bodies. Electric fields can be shielded or weakened by trees, buildings and even human skin, but magnetic fields are not so easily blocked. Most recent studies have focused on the health effects of magnetic fields because they are not readily shielded and are easier to measure than electric fields.

Table 1. Examples of magnetic fields at particular distances from appliance surfaces.

	MILLIGAUSS (mG) at 1 foot	at 3 feet
aquarium pump	0.35-18.21	0.01-1.17
band saw	0.51-14.24	0.05-0.75
can opener	7.19-163.02	1.30-6.44
clock	0.34-13.18	0.03-0.68
clothes iron	1.66-2.93	0.25-0.37
coffee machine	0.09-7.30	0-0.61
computer monitor	0.20-134.7	0.01-9.37
copier	0.05-18.38	0-2.39
desktop light	32.81	1.21
dishwasher	4.98-8.91	0.84-1.63
drill press	0.21-33.33	0.03-8.35
fax machine	0.16	0.03
food processor	6.19	0.35
garbage disposal	2.72-7.79	0.19-1.51
hairdryer	0.1-70	0.1-2.8*
microwave oven	0.59-54.33	0.11-4.66
mixer	0.49-41.21	0.09-3.93
portable heater	0.11-19.60	0-1.38
printer	0.74-43.11	0.18-2.45
portable fan	0.04-85.64	0.03-3.12
radio	0.43-4.07	0.03-0.98
range	0.60-35.93	0.05-2.83
refrigerator	0.12-2.99	0.01-0.60
scanner	2.18-26.91	0.09-3.48
sewing machine	3.79-7.70	0.35-0.45
tape player	0.13-6.01	0.01-1.66
television	1.80-12.99	0.07-1.11
toaster	0.29-4.63	0.01-0.47
vacuum	7.06-22.62	0.51-1.28
VCR	0.19-4.63	0.01-0.41
vending machine	0.46-5.05	0.02-0.59

L. Zaffanella, School Exposure Assessment Survey, California EMF Program, interim results, Nov. 1997.

What kind of scientific studies have been done?

Nobody knows for sure whether exposure to 50 and 60 Hertz fields is a health risk. Three kinds of studies have been done to explore this:

1) laboratory studies that expose human or animal cells or organs to fields, looking for biological changes

2) laboratory studies that expose animals to fields, looking for changes in body function, chemistry, behavior or general health

3) "epidemiological" studies that observe people's health and evaluate whether groups that have high or unusual EMF exposure have a greater chance for developing a disease like cancer than groups with "normal" or usual exposures

What do these studies show?

First, *these studies do not show a clear pattern of health hazards*. Some but not all animal and cell studies have shown biological changes linked with *magnetic field* exposure. However, it is not clear whether these biological changes would be the same in humans. Second, it is not clear which component (frequency, strength, harmonics, etc.) of magnetic field exposure might be hazardous.

Concern about possible health hazards from electric power use is supported by results of some scientific studies, but the evidence they provide is still incomplete and inconclusive and even, in some cases, contradictory. A good deal of research is underway to help resolve these questions and uncertainties. Most but not all epidemiological studies show an association between leukemia (a type of cancer) and an "indirect" estimate of high magnetic field exposure such as living very near a type of powerline that could cause of high magnetic fields or working where there is high electrical exposure. These estimates may not really represent a person's true exposure at the critical time period when they may have started developing an illness. Also, these studies show that some estimates of magnetic field exposure might be *related* to cancer, but this does not necessarily mean that magnetic fields *cause* cancer. Indirect ways of estimating exposure may unintentionally include other risk factors like chemicals used at work or living in a particular neighborhood.

How would magnetic field measurements taken in my house compare to others?

The California Department of Health Services measured the strength of magnetic fields in the bedroom, family room, and kitchen and at the front door of some San Francisco Bay Area houses. Any appliances or electrical devices that were on at the time were left on. As shown in *table 2*, about half of the houses had an average magnetic field level below 0.71 milligauss (mG, the basic unit for measuring magnetic field strength), and 90% of homes had levels below 1.58 mG.

These are measures of the average strength of the 60 Hertz frequency magnetic field at a particular day and time. Field strengths vary with time, day and season depending on electricity use. For example, dinnertime readings are often higher than the middle of the night because appliances are in use. The other magnetic field components (like harmonics of other frequencies and short bursts of stronger fields called transients) are not included in these measurements, so they do not describe other aspects of the fields or other frequencies. Also, the field strength may change over time or distance depending on the location and type of its source.

Table 2. Distribution of average magnetic field strength of San Francisco Bay Area homes.

homes below average field strength	736 homes measured[1]
10%	0.43 mG
25%	0.54 mG
50%	0.71 mG
75%	0.98 mG
90%	1.58 mG

[1]Lee, G., California Exposure Assessment study (preliminary findings). California EMF Program. 1996.

Fairly simple measurements made by a trained technician can show the main indoor or outdoor sources of elevated magnetic fields in a home. Many utility companies and several private businesses can take these measurements. Taking measurements at different distances from powerlines can help show if the lines are sources for elevated magnetic fields inside a home. Turning off the house's main power switch will rule out sources caused by power use inside. In most cases it is possible to find and correct the source of elevated fields if they are due to faulty wiring, grounding problems or choice of lighting fixtures.

What are current government initiatives on EMF?

The State of California

The California Department of Education enacted regulations that require minimum distances between a *new school* and the edge of a transmission line "right-of-way," or the area immediately surrounding lines that utility companies need to access the lines for maintenance and repairs. The setback distances are 100 feet for 50-133 kV lines, 150 feet for 220-230 kV lines, and 350 feet for 500-550 kV lines. These distances were not based on specific biological evidence, but on the known fact that the strength of electric fields from powerlines drops to near background levels at the specified distances, given that no other major sources are present.

In 1993, the California Public Utilities Commission (CPUC) authorized the state's investor-owned utilities to carry out "no and low cost EMF avoidance and measures" in construction of new and upgraded utility projects. The CPUC also established our California EMF research, education, and technical assistance program under the guidance of the Department of Health Services. This program will provide information to assist those responsible for making public policy. However, at present the state of California has no formal rules or guidelines, but advocates "no and low cost" of EMF. This means minimizing EMF exposure when it is easy and inexpensive to do so. Right now there is not enough evidence to justify making regulations governing EMF.

The Federal Government

At the Federal level, the Federal Energy Policy Act of 1992 included a five-year program of electric and magnetic field (EMF) Research and Public Information Dissemination (EMF-RAPID). The EMF-RAPID Program asked these questions: Does exposure to EMF produced by power generation, transmission, and use of electric energy pose a risk to human health? If so, how significant is the risk, who is at risk, and how can the risk be reduced?

In 1998, a working group of experts gathered by the EMF-RAPID Program met to review the research that has been done on the possible health risks associated with EMF. This group reviewed the studies that have been done on the subject, and then voted on whether they believed that exposure to EMF might be a health risk. They then published a report describing their findings. A majority of the scientists on this working group voted that the epidemiology studies of childhood leukemia provide enough evidence to classify EMF as a "possible human carcinogen." This means that, based on the evidence, these researchers believe that it is possible that EMF causes cancer, but they are not sure. They also decided that they did not have enough evidence to determine whether EMF exposure might cause other diseases.

The EMF-RAPID Program released its final report to Congress in 1999. This report explains the program's findings, including the results of its working group and many research projects. The final report states that "the NIEHS believes that there is weak evidence for possible health effects from [power frequency] ELF-EMF exposures, and until stronger evidence changes this opinion, inexpensive and safe reductions should be encouraged." (page 38) For more information on the EMF-RAPID program, or to look at these reports, contact the EMF-RAPID Program, National Institute of Environmental Health Sciences, National Institutes of Health, P.O. Box 12233, Research Triangle Park, North Carolina 27709, or visit their Web site at http://www.niehs.nih.gov/emfrapid. When ordering a copy of the final report, refer to the NIH publication number 99-4493.

Conclusion

Until we have more information, some communities and individuals are adopting the "no and low cost" avoidance strategy. It's easy to move an electric clock a few feet away from a bedside table, and it's simple to sit further away from the computer monitor. Table 1 above shows how quickly EMF decreases as you move away from an appliance. It almost disappears at distances of 3 to 5 feet. It is possible to take measurements in your home to identify sources of EMF, including faulty electrical wiring that can produce elevated magnetic fields and electrical shock. In California, the Public Utilities Commission requires investor-owned utilities to provide magnetic field measurements at no charge to their customers.

Contact us for a more detailed long factsheet. Please send us your questions and comments, too.

CALIFORNIA ELECTRIC AND MAGNETIC FIELDS PROGRAM
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Frequently Asked Questions about Magnetic Fields and Homes

This fact sheet contains information about electric and magnetic fields (EMF) from power lines, building wiring, appliances, and other electrical equipment in residential settings. This information may be of use to people who are buying, selling, or renting homes or apartments, or have questions about EMF in their current residence. Some of the information in this fact sheet is specific to the state of California. For more general information about EMF, please see our long and short fact sheets, available on the Internet at *http://www.dhs.ca.gov/ps/deodc/ehib/*.

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What are Electric and Magnetic Fields?

Wherever there is electricity, there are also electric and magnetic fields (EMF), which are fields of force (or energy) created by electric charges. Electric fields result from the *strength* of the electrical charges, or the voltage, while magnetic fields result from the *motion* of the charge, or the current. Because the electric current creates magnetic fields, appliances must be turned on to produce magnetic fields, but any appliance that is plugged in will produce an electric field. Electric fields are easily shielded: they may be weakened, distorted, or blocked by conducting objects such as earth, trees, and buildings, but magnetic fields are not as easily blocked. The intensity or strength of an electric field in a location is measured in volts per meter (V/m) or in kilovolts per meter (kV/m). The intensity of a magnetic field is measured in gauss (G) or tesla (T). The strength of both electric and magnetic fields decreases as you get further away from their source.

Direct current of the sort from a battery-operated appliance such as a flashlight flows only in one direction, unlike alternating current (AC) sources in which the energy flow changes direction with a specific frequency, measured in cycles per second or Hertz (HZ). Power systems in the United States create a specific type of alternating current electric and magnetic fields, called 60 Hertz or "power frequency" fields. This fact sheet focuses on power frequency fields created by power lines and other electrical equipment, and not on DC fields or on the higher frequency and higher energy fields generated by sources such as cellular phone antennas or television transmitters.

What are Some Sources of Power Frequency EMF in Homes?

There are power frequency electric and magnetic fields almost everywhere we go because electric power is so widely used. Exposure to these fields comes from many sources, such as high voltage "transmission" lines (usually on metal towers) carrying electricity from generating plants to communities and "distribution" lines (usually on wooden poles) bringing electricity from local substations to our homes, schools, and work places. Other sources of exposure are internal wiring in buildings, low voltage currents flowing back to the power grid on plumbing pipes, and electric appliances such as televisions, computer monitors, radios, hair dryers, and electric blankets. Sources with *high voltage* produce strong electric fields, while sources with *strong currents* produce strong magnetic fields.

If you are concerned about EMF from any of these sources in or near your home it may be helpful to know that electric and magnetic fields weaken as you move further away from their source. Electric and magnetic field strength gets lower more rapidly with distance from "point" sources such as appliances than from "line" sources such as power lines. In general, the fields from a particular source are down to "background" level (the typical amount a person might encounter even if that source were not present) about 3-4 feet from an appliance, 60-200 feet from a distribution line, and 300-1,000 feet from a transmission line. Fields can interact to strengthen or weaken their total effect in a given area. Because of this, the field strength at a particular location depends not only on the distance from the major source but also the distance and location of other nearby sources.

Transformers convert high voltage electricity from "primary" distribution lines (that carry power from substations through neighborhoods) to electricity of the lower voltage used in homes, which is carried from the transformer through the neighborhood on "secondary" distribution lines until it is fed off to the individual homes. For overhead distribution lines, the transformers are the canisters or cylinders on some utility poles between the upper primary lines and the lower secondary lines. For underground lines, the transformers are boxes, usually at ground level, that are connected to the power lines below.

Transformers, like appliances, are point sources, and so fields decrease fairly quickly as one moves further away from them. Because of the large amount of electrical current that often goes through transformers, though, the fields from them may be higher than from some appliances and may require a greater distance to reach background levels.

Power substations contain electrical equipment that creates fields, but equipment (mostly point sources) inside most stations does not raise fields outside of the station itself. There are generally many power lines that run into and out of substations, however, and these power lines, like any others, produce fields. So, elevated fields in homes near substations may be from power lines connected to the substation rather than the equipment inside the station itself.

This fact sheet focuses on power frequency magnetic fields, since they have been the object of more concern and study than electric fields. This is because magnetic fields are not easily shielded and therefore can penetrate soil, building materials, and the body surface more easily than electric fields. For this same reason, they are also easier to measure.

How is Magnetic Field Exposure in Homes Measured?

There are several different ways of estimating a person's magnetic field exposure at home. The major ways this has been done are: 1) indirectly by assessing the types and proximity of power lines nearby (wire codes); 2) indirectly by taking area (spot) measurements; and 3) directly by taking repeated measurements with a meter worn by a person while at home (personal measurements).

1. Wire codes

Many early studies of magnetic fields and human health estimated exposure from powerlines by using "wire codes" rather than by directly measuring fields. Wire codes categorize homes based on the types of power lines near the house and their distances from it. The wire code system is based on the fact that magnetic field strength decreases with distance from the field source and the assumption that homes near power lines that have the potential to carry more current would have stronger magnetic fields than homes next to lines that are limited to carrying smaller amounts of current. Table 1 shows one type of wire code system and the ranges of "spot measurements" (brief magnetic field measurements taken at different locations) found in different wire code category homes in one study.[1] Using this system, all homes fit into one of four possible categories based on the type and distance of nearby power lines. These four categories are intended to reflect different levels of magnetic field exposure from power lines. Though the highest fields are found in homes in the highest categories, spot measurements in the homes show that there is a great deal of overlap between the fields found in the different categories. Note that while the average field in homes served by underground lines is lower than those served by above ground lines,[2] these homes still have fields from other sources such as wiring and appliances.

Table 1 Magnetic field spot measurements in residential areas by wire code (strengths in milliGauss)

	Under Line				Outdoor + Front Door				Indoor			
	UG	OL	OH	VH	UG	OL	OH	VH	UG	OL	OH	VH
Mean	X	1.2	2.2	3.3	0.8	0.7	1.1	1.5	0.8	0.9	1.1	1.5
10%	X	0.5	0.5	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5
50%	X	0.9	1.1	1.50	0.7	0.6	0.8	0.9	0.7	0.7	0.9	0.9
90%	X	2.0	5.0	6.1	1.3	1.2	1.9	3.2	1.2	1.5	1.7	2.8

Source: Lee, G., California Exposure Assessment Study (preliminary findings). California EMF Program. 1996

Wire Codes:
UG (Underground) All power lines within 150 feet of the house are below ground
OL (Ordinary Low) The house is 130-150 feet from a transmission line or major primary distribution line, 65-150 feet from a minor primary distribution line, or 51-150 feet from most secondary distribution lines.
OH (Ordinary High) The house is 50-129 feet from a transmission line or major primary, 25-64 feet from a minor primary, or within 50 feet of certain types of secondary lines.
VH (Very High) The house is within 50 feet of a transmission line or major primary or within 25 feet of a minor primary.

Spot measurement categories:
Under Line – Directly underneath the power lines nearest the home being surveyed
Outdoor – Measured in the outdoor areas on the property of the home being surveyed
Indoor – Measured inside the home being surveyed

2. Spot measurements

A second measurement strategy that has been used to estimate an individual's magnetic field exposure is taking spot measurements (measurements over a short time period) in homes. Some people believe that spot measurements represent a person's residential exposure better than wire codes. This belief is based on the fact that spot measurements involve the measurement of actual levels and so could capture exposure from sources other than power lines, such as appliances and home wiring. Wire codes could not be expected to reflect these non-powerline field sources. Spot measurements have their own limitations, however. First, they only measure the field levels at one point in time, though magnetic fields change over time depending on energy use. In addition, they only measure magnetic fields at a few spots in a given home, typically the centers of the rooms that are used most often. These measurements may not capture the levels near walls or particular appliances, though people may spend time in these other locations.

Table 2A Distribution of average magnetic field strength in San Francisco Bay Area homes

Percent of homes with average spot measurements below field strength	Field strength
10%	0.4 mG
25%	0.5 mG
50% (median)	0.7 mG
75%	1.0 mG
90%	1.6 mG

Lee, G., California Exposure Assessment Study (preliminary findings). California EMF Program. 1996

Table 2B Percentage of San Francisco Bay Area homes in various milliGauss ranges

Field Strength Range	Percentage of homes with average spot measurements in range
0-0.7 mG	45.0%
0.7-1.0 mG	29.5%
1.0-2.0 mG	19.3%
2.0-3.0 mG	3.2%
3.0-4.0 mG	1.7%
4.0+ mG	1.3%

Lee, G., California Exposure Assessment Study (preliminary findings). California EMF Program. 1996

Table 2 shows magnetic field home spot measures from a survey conducted by the California Department of Health Services of about 600 homes in the San Francisco Bay Area and individuals residing in these homes. For the home spot measurements, the strength of magnetic fields was obtained for the bedroom, family room, and kitchen, and averaged for the total home exposure. Any appliances or electrical devices that were on at the time of measurement were left on. As shown in Table 2A, about half of the houses had an *average* magnetic field level below 0.7 milliGauss (mG) and 90 percent had *average* levels below 1.6 mG. Measurements from a national survey were similar.[3] All of the measurements reflect the average field strength of the 60-Hertz frequency magnetic fields when the measurements were taken, and the levels could be higher or lower at other times. For example, readings taken at dinnertime, when more appliances are in use, are often higher than ones taken in the middle of the night. Table 2B shows the percent of the same houses that fell into certain milliGauss categories.

3. Personal measurements

In fact, neither wire codes nor spot measurements capture the true magnetic field levels experienced by people while they are at home. Some recent studies have attempted to capture a person's actual exposure by having study participants wear magnetic fields meters, generally for 24 hours, so their measurements can be recorded throughout a full day. Participants keep track of where they are throughout the day, so their location (at home, at school or work, etc.) can be matched to their measurements. Table 3 shows the personal average magnetic field measurements for about 600 San Francisco Bay Area residents while they were at home. These measurements are similar to the home spot measurements. Overnight exposures were slightly lower than those found for the "awake" times. Comparing Table 2A and Table 3 demonstrates that the spot measurements taken in the middle of rooms in these women's homes provide a good estimate of the magnetic fields these same women experienced as they moved around inside those houses. The personal measurements are a little higher than the spot measurements.

The strength of the personal magnetic field exposures may be measured in different ways. The average shown in the table above captures the average field strength over a given time period. Another thing to consider is that a person's exposure over time may be of a constant strength or the strength may vary. One way of assessing the changes in strength over time is by looking at how much and how quickly the intensity changes over time, or the "rate of change." This can be assessed using a "rate of change metric" (RCM). A slightly different way of measuring fields is to compare the minimum level to the maximum level experienced over time; this shows the overall range of

Table 3 Distribution of average home personal magnetic field measurements of residents (strengths in milliGauss, as measured with a meter worn by a resident of the home during the time spent in the home)

Percent of homes (persons) with average measurements below field strength	Personal Average Total Home	Personal Average Home "awake time"	Personal Average Home "bed overnight"
10%	0.5	0.7	0.4
50% (median)	0.7	0.8	0.6
90%	1.7	1.8	1.6

Lee, G., California Exposure Assessment Study (preliminary findings). California EMF Program, 1996

intensity, but not the rate at which the level changes. These metrics may capture different sources of magnetic field exposure. A person with a high average exposure may not necessarily have a high RCM.

Figures 1A and 1B show the overnight magnetic field tracing for two different people, John and Joan. The strength of the field is on the vertical y-axis while the time period is on the horizontal x-axis of each graph. Both John and Joan have the same average exposure (about 2.0 mG). However, the variation in their measurements (the rate of change metric) is different. Joan's nighttime exposure is constant in field strength while John's nighttime exposure fluctuates considerably. As a result, John has a greater range of nighttime exposure (1 mG minimum to 3 mG maximum) than Joan, whose minimum and maximum values are the same.

In the study of San Francisco Bay Area women mentioned above, the maximum magnetic field experienced by 75% of women was above 14 mG, 50% experienced brief maximum fields above 23 mG, and 25% experienced maximum fields above 35 mG. Most women only experienced a few such high exposures a day, probably from moving near appliances, underground power lines, or indoor fields from building wiring or plumbing.

Though these personal measurements capture a person's actual exposure at different places and times, rather than the estimated average fields in their homes, this strategy also has limitations. For example, it is possible that the measurements may be taken on an atypical day, one on which a person does not participate in usual daily activities or is exposed to different sources than on most days. For example, a person who cooks with an electric stove almost every day may seem to have lower exposure if he is measured on a day when he does not cook. So, a person's average daily exposure over the course of a year may be very different from that person's exposure on any given day.

Figure 1A

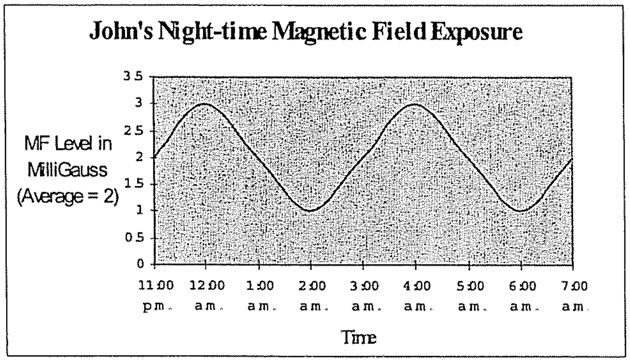
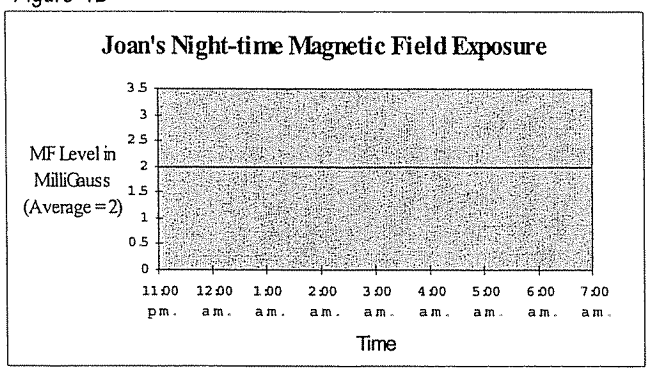


Figure 1B



Advantages and Limitations of the Different Measurement Strategies

Each of these ways of measuring a person's home magnetic field exposure has advantages and limitations. Wire codes estimate exposure on the basis of something relatively constant over time: proximity to different types of power lines. Because of this they might provide good estimates of exposure from power lines, even for times in the past. The different wire code categories overlap, however, and only consider power lines, not other sources, so wire codes may not capture differences in exposure between homes as well as some of the other measurement strategies. Also, wire codes may only capture certain types of exposures such as the average level rather than the level's rate of change.

Spot measurements capture more of these differences because they measure actual fields at different locations in the home; however, they are generally only taken at specific locations around the home and at one point in time, and so may not capture people's actual exposure in the areas where they spend time or over the course of a year. Personal measurements capture a person's actual exposure, but generally only measure a short period of time that may not be representative of a person's exposure on a typical day or a person's average annual or lifetime exposure. Unlike spot measures, measurements taken over a longer period of time (i.e., for a 24-hour period) allow researchers to see some changes in the exposure over time.

How High are the Magnetic Fields Likely to Be in A Home Near an Overhead Power Transmission Line (Usually on a Large Metal Tower)?

Every situation is different because the fields near any power line depend on several factors, including the exact distance of a home from the line and many engineering aspects of how the lines are set up. As stated earlier, fields from power transmission lines often reach background levels between 300 and 1,000 feet from the line. The only way to be sure of the fields in a given area at a particular time is to get measurements taken.

What is a "Safe" Level of Magnetic Field Exposure?

Scientists are not sure whether there are health risks from exposure to power frequency magnetic fields or, if so, what is a "safe" or "unsafe" level of exposure. There have been many studies on this but none conclusively show whether magnetic fields are a health risk, and some studies have had contradictory results. In 1998, a work group formed by a federal program that studied this issue classified EMF as a "possible human carcinogen" for childhood leukemia, meaning that they believe that it might increase the risk of getting childhood leukemia, but they are not sure. That program's final report states that "... [power frequency] ELF-EMF exposure cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard."[4]

But because it is not clear whether exposure to EMF increases health risks, the report does not recommend taking difficult or expensive actions to reduce exposure. It does suggest that people consider reducing their exposure if it is easy or inexpensive to do so.

Because we do not know whether electric and magnetic fields are a health risk, it is impossible to say whether a given amount of magnetic field exposure or particular distance from a power line or other source is "safe" or "unsafe." It is possible to compare the levels measured in a home to average (or typical) levels found in a survey of homes such as the survey conducted by the California Department of Health Services (CDHS).

CDHS is currently conducting a Risk Evaluation to determine how likely it may be that EMF, especially magnetic fields, might increase health risks. Researchers are reviewing the evidence and writing a report to explain their conclusions and recommendations. This report is expected to be available by the end of 2001.

Are There Any Government Standards for Magnetic Fields Levels in Homes?

There are no federal or California state laws limiting the level of EMF in residences or the amount to which a person can be exposed. This is because no one is certain whether magnetic fields might increase health risks. Still, in some cases the effect of EMF on residences may be considered in new development. The California Public Utilities Commission, which regulates most of the electric utility companies in California, encourages utilities to take low-cost actions to reduce the fields created by new power lines and facilities. Local governments have the authority to approve new residential and commercial development, and sometimes consider the location of nearby power lines and other electrical equipment in their approval process.

Table 4 Setbacks for siting new schools near power transmission lines

Transmission line voltage	Required setback
50-133 kV	100 feet
220-230 kV	150 feet
500-550 kV	350 feet

School Facilities Planning Division, California Department of Education, "School Site Selection and Approval Guide," 1993

City and county governments can require new building projects to meet certain conditions, and in some cases may require projects to take action to minimize fields where people will live or make possible tenants and buyers aware that they are near electrical facilities. These requirements vary by location and sometimes by project.

Currently, the only relevant state regulation in California requires that when new schools are built, they must be at least a minimum distance from transmission lines. The required setback varies depending on the voltage of the line (see Table 4). This regulation does not apply to existing schools that are near power lines, and is not based on any evidence that the setback might decrease health risks. For more information on this regulation, contact the School Facilities Planning Division of the California Department of Education.

If I Am Concerned About the Possible Health Effects of Magnetic Fields, What Factors Should I Consider When Looking at A Home or Apartment?

If you are concerned about EMF, there are questions that you can ask when buying or renting a home or apartment to help you address your concerns. Some questions include:

- Are there any overhead or underground power lines nearby? If so, what types (transmission, sub-transmission, overhead distribution, or underground distribution) and how far are they from the home?
- Are there any electrical facilities (such as power stations) located in the immediate area?
- Does the electrical wiring in the home meet current electrical safety standards? Improper wiring can cause high magnetic fields in the home's electrical system or on metal plumbing pipes, and may also create a potential fire or shock hazard.
- How old is the wiring, and has it been updated using current standards? Older "knob and tube" wiring creates higher fields than more modern wiring.
- Where are the other major sources of high EMF in and near the home located? These sources may include electric appliances, transformers, track lighting, lights with dimmer switches (if not wired correctly), and the place where the electrical wire from the power line enters the building (called the "service drop").
- How close are these sources to the areas in which your family members will spend most of their time (bedrooms, living room, etc.)?

Where you live is a very individual decision, but the answers to these questions may help you decide whether you are concerned about EMF exposure in the home.

How Do I Find Out the Magnetic Field Levels in A Residence?

You can learn whether the field levels are above average in a home or yard by getting magnetic field measurements taken by your utility company or a consultant.

In California, you can ask your utility company to take measurements of field levels on your property. California requires most utilities to do this free of charge for their customers. To get measurements taken by your utility company, call their customer service telephone number and tell the operator that you would like to get the electric and magnetic field levels measured in your home. If you are the owner or current utility customer of the property you would like measured, you should be able to make an appointment to have measurements taken. If you are considering renting or buying the property but do not yet live there, your utility company should be able to explain to you the requirements for getting the current customer or homeowner's permission to have measurements taken on their property; your real estate agent or rental agent may be able to help with this.

If you live outside of California and your utility does not take measurements, or if you prefer not to have your utility company take measurements, you can take measurements yourself with the proper equipment or pay a consultant to do this. Magnetic fields are measured with an instrument called a gaussmeter. There are many different types of these meters available; a publication focusing on EMF called Microwave News has a list on the Internet at ***http://www.microwavenews.com/EMF.html*** of some meters and the companies that sell them. There may also be other meters available through other sources.

To find a private consultant to take measurements for a fee, you should look for someone experienced in taking these measurements. The California EMF Program has a list of non-utility measurement providers that volunteered information about their businesses in order to make their services known. Another resource that may be helpful in finding a consultant to take measurements is the National Electromagnetic Field Testing Association (NEFTA), which may be able to refer you to consultant in your area. The NEFTA Web site can be accessed at ***http://kato.theramp.net/nefta/***. The Public Health Institute, the California Department of Health Services, and the California EMF Program do not certify, accredit, license, or endorse any EMF measurement consultants, EMF meters, or their providers.

The person taking measurements should measure field levels in several places on the property, especially inside the rooms in which people will spend a great deal of time (such as bedrooms). If there are power lines or other electrical equipment nearby, measurements should be taken at different distances from them, to discover whether the fields from those sources are raising field levels inside the home. A good technician will also be able to identify areas with unusually high fields and the sources (such as improper wiring or power lines) of those fields.

How Do I Interpret Measurements Once I Have Them?

Because we do not know whether EMF exposure is a health risk, magnetic field measurements may allow you to compare the levels in your home to levels in other homes, but even if the levels are above average, this does not necessarily mean that they increase your health risks. Similarly, if the levels are below average, this does not necessarily mean that the field exposure in the house is "safe." There is no general agreement about whether exposure to magnetic fields might increase health risks or, if it does, what level could be considered safe; these measurements will just give you an idea of whether the magnetic field levels in your home are similar to measurements typical in other homes or residential settings.

If you get measurements taken, your utility or other measurement provider may also be able to give you some information about how the measurements compare to those in other homes. You may compare your measurements to those found for various published home surveys such as the 600 homes surveyed by the CDHS (as summarized in Tables 1, 2A, and 2B).

How can I reduce my EMF exposure from sources in and near my home?

Until we have more information, some communities and individuals are adopting a "no and low cost avoidance" strategy. Whether or not you get magnetic field measurements taken in your home, there are things that you can do to reduce your exposure. For example, you can move electrical appliances further away from places where you spend your time. In most cases, fields almost disappear at distances of 3 to 5 feet from a regular household appliance. It is usually easy to move an electric clock a few feet away from your bed, or to sit further away from your computer monitor. Sometimes, you may have sources in or near your home that cannot be moved, like major appliances or power transformers connected to overhead or underground power lines. If you find that this type of source is producing higher fields in your home, you may be able to rearrange your furniture so you spend less time near the source. For example, if there is a power transformer on the outside of your bedroom wall, you might be able to move your bed to the other side of the room or to another room so you spend less time in the field from this source.

If you are building a new home or remodeling or adding to your home, there are things that you can do to minimize fields in the areas where people spend time. Proper wiring and the thoughtful placement of electric appliances can help reduce exposure. The *EMF Checklist for School Buildings and Ground Construction* provides some specific ideas for reducing EMF in schools that may be helpful when planning and carrying out residential construction.[5] The California EMF Program also co-sponsored a video in which an EMF consultant demonstrates techniques that electricians can use to identify and correct some common wiring errors that create high fields and may pose a potential fire hazard. This video was created for schools, but may also be useful for residential settings. The school checklist and a description of this video (with ordering information) are available on the Internet; go to *http://www.dhs.ca.gov/ps/deodc/ehib/* and click on California Electric and Magnetic Fields Program.

How Important Should EMF Be When I Am Deciding Where To Live or What Home To Buy?

In the absence of conclusive evidence that EMF is or is not a health risk, it is up to each individual to decide how important the presence of EMF sources is in choosing a place to live. EMF may be one of many factors considered in this choice. Other important factors may include a home's cost, the quality of local schools, and proven risks of the location, such as the possibility of earthquake, flooding, or fire, or the presence of traffic, radon, or air pollution. To some people even limited evidence for a possible EMF risk weighs heavily in their decisions. For others, different considerations take precedence. There really is no one right answer to this question because each situation is unique.

[1] Lee, G., California Exposure Assessment Study (preliminary findings), California EMF Program, 1996.

[2] The reason that underground lines usually produce lower fields in nearby houses than overhead lines is not because the dirt blocks the magnetic field; it is because several heavily insulated cables can be placed closer to each other than relatively uninsulated overhead cables could be, allowing the magnetic fields from the different cables to cancel each other out. Nonetheless, fields directly above an underground line can be quite high because they are only a few feet below the surface.

[3] Zaffanella, L., Survey of residential magnetic Sources, EPRI Final Report, 1993. No. TR 102759-v1 and No. TR 102759-v2.

[4] National Institute of Environmental Health Sciences, *Assessment of health effects from exposure to power-line frequency electric and magnetic fields,* NIEHS Final Report to Congress, 1999.

[5] Cavin, B., *EMF Checklist for School Buildings and Grounds Construction,* California EMF Program, 1996.

Electric and Magnetic Fields in California Public Schools

This fact sheet is intended for those interested in learning about electric and magnetic field (EMF) exposure in schools. Specifically, this document will explain significant results of the California Electric and Magnetic Fields Program's School Exposure Assessment Survey (*The Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for California Public School Environments*[1]) and will describe how to compare the Survey's results with EMF measurements of your school.

This document, however, does not go into depth about electric and magnetic fields or the research being conducted on them. For general EMF information, please consult our other fact sheets, all of which can be found on the "General Information" page of our web site.

The School Exposure Assessment Survey

Over the past several decades, various studies have been conducted to determine if EMF causes disease. Although some studies have determined that there could be a health risk associated with magnetic field (MF) exposure, evidence has not been conclusive. However, because of the possible association between magnetic field exposure and childhood leukemia, the California EMF Program contracted Enertech Consultants in 1996 to conduct *the Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for California Public School Environments*.

This three-year long survey aimed to (1) identify and describe power frequency (60 Hz) magnetic fields (MF) found in schools, (2) assess costs of reducing exposure to EMF in California Public Schools, and (3) use the collected data to influence policy regarding EMF levels and sources in schools[2].

How the Survey was Conducted

Magnetic fields were the main focus of this survey, and these results are summarized here. Electric fields and transient field results can be found in the main report. Technicians measured fields in various school areas, including classrooms, staff-occupied indoor areas, student occupied indoor areas, and outdoor areas (including playgrounds). For all the schools combined, measurements were taken in a total of 5,403 areas, 3,193 of which were classrooms[3]. Once collected, these measurements were entered into a comprehensive database where they were categorized and analyzed. Measurements were given in milligauss (mG), the unit used to measure magnetic strength.

How The Survey Data Relates To Your School

As it is unknown whether magnetic fields are a health hazard, it is impossible to determine a "safe" level of MF exposure. Consequently, the survey aimed to reveal what typical school MF levels and sources are, so concerned schools can compare their measurements and associated sources to those of other California schools.

> The following is an example of how you could compare your measurements:
> Your school had measurements taken, revealing that the average MF level in your classroom is 2.11 mG. You can then compare this measurement to those in this fact sheet. Table 2 of this document reveals that 0.39 mG is the average magnetic field in California classrooms. By comparing this number with your measurement of 2.11 mG, you can see that the MF levels of your classroom are above average, and that 95% of schools surveyed had measurements less than yours.

Survey Results

Table 1 reveals that 79.9% of surveyed school **areas** had average magnetic fields less than 1 mG. Only 6.9% of school areas had average magnetic fields greater than 2 mG. 83.1% of school **classrooms** had average magnetic fields less than 1 mG, and only 5.7% of **classrooms** had average magnetic fields greater than 2 mG[4].

Table 2 is a specific breakdown of survey measurements. This table shows percentiles of average magnetic field levels in the school areas and classrooms surveyed. The average fields measured in school **areas** were less than 0.42mG for 50% of the areas. 90% of the **areas** had average magnetic fields less than 1.58 mG, or conversely, only 10% of areas had levels of 1.58 mG or greater. Only 5% of **classrooms** had average fields below 0.09 mG[5].

Table 3 shows the average field measurements for other school areas measured[6]. For example, 90% of surveyed sports fields had average fields less than 0.35 mG.

In some instances, the magnetic field levels correspond to how many electrical devices ("operator sources") exist in the area. In other words, a place with many lights and appliances turned on, such as a home economics classroom or a kitchen, is likely to have higher magnetic field levels than a regular school classroom. In other instances, MF levels are a result of additional factors, such as wiring errors or nearby power lines.

Table 1: Average Magnetic Field Levels in Schools

	<1mG	>2mG	>3mG	>4mG
Areas	79.9%	6.9%	3.0%	1.5%
Classrooms	83.1%	5.7%	2.1%	1.2%

Higher than Average Measurements

The survey also identified specific sources of the fields, so as to determine how great of a magnetic field each particular source, if acting alone, would emit in a classroom. The five sources most frequently found to cause higher than average magnetic fields are (in order of most to least common): net currents; fluorescent lights; distribution lines; electrical panels; and office equipment[7].

The field source which produced large magnetic field values in the greatest amount of classrooms was net currents. Normally, current flows from the power source to the appliance and back to the power source. The current flowing one way generates a magnetic field which is cancelled by the field generated by the current flowing back. When wiring is not connected correctly, the forward and return currents have different intensities. The difference between the two is called the "net current." The field due to the net current is not canceled and extends over a relatively large distance from the wire.

It is important to note that net currents, the most frequent source of higher than average magnetic field levels, do not need to exist since they are solely the result of wiring which does not conform to the wiring code. The codes are intended to reduce fire and shock hazards. High readings should therefore serve as an encouragement to check internal wiring errors.

Table 2: Percentiles of Average Magnetic Field Levels

	5th Percentile	50th Percentile	90th Percentile
Areas	0.06 mG	0.42 mG	1.58 mG
Classrooms (portable and regular)	0.09 mG	0.39 mG	1.48 mG

Table 3: Percentiles of Average Field Measurements in School Areas

	5th Percentile	50th Percentile (median)	90th Percentile
School Sports Field	0.01 mG	0.07 mG	0.35 mG
Playground	0.01 mG	0.15 mG	0.53 mG
Outdoor Areas	0.01 mG	0.20 mG	0.83 mG
School Classrooms (portable)	0.10 mG	0.30 mG	1.01 mG
School Classrooms (regular)	0.09 mG	0.42 mG	1.53 mG
Computer Classrooms	0.21 mG	0.59 mG	2.08 mG
Home Economics Classrooms	0.26 mG	0.82 mG	2.87 mG
Kitchens	0.25 mG	1.05 mG	3.03 mG

The specific location in which the magnetic field readings are taken influences the measurements. For example, if measurements are taken in a classroom located directly above the school's power transformer, it is quite likely that the measurements are going to be extraordinarily higher than an average classroom's measurements.

At this point in time, we do not know what is a safe level of exposure, what is hazardous exposure, or if either exist. However, if your measurements are significantly higher than the California school average, reduction to average levels may be desirable if you are concerned about magnetic field exposure. And if your school intends to reduce MF levels, it is important to determine which sources produce large magnetic fields in your school since those are the field sources that would need the most immediate attention in order to reduce your school's magnetic field levels.

School verses Home Averages

In a separate survey, the California Department of Health Services measured the strength of magnetic fields in 700 San Francisco Bay Area Homes[8]. Measurements, taken in the bedroom, family room, kitchen, and at the front door, revealed magnetic field averages similar to those of school averages. Table 4 shows the average magnetic field measurements in 50% and 90% of homes surveyed. As the table reveals, in 90% of both school areas and homes, magnetic field levels were below 1.58 mG[9].

Average field levels in homes are typically close to the same, if not slightly higher, than levels in schools. Consequently, if you are concerned about a child's total daily magnetic field exposure, you may also want to consider checking field levels both in the home and school environments, since children, when not in school, spend a large portion of their time at home.

Table 4:
Average Magnetic Field Exposure in Schools and Homes

	50%	90%
School Areas	<0.42 mG	<1.58 mG
Homes	<0.71 mG	<1.58 mG

Area Versus Personal Measurements

To obtain data for both the School Exposure Assessment Survey and the EMF in Bay Area Homes Survey, consultants took area measurements of magnetic fields. This means consultants used meters which measured fields found in specific areas. However, area measurements do not necessarily represent a person's exposure. In a sub-study[10] to the School Exposure Survey, 30 teachers of two of the participating schools were asked to wear measurement meters while at school. Their personal classroom measurements were later compared to the area measurements found in their classrooms. 16 of the teachers' personal measures were similar to their classroom area measures, while 9 teachers had lower personal measures and 5 had higher personal measures than their area measures.

There are several possible reasons for these differences: 1) personal exposure measurements depend on the actual locations in the classroom where the individual spends most of his/her time while the area measurement is the average of measurements taken at many point in the entire area; 2) fields may vary from day to day, and area measurements and personal measurements were taken on different days; and 3) personal measurements may be strongly affected by intense exposures due to electrical devices such as copiers, computers, overhead projectors, TV/VCRs, and fish tank pumps. These sources do not have a significant affect on area measurements since they usually only affect a couple of the many individual measurements that go into determining the average area measurement. However, they can greatly affect one's personal exposure if operating one or more of these devices is a routine part of that individual's work pattern.

Low and No Cost EMF Reduction Options

To help analyze options and cost estimates of reducing magnetic fields in schools, Enertech Consultants and Power Engineers created a computer program entitled *The California School EMF Reduction Cost Program.* This program provides cost estimates for various location scenarios and for various methods of reducing magnetic fields in and around California schools.

Additionally, the California EMF Program created a list of No and Low Cost Options for reducing field levels. Most of these options are ideal for new schools or schools planning to remodel. These options are found in the *School Design Guidelines Checklist*[11].

Some low-cost options from the *Checklist* are:

- Confirm that existing wiring and grounding meet electrical codes, and correct any faulty wiring or grounding (repairs of wiring errors that cause large net currents could occur during routine maintenance checks).

- Insure that new building additions do not increase magnetic fields in existing areas.
- Rearrange usage of space if existing facilities are too difficult to change. For example, a room next to a facility with high magnetic fields can be turned into a storage room during remodeling, rather than a classroom or other area where people spend large amounts of time.

Current Government Initiatives

The California Department of Education has enacted policy regulations that require new schools to be of certain distances away from the edge of a transmission line "right-of-way" (the area immediately surrounding the power line). 1994 regulations require new schools to be set back 100 feet for 50-133 kV lines, 150 feet for 220-230 kV lines, and 350 feet for 500-550 kV lines[12]. These distances are not based on biological evidence of a health hazard associated with electric and magnetic fields, but rather on the knowledge that magnetic fields strength decreases to background levels with increasing distance. The Federal government has conducted magnetic field research, but has not enacted any regulations[13].

Getting Measurements Taken At Your School

Any school can have magnetic field measurements taken to determine how their school compares to others. Most utility companies in California will take free measurements for their customers. Some EMF consultants can take more detailed magnetic field measurements for a fee.

Resources About EMF In Schools

The executive summary of the "Exposure Assessment Survey" and the "School Design Guidelines Checklist" can be accessed from the "General Information" page of our web site. The "Residential Measurements Fact Sheet" will be accessible from the "General Information" page around mid-year 2001. The entire "Exposure Assessment Survey," which contains specific magnetic field level breakdowns for all school areas surveyed, can be obtained by contacting: City Copy Center, 580 14th Street, Oakland, CA 94612 or (510) 763-0193.

[1] "Electric and Magnetic Field Exposure Assessment of Powerline and Non-Powerline Sources for California Public School Environments." California EMF Program and Enertech Consultants. (January 2000).

[2] Ibid., S-1.

[3] Ibid., S-3.

[4] Ibid., S-5, S-6.

[5] Ibid., 8-9 .

[6] Ibid., section 8.

[7] Ibid., S-9, Table 3.

[8] EMF in Bay Area Homes Study. The California EMF Program.

[9] Ibid., 8-9. "California Exposure Assessment Study." Preliminary Findings. The California EMF Program and Gerri Lee. (1998):5-6.

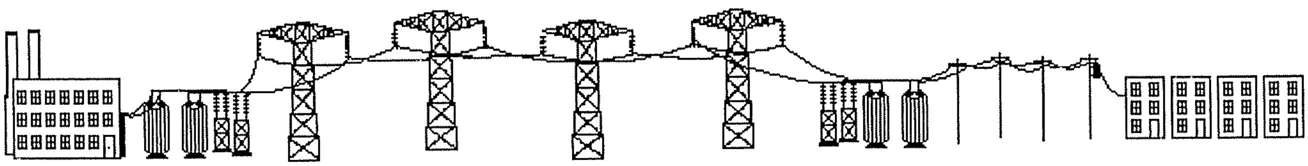
[10] Sub-study conducted by Geraldine Lee of the California Department of Health Services in 1997.

[11] "EMF Checklist for School Buildings and Ground Construction." California EMF Program and Brooks Cavin, III. (1996).

[12] "Rationales for Statewide Policies Addressing Magnetic Fields in Public Schools." California EMF Program, Brock Bernstein and H. Keith Florig. (November 2000, draft copy): 17.

[13] "Short Factsheet on EMF." California EMF Program. (1999): 3.

60 HERTZ ELECTRICAL POWER



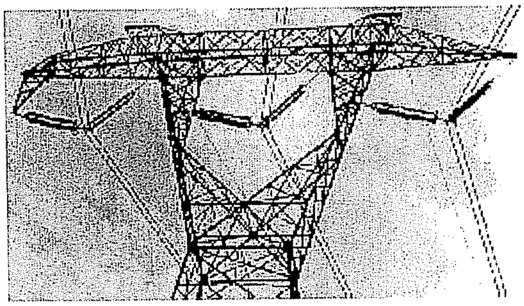
GENERAL INFORMATION

The United States electric power system operates at 60 cycles a second or hertz (Hz). This means that the electric charges (current) flowing in the system change direction 60 times a second. This changing of direction of current is called alternating current or AC. AC fields induce weak electrical currents in conducting objects, including humans, and have been the focus for research on how electric and magnetic fields could affect human health.

Electric and magnetic fields have different properties. Electric fields are easily shielded or weakened by conducting objects (trees, buildings, etc.) but magnetic fields are not. Both electric and magnetic fields diminish with increasing distance from the source. Magnetic fields are typically measured in gauss, a unit of magnetic field strength or magnetic flux density. 1,000 milligauss (mG) = 1 gauss. Recent interest and research have focused on the potential health effects of magnetic fields. Some epidemiological studies have suggested that a link may exist between exposure to these fields and certain types of cancer, primarily leukemia and brain cancer. Other studies have found no such link. Laboratory researchers are studying how such an association is biologically possible. At this point, there is no scientific consensus about this issue, except a general agreement that there is a cause for concern and that more information is needed. A national research effort is under way, and major study results are expected in the next few years.

It is not know at this point whether exposure to magnetic fields from power frequency sources constitutes a health hazard. Therefore, it can not be determined what levels of exposure are "safe" or "unsafe". Some studies have shown that exposure to higher levels of this radiation is not necessarily worse than exposure to lower levels. More research is required to identify dose-response relationships. There is some evidence from laboratory studies to suggest that there may be "windows" for effects. This means that biological effects are observed at some frequencies and intensities but not at others. Also, it is not known if continuous exposure to a given field intensity causes a biological effect, or if repeatedly entering and exiting of the field causes effects. In light of all this uncertainty, it is impossible to say what is a "safe" distance from any magnetic field source or what is a "safe" exposure. The only thing possible at this point in time is to make comparisons. For instance, the typical home has a background magnetic field level (away from appliances) that ranges from 0.1 to 4.0 milligauss. Although some experiments with cells have reported effects at field levels as low as 2 milligauss, there is no laboratory evidence for adverse human health effects at this level.

POWERLINES (To the Top)



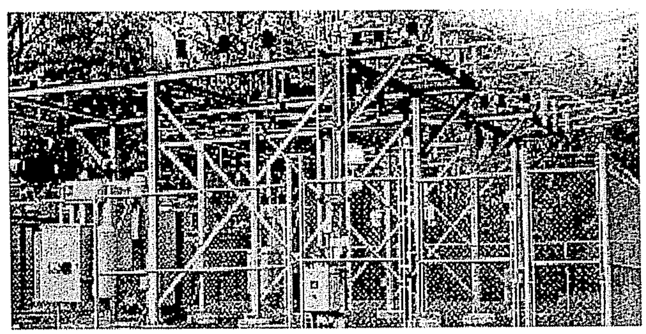
Transmission and distribution lines can be collectively referred to as power lines. Magnetic field levels from power lines will be determined by the amount of current flowing through the line, the arrangement and proximity of the lines themselves with respect to each other, the height of the line above the ground, and the proximity of the lines to other power lines.

Transmission lines carry electricity over long distances and usually operate at voltages of 100 kilovolts and above. For any transmission line in New Jersey, at a perpendicular distance of 400 feet from the center of the line configuration, the magnetic field level on the ground from the line will be approximately 1 milligauss or less. At distances closer than 400 feet, it is difficult to predict what the magnetic field level will be as each situation becomes unique to that particular line. Some transmission lines carry very little current and expose people to lower magnetic field levels than what they would encounter from a distribution line. Measurements made by Department staff under transmission lines in New Jersey have ranged between 8 - 130 milligauss. In general, fields from both transmission lines and distribution lines will vary, depending on the time of day, the day of the week, the time of year and the ambient temperature. However, for transmission lines, magnetic fields will rarely vary by more than a factor of two.

Distribution lines operate at lower voltages and bring power from substations to businesses and homes. Distribution lines may expose people to magnetic field levels as high or higher than transmission lines. This is because they are physically closer to the ground than transmission lines. For this same reason, distribution lines that are buried underground can sometimes expose one to a higher magnetic field if one is standing directly over top of them than what one would receive from the same line mounted overhead on a pole. The Department has received information from electrical utilities in New Jersey that some underground distribution lines operating at a voltage of 69 kilovolts may produce magnetic field levels as high as 55 milligauss directly above the line. 50 feet from the center of the line, this level drops to 1 milligauss. In general, most magnetic fields from distribution lines will be a lot lower and may even be as low as 1 milligauss, directly above or below the line.

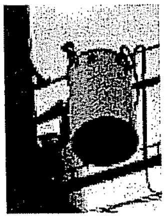
SUBSTATIONS (To the Top)

Electrical substations serve many functions in controlling and transferring power on an electrical system. Substations may utilize transmission lines, distribution lines or a combination of both. In general, the strongest magnetic fields around the outside of the substation comes from the power lines entering and leaving the station. While transformers inside the substation can produce high magnetic fields, the fields remain localized around the transformers. Beyond the substation fence, the magnetic fields produced by the equipment within the station are typically indistinguishable from background levels.



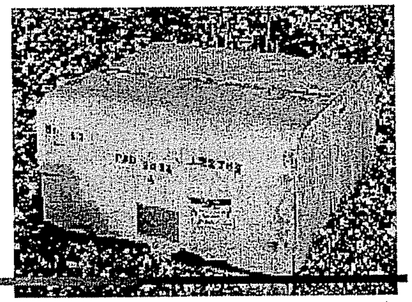
TRANSFORMERS (To the Top)

Transformers are electrical devices used to adjust the voltage-current relationship of an electrical power circuit for best efficiency during transmission and distribution use. There are electric and magnetic fields near a transformer and around the lines that connect to them. But the fields tend to drop off rapidly as one moves away from the transformer. Utilities use a variety of transformers throughout their systems. Step-up transformers are used at the power generating station to raise the voltage so the power can be economically delivered over transmission lines. The magnetic fields from these types of transformers are high but localized and to do not travel beyond the bounds of the substation. Step-down transformers are used to reduce line voltages.



Overhead (pole-mounted) transformers are used where distribution lines are overhead and surface (pad-mounted) transformers are used where distribution lines are underground. Frequently in urban situations, transformers can be located within buildings. If the transformer is what is referred to as a network transformer, which can supply power to an entire block, magnetic fields on the floor directly above the transformer can be as high as 700 milligauss. Since magnetic fields remain localized around the transformer itself, a pole mounted transformer will have very little impact on ground level magnetic fields, which will be dominated by the overhead distribution lines coming in and going out of the transformer.

Pad mounted transformers have magnetic fields similar in intensity to kitchen appliances. The magnetic fields near this type of transformer are elevated close to the surface of the transformer. A few feet away, the levels drop off to background.



APPLIANCES (To the Top)

Appliances that operate either on batteries or by plugging into the household wiring usually come equipped with an AC/DC switch. If DC is chosen, current flows one way from the batteries to the appliance. DC fields, unlike AC fields, do not induce electrical currents in humans unless the DC field changes in space or time relative to the person in the field. In most situations, a battery operated appliance is unlikely to induce electrical current in the person using the appliance.

In general, appliances using AC have potentially high, localized magnetic fields that decrease rapidly with distance. Magnetic fields from appliances are often stronger than the fields directly beneath power lines. The intensity of the magnetic field from an appliance appears to be related to product function and design. Here are some examples of average magnetic field levels 6 inches away from certain appliances:

- Hair dryer - 300 milligauss
- Electric shaver - 100 milligauss
- Blender - 70 milligauss
- Can opener - 600 milligauss

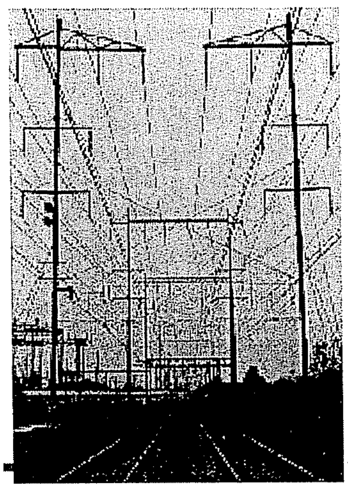
- Coffee maker - 7 milligauss
- Microwave oven - 200 milligauss
- Color TV (1 foot away) - 7 milligauss

An example of how rapidly magnetic fields from appliances drop over distance:

Can opener:

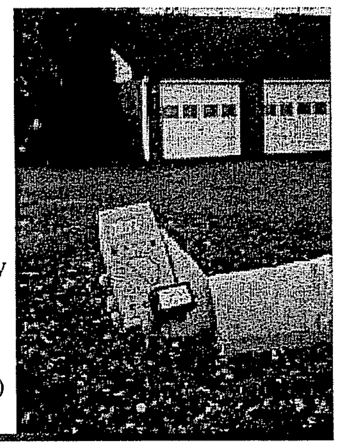
1. At 6 inches - 600 milligauss
2. At 1 foot - 150 milligauss
3. At 2 feet - 20 milligauss
4. At 3 feet - 2 milligauss

TRAINS (To the Top)



Some trains run on AC while others use DC. Some trains that use AC operate at 25 or 16.75 hertz. Very little is known about the biological effects from 25 or 16.75 hertz AC or DC. Areas of strong AC magnetic fields have been measured close to the floor on some DC trains. Magnetic fields measured in trains powered by 60 hertz AC have been reported to be as high as 500 milligauss in the passenger areas at seat height. Department staff have not made any measurements on train lines.

MEASURING MAGNETIC AND ELECTRIC FIELDS (To the Top)



The measurement of electric and magnetic fields from nonionizing radiation sources is a complex task. The Department does not have a certification program for testing or measurement firms and therefore, cannot endorse any such companies. The best way to obtain accurate readings of 60 hertz electric and magnetic fields is to contact the owner (electric utility) of the power lines in question and request that measurements be made. Please be aware that the utility supplying power to the house may not be the same utility that owns the high voltage transmission lines running by the property of interest. Utility personnel have been trained in this area of expertise and will probably provide the most accurate readings. They are usually reluctant to interpret any readings although they may try to put them into perspective. Anyone having any questions regarding measurements should contact the Department. As a quick rule of thumb, typical magnetic field levels found in homes range from 0.1 - 4.0 milligauss. Any readings above that are not necessarily hazardous, but higher. It is not necessary to obtain readings if a power line is more than 400 feet away from the home or area of interest.

For more information on this topic, please visit the following Internet areas: ***Please read this Disclaimer prior to connecting to these websites.***

Power Lines and Cancer: FAQ's from John E. Moulder, PH.D. of the Medical College of Wisconsin

FCC OET Bulletin No. 56 (Q&A about Biological Effects and Potential Hazards of Radiofrequency Radiation)

Power Lines Project - Questions and Answers

Public and scientific concerns regarding possible health risks from human exposure to electric and magnetic fields (EMF) have become a major issue and have resulted in considerable national debate and research. We are pleased to answer the questions most frequently asked of the Health Department.

Electric and Magnetic Fields

1. **What is EMF?**

   EMF stands for either electromagnetic fields, or electric and magnetic fields. These fields occur wherever there is electricity -- near radio and microwave towers, high voltage transmission lines, low power electrical distribution lines, household appliances and office electrical equipment. The term electromagnetic fields generally refers to the high frequency radio waves in which the electric and magnetic fields are inseparable. At low frequencies, including the 60 Hertz at which electric power is delivered to our homes and factories, electric and magnetic fields are independent and measured separately. An electric field exists when an appliance is "plugged-in." The magnetic field only exists when the appliance is "turned on" and operating.

   Electric and magnetic fields result from electrically charged particles. Charged particles in motion are referred to as electric current (measured in amperes). The force that makes the charges move is the electric potential or voltage. The electric field is produced by the voltage; the magnetic field is produced by the current. The concept of electric and magnetic fields describes how charged particles exert forces on objects some distance from the electricity. For example, currents within the earth cause a compass needle to point north.

   One important feature of electric and magnetic fields is that the fields will weaken with distance from the source. Sources include electric power lines, household wiring, and everyday home appliances such as clothes dryers, electric blankets, waterbeds, hair dryers, toasters, stoves and televisions.

2. **What can EMFs do to me?**

   Electric and magnetic fields can cause small electric fields in our bodies. These fields are much weaker than the fields that occur naturally in the body, but there is some evidence they might affect some cell functions. There have been several studies conducted to determine whether exposure to magnetic fields causes disease in humans.

   There are many unanswered questions raised by the research done so far. There have been both positive and negative studies. We are not sure if EMF exposure adversely affects human health. More extensive studies of EMFs are needed.

Health Effects

3. **What do we know about the relationship, if any, between electric and magnetic field exposure and health effects?**

   The New York State Power Lines Project, a $5 million research program partially funded by the eight New York State electric utilities and completed in 1987, was conducted to address the lack of scientific information about the effects of EMF on health. The studies from that project, as well as subsequent research, suggest that exposure to EMF may possibly be related to a number of health effects. However, these studies do not provide firm evidence that EMF exposure causes health effects. Extensive further research is needed for us to better understand any link between exposure to EMF and health problems.

4. **What about the most recent studies involving cancer among people living or working near magnetic fields? Do they provide any additional information about EMF and human health?**

   A number of studies have been conducted which suggest, but do not prove that magnetic fields cause cancer. No study to date has demonstrated conclusively that exposure to EMF adversely affects humans.

5. **Don't studies show that children exposed to electromagnetic fields have an increased risk of leukemia?**

   Over the last several years, several studies have been done looking for possible links between childhood cancers and EMF exposures. Two early studies conducted in Denver suggested a possible association. A follow-up study done in Los Angeles found an association between childhood leukemia and estimated EMF exposure in children's homes. The risk, in all studies, was small.

   More recently, a study done in Sweden found a possible statistical association between childhood leukemia and EMF exposure for people living near large overhead electrical transmission lines. Another study conducted in Denmark found no association between leukemia risk and EMF exposure. Other research studies are currently underway. No laboratory research has been able to confirm a definite link between leukemia and EMFs.

6. **Are pregnant women and unborn children more sensitive to EMFs?**

   This question has not been studied as extensively as cancer, and so may be viewed as even more uncertain.

7. **Does exposure to electric and magnetic fields increase the risk of breast cancer?**

   No one knows for sure. There is some evidence that EMF exposure may be associated with an increased risk of breast cancer. Studies of men exposed to high levels of EMF as part of their jobs have found an increased risk of these men developing breast cancer. There is also some evidence from laboratory studies that indicates that EMF exposure may interfere with certain hormones that may play a role in the development of breast cancer. There is little scientific data demonstrating an increased risk of breast cancer among women exposed to EMFs, but this question requires further scientific study. Recently, the National Cancer Institute funded a large study of the possible association between breast cancer risk and EMF exposure in the State of Washington.

8. **What is a safe level?**

   There is no number to which we can point and say, "that is a safe or dangerous level of EMF exposure." We don't know if EMF exposure is harmful. We don't know if certain levels of EMFs are safer or less safe than other exposures. We do not know if continuous exposure to a given field intensity causes a biological effect, or if rapid changes in exposures cause effects.

9. **Can we use the Swedish study to set a standard to limit public exposure to EMFs?**

   It has been suggested that the data from the Swedish study could be used to set an exposure standard, but the study did not find an association between actual EMF measurements and leukemia risk. Until more scientific data are available, it is difficult to set precise exposure standards.

Sources of EMF

10. **What are power lines and transformers?**

Transformers are electrical devices used to increase or decrease the voltage in the electrical power system for best efficiency during transmission, distribution and use. Utility companies use a variety of transformers throughout their systems. Step-up transformers are used at the power generating station to raise the voltage and decrease the current so the power can be economically delivered over transmission lines. Step-down transformers are used to reduce the transmission line voltage for distribution to neighborhoods.

Transmission and distribution substations, located where a transmission line has to feed a number of lower-voltage distribution lines, are fenced yards containing transformers and other electrical equipment. Pole-mounted transformers are used to reduce voltage for household use where distribution lines are overhead, and surface (pad-mounted) transformers are used where distribution lines are underground. Frequently, in urban settings, the distribution substations are located within buildings.

It is interesting that the only connection between the high voltage and low voltage side of a transformer is through a magnetic field in the iron core within the transformer. The iron is very good at confining the magnetic field, so very little magnetic field gets out of a transformer. However, the power lines (transmission lines and distribution lines) connected to the transformer produce both magnetic and electric fields whenever they are carrying current and voltage.

11. **What is that metal electrical box on the corner of my lot?**

If the electric distribution lines in a neighborhood are underground, the boxes are probably surface (pad-mounted) transformers. Each transformer provides electrical service to several different residences (typically four to eight) in a neighborhood.

12. **Do transformers emit EMFs?**

There are electric and magnetic fields near the transformer and the lines that connect to them (see question 10). The fields tend to drop off very quickly as one moves a short distance away from the transformers.

13. **What is a right-of-way (ROW)?**

A right-of-way (ROW) is the area of land around a power line that the utility has acquired for the construction and operation of the line.

14. **Should I buy/rent a house near a power line or substation?**

The evidence on EMF effects is not clear enough to determine whether or not locating near a power line or a substation presents any health problem. Field levels decrease as distance from a source increases. See also the answer to Question 17.

Measurements

15. **What is a gauss?**

The gauss is a unit of measure for the strength of a magnetic field, also known as magnetic flux density. We normally speak of magnetic fields in terms of thousandths of a gauss or milligauss, abbreviated "mG."

16. **Is it true that levels below 2 milligauss (mG) are safe? Is there a standard?**

We do not yet know what, if any, magnetic field levels are safe or unsafe. The level of 2 mG is the level researchers chose in four epidemiological studies of increased risk of childhood cancer in relation to power lines near the home, to distinguish between the average-exposed and the most-exposed children. The meaning of the studies is uncertain and additional studies are needed to verify if this is really a cause of increased risk of disease.

17. **What is a safe distance from a magnetic field source?**

Since we do not know if EMF exposure is harmful, we do not know what intensity of field is safe or unsafe. Therefore, we cannot say what is a safe distance. A related question is, "At what distance is the strength of the field comparable to that from the background field levels?" It depends on the source of the magnetic field and what the background field level is. Background magnetic fields typically range from less than one mG up to several mG. In the case of most high voltage power lines, at 300 feet from the center span, the magnetic field will usually drop below 2 mG. For most high voltage lines the magnetic field will often fall below 2mG 50 to 100 feet from the wires and always within 300 feet. In the case of a counter top electric mixer, the magnetic field is usually below 2 mG approximately 3 feet away (see Table I). Remember, 2mG is just a measurement, not a "safety standard".

18. **Should I have the fields in and around my home measured?**

This is a question each individual has to answer. Without any safety standards, measurement results are difficult to interpret. However, they will help identify sources of magnetic fields in and around the home and may assist those who wish to reduce their exposure.

19. **How do I get my house measured?**

In most instances, depending on where you live, the local electric utility will either conduct field measurements around your home or put you in contact with a consultant who can make the measurements. Consulting firms may also be found through advertisements in environmental and computer magazines.

20. **Can I trust the measurements made by the utility?**

Yes. Utilities have the expertise and proper equipment to make accurate measurements. There is no reason to believe that the utility will mislead people by providing false readings. It is important to remember that readings will vary depending on factors such as the time of day the measurements are taken. The differences in readings will usually depend on the appliances you are using and the amount of power flow on any nearby power lines at the time, as well as the amount of electricity other consumers are using.

21. **How do we get the magnetic field levels near our school measured?**

Your school officials may call your local electric utility for electric and magnetic field measurements.

On March 1, 1993, the Attorney General of New York State requested the state's electric utilities to conduct a comprehensive EMF measurement program and survey of the location of power lines near primary and secondary schools that have transmission lines operating at 69 kilovolts (kV) and above, on, adjacent to, or within 100 feet of school property.

22. **Measurements have been taken in my child's school. I know what the measurements are, but what do they mean?**

While the possibility of a public health concern has been raised in some epidemiological studies, we do not yet have enough information to say whether or not EMFs at any levels pose a health risk.

Standards

23. **Are power line electric and magnetic fields regulated in New York State?**

Yes. The Public Service Commission requires that new high voltage transmission lines in New York be designed so that the maximum magnetic fields at the edge of the right-of-way will not exceed the maximum magnetic field levels produced by the average of 345 kV lines now in operation. This interim magnetic field standard of 200 milligauss at one meter above the ground at the edge of the right-of-way applies when the line is operating at its highest continuous current rating. This happens infrequently. Routine operations create lower fields.

An interim electric field standard limits new high voltage transmission lines to 1.6 kilovolts per meter (kV/m) at the edge of the right-of-way.

Since at this time there is no technical or scientific way to determine what levels of electric or magnetic fields may be safe or unsafe, the Public Service Commission's standards are established on an interim basis to ensure that future lines do not produce unnecessarily high electric or magnetic fields.

No standards have been adopted or proposed for electrical substations, low voltage electric distribution lines, or household wiring and appliances, although some manufacturers have reduced the electric and magnetic fields in their appliances, e.g., electric blankets.

Avoidance

24. **What is "prudent avoidance" - how can I apply it to my life?**

Prudent avoidance is an approach to making decisions about risks. This decision-making process is based on judgment and values, can be applied by groups and individuals, and can be considered for all aspects of our lives, not just EMFs. Prudent avoidance applied to EMFs means adopting measures to avoid EMF exposures when it is reasonable, practical, relatively inexpensive and simple to do. This position or course of action can be taken even if the risks are uncertain and safety issues are unresolved.

Some examples of prudent avoidance are:

1. some people have chosen to use electric blankets only to warm their beds, turning them off before getting in. This is a certain way to avoid exposure to the blanket's magnetic fields.

2. a motor driven electric clock may produce a steady, fairly strong magnetic field exposure if placed near the bed. One can move it, or replace it with a newer digital clock which may produce lower fields.

25. **How can I stop the fields from coming into my house? Can I shield them?**

There is no simple way to block magnetic fields since the fields are generated by the electrical system and devices in the home, including wiring and appliances. Electric fields from outside the home, power lines, etc., are shielded to some extent by natural (trees and shrubs) and building materials, but magnetic fields are not. The further a building is from an EMF source, the lower the fields at the building would be. But keeping fields out of the home entirely would mean not using any electricity in the home. Often the fields from sources inside the home, e.g., appliances, wiring, etc., will have higher strength fields than those from sources outside the home.

26. **How can exposures from video display terminals (VDTs) and other devices be reduced?**

a. by sitting at arms length from a terminal, or pulling the keyboard back still further, since magnetic fields fall off rapidly with distance.

b. by switching VDTs off (not the computer necessarily) when not in use.

c. by spacing and locating terminals in the workplace so that work stations are distant from the higher fields emitted from the back of neighboring terminals. Fields will penetrate partition walls, but do fall quickly with distance.

d. by not standing close to sources of EMFs, such as microwave ovens, while in use. Standards are in place to limit microwave emissions. However, the electric power consumption by a microwave oven results in high magnetic fields close to the unit. The same is true of other appliances.

Next Steps

27. **What research is currently underway?**

World-wide, there are more than 230 research projects underway, including epidemiological studies, laboratory studies on biological effects, and exposure and measurement studies.

28. **What is being done to follow up on the New York State Power Lines Project Panel's recommendations?**

The Health Department and the Public Service Commission have been very interested in promoting further scientific research about EMF exposures. When the federal government was slow in developing such research, the two agencies helped to organize a national EMF research program involving state and federal regulatory, health and environmental officials. In 1992, Congress passed legislation setting up and funding a $65 million national five-year EMF research program directed by the federal Department of Energy and the National Institute of Environmental Health Sciences. State health and regulatory officials, including a representative from the New York State Department of Health, will serve on the program's Advisory Committee. At least half of the funding for this research program is to come from non-federal sources including electric utilities, producers of electrical equipment, and others.

For more information, or a copy of the full Power Lines Project report, call the CEH Hotline at 1-800-458-1158.

Table I
Examples of Magnetic Fields At Distances From Appliance Surfaces
Magnetic Fields in Milligauss

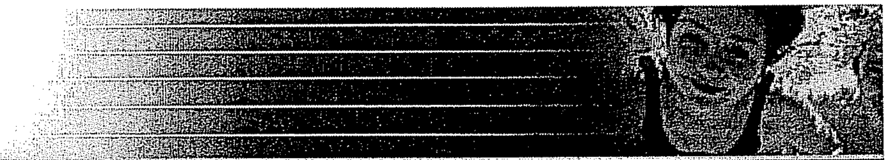
Appliance	At 4 Inches	At 1 Foot	At 3 Feet
Clothes Dryers	4.8 to 110	1.5 to 29	0.1 to 1
Clothes Washers	2.3 to 3	0.8 to 3.0	0.2 to 0.48
Coffee Makers	6 to 29	0.9 to 1.2	<0.1
Toasters	10 to 60	0.6 to 7.0	<0.1 to 0.11
Crock Pots	8 to 23	0.8 to 1.3	<0.1
Irons	12 to 45	1.2 to 3.1	0.1 to 0.2

Can Openers	1300 to 4000	31 to 280	0.5 to 7.0
Mixers	58 to 1400	5 to 100	0.15 to 2.0
Blenders	50 to 220	5.2 to 17	0.3 to 1.1
Vacuum Cleaners	230 to 1300	20 to 180	1.2 to 18
Portable Heaters	11 to 280	1.5 to 40	0.1 to 2.5
Hair Dryers	3 to 1400	<0.1 to 70	<0.1 to 2.8
Electric Shavers	14 to 1600	0.8 to 90	<0.1 to 3.3
Televisions	4.8 to 100	0.4 to 20	<0.1 to 1.5
Fluorescent Fixtures	40 to 123	2 to 32	<0.1 to 2.8
Fluorescent Desk Lamp	100 to 200	6 to 20	0.2 to 2.1
Saber & Circular Saws	200 to 2100	9 to 210	0.2 to 10
Drills	350 to 500	22 to 31	0.8 to 2.0
Source: Gauger, Jr, Household Appliance Magnetic Field Survey IEEE transactions on power apparatus and systems PA-104 (Sept. 1985)			

Send questions or comments to: ceheduc@health.state.ny.us

Revised: July 2002

VDH VIRGINIA DEPARTMENT OF HEALTH
Protecting You and Your Environment



Updated: 24-Jun-2003

Special Topics

Non Ionizing Radiation

Most people think of ionizing radiation when they hear the word "radiation." Radiation is one of sev ways energy is transferred. If the energy is great enough to create ions, then the radiation is capa causing damage to biological material and causing other health effects, such as radiation sickness, genetic defects, and cancer. If the radiant energy transferred is not enough to cause ionization, th radiation is called non-ionizing radiation. Nonionizing radiation can also cause damage to living ma primarily by heating effects. Examples of nonionizing radiation are listed below along with web addı of organizations that may have useful information:

OSHA Nonionizing radiation Regulations http://www.osha.gov/pls/oshaweb/owadisp.show_docum p_table= STANDARDS&p_id=10627&p_text_version=FALSE

Occupational Safety and Health Administration http://www.oshaslc.gov/SLTC/radiofrequencyradi rfpresentation/nonionizing/nonionizing2handout.html

Radiofrequency (RF) waves are in the upper spectrum of the electromagnetic waves. They are u: primarily for communications, such as radio, television, cell phones and other services. The Federa Communications Commission (FCC) regulates the use of RF by assigning frequencies and power limitations to their licensees. RF radiation levels used in these applications are safe for the general public; there are some precautions that occupational workers need to observe, particularly while wo near transmitting antennas.

Federal Communications Commission http://www.fcc.gov/oet/rfsafety

Occupational Safety & Health Administration http://www.osha-slc.gov/SLTC/radiofrequencyradiation/index.html

FDA Cell Phone page http://www.fda.gov/cellphones/

Medical College of Wisconsin http://www.mcw.edu/gcrc/cop/cell-phone-health-FAQ/toc.htm

Microwaves and radar are high frequency RF waves and have applications in telephone communica satellite communications, navigation, law enforcement, and aeronautics. The FCC also regulates th spectrum of the RF as well. Again the RF levels used in these applications are safe for the general there are some precautions that occupational workers need to observe, particularly while working r transmitting antennas, or the waveguides. There are other applications not related to communicati and therefore not regulated by the FCC. For example there are RF sealers that are used to seal pla wrappers in packaging, or medical devices used to heat portions of the body.

Electromagnetic Force (EMF) occurs whenever there is an electrical current and associated with a electric field is also a magnetic field. During the past two decades there have been reports suggest that high voltage electric transmission lines may cause leukemia in children and other biological eff

National Institute of Health http://www.niehs.nih.gov/emfrapid/home.htm

Magnetic Resonance Imaging uses a very strong magnet and a RF coil to transmit a signal that the protons in the hydrogen atoms to become all aligned in the same direction. The RF coil then be a radio receiver to detect how many hydrogen atoms return to their original spin direction. The concentration of hydrogen atoms in this medical imaging technique assists physicians to identify ce medical conditions. There are no known ill health effects from strong magnetic fields; however, the missile hazard. Patients with metal implants may experience some localized heating from the RF co Loose metal objects can be drawn to the magnet at high velocities. Also magnetic storage devices become damaged, such as credit and bank cards with magnetic strips.

Ultraviolet light (UV) in tanning may damage the skin and prematurely age the skin. UV may als cause skin cancer. The US Food and Drug Administration regulates the manufacture of tanning lam and medical tanning lamps.

FDA Center for Devices and Radiological Health (Sunlamps) http://www.fda.gov/cdrh/radhlth/sunlamp.htm

FDA Center for Devices and Radiological Health (Tanning)
http://www.fda.gov/cdrh/consumer/tanning.html

Federal Trade Commission http://www.ftc.gov/bcp/conline/pubs/health/indootan.htm

VDH Cancer Prevention Program http://www.vahealth.org/cancerprevention/index.htm

Lasers are devices that modify light to form a powerful beam of energy capable of causing biologic damage. Lasers are classified by their wavelength and energy, which provides a reference to judge potential danger. Lasers have applications in industry, medicine, communications, entertainment a research. Improper use of a laser may cause blindness. Lasers used in surgery also create a hazar health care personnel from the vaporization of biological material if the area is not well ventilated.

University of Texas Environmental Health & Safety
http://www.utexas.edu/safety/ehs/radiation/lasers.html

Ultrasound is a high frequency sound wave transmitted in water or biological tissue. Low energy ultrasound has application in medicine as a diagnostic imaging technique, particularly in obstetrics, cardiology. There are no known ill health effects from diagnostic ultrasound; however, all medical procedures incur a risk. High power ultrasound waves are used to break up kidney stones instead surgically removing the stones.

To: Gary Ginsberg@EEOH_CHA@BPHS
From: "Schaefer, David" <dschaefer@BSWLAW.com>
Cc:
Subject: Connecticut Siting Council Docket No. 272
Attachment: 818230.PDF,815704.PDF,818255.PDF
Date: 3/18/04 12:47 PM

Attached is the testimony filed with the Siting Council on behalf of my clients, Ezra Academy, Congregation B'nai Jacob, The Jewish Community Center of Greater New Haven and The Jewish Federation of Greater New Haven. We have filed an Appendix with the Council which contains copies of the studies and articles referenced in the testimony. I can email all or any portion of those references to you if it would be of assistance.

David <<818230.PDF>> Schaefer <<815704.PDF>> <<818255.PDF>>

David Schaefer

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271 Whitney Ave.
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THE CONNECTICUT SITING COUNCIL
DOCKET NO. 272

Application of Northeast Utilities Service Company
for a Certificate of Environmental Compatability
and Public Need for a new 345-kV Electric Transmission Line Facility
between Scovill Rock Switching Station in Middletown
and Norwalk Substantion in Norwalk

Testimony of

Dr. Leonard Bell

Dr. Peter Rabinowitz

Dr. Carl Baum

Dr. Alan Gerber

Dr. David Carpenter

On Behalf of

**Ezra Academy, Congregation B'nai Jacob,
The Jewish Community Center of Greater New Haven and
The Jewish Federation of Greater New Haven**

March 16, 2004

THE CONNECTICUT SITING COUNCIL
DOCKET NO. 272

Application of Northeast Utilities Service Company
for a Certificate of Environmental Compatability
and Public Need for a new 345-kV Electric Transmission Line Facility
between Scovill Rock Switching Station in Middletown
and Norwalk Substantion in Norwalk

Supplemental Testimony of

Dr. Eric Grubman

On Behalf of

Ezra Academy, Congregation B'nai Jacob, The Jewish Community Center of Greater New Haven and The Jewish Federation of Greater New Haven

March 16, 2004

David R. Schaefer
Email: dschaefer@bswlaw.com

March 17, 2004

HAND DELIVERY

Connecticut Siting Council
10 Franklin Square
New Britain, CT 06051

Re: **Application to the Connecticut Siting Council for a Certificate of Environmental Compatability and Public Need for a 345 kV Electric Transmission Line Facility and Associated Facilities Between Scovill Rock Switching Station in Middletown and Norwalk Substation in Norwalk**
Docket No. 272

Dear Sir/Madam:

Enclosed for filing in the above-referenced proceeding please find the following:

1. An original and 15 copies of the Testimony of Drs. Bell, Rabinowitz, Baum, Gerber and Carpenter;

2. Four bound copies of Appendices 1 and 2 containing copies of the articles and studies referenced in the above-referenced testimony; and

3. An original and 15 copies of the Testimony of Dr. Eric Grudman.

Since each of Appendices 1 and 2 to the Testimony of Dr. Bell, et al. are voluminous, such appendices are filed under your bulk filing procedure and copies of the Appendices have not been served on all parties.

Please "file-stamp" the enclosed copies of the above-referenced filings and provide same to my messenger or return the file stamped copies to me in the enclosed self-addressed, stamped envelope. If you have any questions on the above, please do not hesitate to contact me.

Sincerely,

David R. Schaefer

DRS:djm
Enclosures
818255.doc

cc: Service List

EMail Correspondence

To: Gary Ginsberg@EEOH_CHA@BPHS
From: Peter Rabinowitz <peter.rabinowitz@yale.edu>
Cc:
Subject: peak load assumptions
Attachment: TOWNS-02 03-16-04 Filing1withloadestimates.pdf,attach2
Date: 3/24/04 9:00 AM

Gary, it was good to meet with you on Monday. I'm attaching one of the responses by Utilities regarding load assumptions on line- see page 4: Peter Brandien's testimony- he states that New England will exceed average loads more than half the hours in a calendar year. I believe there are some other statements- this is the first one I could put my hands on.
best,
Peter

March 16, 2004

Ms. Pamela B. Katz
Chairman
Connecticut Siting Council
10 Franklin Square
New Britain, CT 06051

Re: Docket No. 272 - Middletown-Norwalk 345kV Transmission Line

Dear Ms. Katz:

This letter provides the response to requests for the information listed below.

While it is not possible to provide all the information requested at this time, the Company is attaching the information which has been completed.

Response to TOWNS-02 Interrogatories dated 02/17/2004
TOWNS - 033 , 034 , 035 , 039 , 040 , 041 , 043

Very truly yours,

Anne B. Bartosewicz
Project Director - Transmission Business

ABB/tms
cc: Service List

CL&P/UI
Docket No. 272

Witness: Dr. Bailey
Request from: Connecticut Siting Council

Question:
Reference the Exponent "Electric and Magnetic Field Assessment: Middletown-Norwalk Transmission Reinforcement" ("the Exponent EMF Assessment") included in Volume 6 of the Application.

a. Please state whether it is Exponent's position that no adverse effects on human health or cancer can be caused by prolonged exposure to EMF of any magnitude.

b. If the answer to part a. of this question is no, please specify the magnitude of the magnetic field (in milligauss), i.e., what levels of EMF, that could have adverse effects on human health, compromise normal function, or cause cancer.

c. Please provide the health and scientific studies which form the basis for the answer to part b. of this question.

Response:
a. The portion of the Exponent report that discussed research on EMF and human health was prepared by William H. Bailey, Ph.D. It is his opinion that the weight of the evidence does not support the hypothesis that EMF at environmental levels cause cancer or adverse effects on human health. Environmental levels refers to levels of EMF encountered by people living, working, going to school, etc in the vicinity of sources of power frequency EMF, including power lines.

b. Exposure to magnetic fields at levels above those encountered in occupational environments might be sufficient to induce electric fields within the body of such a magnitude that adverse responses resulting from stimulation of excitable tissues such as nerves and muscles could occur. The most recent standard recommended by the IEEE International Committee on Electromagnetic Safety (ICES) suggests occupational exposure limits for whole body exposure of 20 kV/m and 27,100 mG to prevent such effects.

c. The studies and reviews of the literature considered by Dr. Bailey over the past 30 years are too voluminous to identify and list. However, an important subset of these studies would include most of the studies cited in recent literature reviews by the National Institute of Environmental Health Sciences (1998) and the International Agency for Research on Cancer (2002).

CL&P/UI
Docket No. 272

Data Request TOWNS-02
Dated: 02/17/2004
Q- TOWNS-034

Witness: Dr. Bailey
Request from: Connecticut Siting Council

Question:
Please indicate whether the proposed magnetic fields (mG) presented on Tables 5, A-1, A-2, and A-3 in the Exponent EMF Assessment reflect the total magnetic field from all of the transmission lines, including the proposed 345-kV line, that would be within the same right-of-way or only the magnetic field from the proposed 345-kV line.

Response:
The calculated Electric and Magnetic field levels were based on all of the transmission lines within the right-of-way for both the existing, proposed, and alternative cases. These calculations did not incorporate electric and magnetic field contributions from other sources outside the transmission right-of-way.

CL&P/UI
Docket No. 272

Data Request TOWNS-02
Dated: 02/17/2004
Q- TOWNS-035
Page 1 of 1

Witness: Peter T. Brandien
Request from: Connecticut Siting Council

Question:
Reference pages 23 and 24 of the Exponent EMF Assessment. If the projected peak load is 27 GW and the average load is 15 GW, specify how many hours of the year the New England load would exceed 15 GW.

Response:
For the year 2002, New England experienced load in excess of 15 GW for 4187 hours, almost 48% of the year. It is reasonable to conclude that when New England peak load periods approach 27.7 GW, New England load will exceed 15 GW more than half the hours in a calendar year.

Witness: Dr. Bailey
Request from: Connecticut Siting Council

Question:
Reference Table 5 in the Exponent EMF Assessment.

a. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 8.6 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

b. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 8.6 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

c. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 9.6 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

d. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 9.6 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

e. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 11.4 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

f. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 11.4 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

g. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 13.8 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

h. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 13.8 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

i. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 17.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

j. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 17.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

k. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 19.8 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

l. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 19.8 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

m. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 21.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

n. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 21.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

o. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 28.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

p. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 28.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

q. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 31.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

r. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 31.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

s. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 31.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

t. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 31.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

Response:

CL&P and UI are not scientific organizations and do not develop scientific opinions of their own. Rather, they look to national and international organizations that have drawn upon the multidisciplinary expertise of scientists within their organization or outside scientific advisory panels for guidance as to what conclusions may be drawn from the scientific literature on EMF.

Dr. Bailey's response to this question is as follows:

The magnetic field values listed in Table 5 of the Exponent Report are calculated values at the edge of the right-of-way at an average projected system power flow. (Please note that a revised Table 5 was filed on 3/15/04.) As explained in my prefiled testimony, it would be erroneous to interpret these values as estimates of a person's level of *exposure* to EMF. A magnetic field value calculated or measured at a particular location in an instant in time is not a measure of human exposure.

The epidemiology studies of human populations in residential settings have used various methods to estimate their total long-term exposure to magnetic fields. These methods have included surrogates for measurements of long-term exposure including distance to power lines, the number and size of conductors, spot measurements in home, schools, or workplaces, repeated personal measurements over one or two days, and calculations of the magnetic field at a residence based upon annual average loading of nearby power lines. These surrogates for actual measurements of long-term exposure have been used in community studies to compare the estimated exposures of groups of persons with and without the disease of interest, with the idea being that differences in the exposures of these groups might shed light on factors that might affect the etiology or development of the disease.

For example, in the studies of childhood leukemia, the investigators used the above methods to compare the exposures of a group of children with leukemia to other children in the same community without leukemia. The results of such studies may indicate differences in the relative exposures of the groups – indicating a statistical association between the exposure and the disease. However, by themselves they provide little basis to discern a cause and effect relationship, especially since bias and confounding cannot be ruled out, and there is virtually no biologic data or mechanisms that support the plausibility of a causal relationship.

Hence, it would not be correct to regard the associations in EMF epidemiologic studies as providing estimates of effect thresholds

As is also discussed in the Exponent report and in my prefiled testimony, there is no basis in the experimental literature to conclude that long-term exposure to magnetic fields at the levels indicated pose any risk of cancer or toxicity.

CL&P/UI
Docket No. 272

Data Request TOWNS-02
Dated: 02/17/2004
Q- TOWNS-040

Witness: Dr. Bailey
Request from: Connecticut Siting Council

Question:
Reference Table A-1 in the Exponent EMF Assessment.

a. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 25.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

b. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 25.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

c. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 30.7 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

d. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 30.7 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

e. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 96.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

f. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 96.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

Response:
See response as to TOWNS-002, Q-TOWNS-039.

Witness: Dr. Bailey
Request from: Connecticut Siting Council

Question:
Reference Table A-3 in the Exponent EMF Assessment.

a. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 10.7 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

b. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 10.7 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

c. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 12.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

d. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 12.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

e. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 16.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

f. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 16.3 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

g. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 17.1 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

h. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 17.1 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

i. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 28.1 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

j. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 28.1 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

k. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 38.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

l. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 38.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

m. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 39.4 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

n. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 39.4 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

o. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 39.9 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

p. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 39.9 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

q. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 41.2 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

r. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 41.2 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

s. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 44.7 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

t. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 44.7 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

u. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 45.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

v. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 45.0 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

w. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 49.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

x. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 49.5 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

y. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 58.4 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

z. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 58.4 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

aa. Describe the evidence that, in the opinion of Exponent, CL&P and UI, would support the conclusion that long-term exposure to a magnetic field of 58.8 mG would not have adverse effects on human health, compromise normal function, or cause cancer.

bb. Provide copies of the health and scientific studies which form the basis for the conclusion that long-term exposure to a magnetic field of 58.8 mG would not have adverse effects on human health, compromise normal function, or cause cancer. Please identify the specific statements, tables and findings in each such study which support this conclusion.

Response:
See response as to TOWNS-02, Q-TOWNS-039.

CL&P/UI
Docket No. 272

Data Request TOWNS-02
Dated: 02/17/2004
Q- TOWNS-043

Witness: Dr. Bailey
Request from: Connecticut Siting Council

Question:
Provide copies of each of the health and scientific studies discussed or included as references in the Exponent EMF Assessment.

Response:
All of these studies are publically available, in many cases on the internet. Production of even a single copy of every one of the referenced studies and reports would be a overly burdensome and wasteful. Accordingly the Companies object to this request.

WHO Website Describing Ongoing EMF Research

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Research agenda: Previous page | 1,2,3,4

EMF research priorities

A. Radio frequency fields

- Link to new RF research agenda 2003

:: Contents

In 1997, the WHO International EMF Project developed a Research Agenda in order to facilitate and coordinate research on the possible adverse health effects of non-ionizing radiation. In subsequent years, this agenda has undergone periodic review and refinement.

A major update to the RF (radiofrequencies) Research Agenda was undertaken with the input of an ad hoc committee of invited scientific experts who met in Geneva in June 2003. Further input to the RF Research Agenda came from a WHO Workshop "Adverse Temperature Levels in the Human Body" held in Geneva in March, 2002, (see Goldstein et al., Int. J. Hyperthermia 19, 373-384, 2003). The committee reviewed research in the following areas: Epidemiology and Human Laboratory Studies, Animal and Cellular Studies, and Dosimetry. Consideration was restricted to RF; possible effects non-ionizing radiation from static fields, wide-band and power frequencies will b considered separately.

The RF Research Agenda defines high priority research whose results would contribute to the WHO I assessment for RF exposures. Researchers are encouraged to use the Research Agenda as a guide t that have high value for WHO health risk assessments. To maximize the effectiveness of large resea programs, government and industry funding agencies are encouraged to address the WHO Researcł in a coordinated fashion. Such coordination will minimize unnecessary duplication of effort and will e most timely completion of the studies identified as being of high priority for health risk assessment.

B. Intermediate frequency fields

The general consensus of the working groups was that present scientific evidence does not show he hazards from IFs at exposures below recommended guidelines. However, the biological data are spa particularly in relation to effects of low level exposure.

A few epidemiology studies have suggested links between IF exposure and health effects, but they a compromised by technical problems and cannot be reliably interpreted. Even for established hazard: a need to determine thresholds better, particularly for fields with complex waveform, pulsed fields, a partial-body exposures. Any epidemiological studies at IFs should be preceded by pilot studies demc their feasibility.

C. ELF electric and magnetic fields

Some epidemiological studies have suggested an increased risk of leukaemia in children living near lines. Whether this is due to exposure to ELF magnetic fields or some other factor in the environmer to be determined. Other unresolved issues for health relate to studies suggesting that ELF exposure associated with increases in breast and other cancers in adults, neurodegenerative diseases, such a: Alzheimer's, and subjective or non-specific effects, eg "hypersensitivity" to electricity.

There have been no published studies specifically investigating possible biological effects from expos transients (from switching electric currents) or high frequency harmonic fields that are normally superimposed on 50/60 Hz fields in living and working environments. On theoretical grounds, transi high frequency harmonic fields are more likely to cause biological effects than sinusoidal 50/60 Hz fi Additional studies identified as necessary to complete WHO's EMF Research Agenda include:

i. Thorough surveys of transients and other perturbations of 50/60 Hz fields are needed to bet characterize actual fields and to determine their prevalence in the environment. These fields likely to produce biological effects that pure sinusoidal 50/60 Hz since they may induce signa above their normal electrical noise levels.

ii. At least two 2-year standard bioassay animal studies, like those conducted by the US Nation Toxicology Program, with exposures to ELF fields that include transients (described in (I) abo test for common types of cancer.
iii. At least one 2-year standard bioassay animal study, similar to that described in (ii) above, u sinusoidal 50/60 Hz fields and two such studies using transient-perturbed fields, to test spec breast cancer.
iv. Epidemiologists and physical scientists should discuss how to refine their methodologies and assessment of past and present exposure to 50/60 Hz fields and transients. This should be f pilot studies that test and validate these refinements. At least two further large, multi-centre epidemiological studies of childhood leukemia are needed that use the best available methoc exposure assessment, including assessment of transient and higher frequency harmonic fielc
v. Large epidemiological studies are also needed to investigate possible associations between e to 50/60 Hz fields and breast cancer or neurodegenerative diseases. These studies should be conducted on highly exposed occupational groups using the best available methods of expos assessment.
vi. Human volunteer studies are needed to determine whether ELF fields affect certain hormone (e.g. melatonin). These studies should extend the exposures beyond the one night used in p experiments and also test both sexes. It is important that future studies test for effects caus transients and other perturbed fields.
If results of current studies of people claiming hypersensitivity ELF fields are confirmed, part studies of their responses to fields applied in controlled laboratory situations, these reports s investigated to determine what further research is needed.
vii. In vitro studies are needed that are directly relevant to possible in vivo effects, and that add issues of ELF exposure thresholds and reproducibility for reported positive effects on cell cycl proliferation, gene expression, signal transduction pathways and membrane changes.

Theoretical modelling investigations are also needed that support in vivo studies by proposing testal mechanisms on how low-intensity fields and realistic environmental transients might interact with bi systems.

D. Static fields

Research to date indicates that static electric fields do not produce deleterious health effects in hum levels found in the environment or workplace. Therefore, further research into their possible effects recommended at this time.

Static magnetic fields are known to produce health effects only at very high field strengths. Technol such as magnetically levitated trains, medical diagnosis and treatment, and industrial applications a increasing in use or are being developed. They use intermediate or high-intensity static magnetic fie could increase public and worker exposure significantly. More information on possible long-term effe health from exposure to static magnetic fields is needed. Studies needed to provide this information

i. At least two standard 2-year animal bioassay studies concentrating on cancer-related effects studies should follow criteria used by the US National Toxicology Program
ii. At least two large-scale, multi centre epidemiological studies on workers that characterize st magnetic field exposure well, minimize confounding factors, and include measurements of e› from other sources of EMF.
iii. Additional studies are needed that examine biological effects of exposure to combined static time-varying fields, including transients, particularly those found in transportation systems.

Research agenda: 1,2,3,4 | Guidelines for quality EMF research

RELATED STORIES

- Research
- EMF research database
- Health risk assessments
- Scientific reviews

International **EMF** Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	293
Title	Evaluation of Low Frequency Residential Magnetic Fields of Cases and Control Persons: Epidemiological Analysis of Childhood Leukemia
Study Type	Epidemiology
Model	ELF exposure and childhood leukemia
Details	Residents near ELF sources (50-60 Hz) analyzed for leukemia incidence (from German leukemia registry)
Reference	Ongoing
Principal Investigator	Michaelis, J.
Funding Agency	BfS
Country	GERMANY
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	295
Title	Teratogenic Effects of Static Magnetic Fields Above 2T
Study Type	In Vivo
Model	ELF exposure in mice and teratogenicity
Details	50-60 Hz/teratogenicity in mice
Reference	Ongoing
Principal Investigator	Haase, A.
Funding Agency	BfS
Country	GERMANY
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	296
Title	Investigation of possible mechanisms for Tumor Promotion or Co-promotion of ELF Magnetic Fields
Study Type	In Vivo
Model	50-60 Hz exposure to DMBA initiated rats - mammary tumor model
Details	
Reference	Ongoing
Principal Investigator	Loscher, W.
Funding Agency	BfS
Country	GERMANY
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	297
Title	Comparative Study on the Biological Effectiveness of Extremely Low Frequency Electromagnetic Fields in non-Transformed and Transformed human cells
Study Type	In Vitro
Model	50-60 Hz/cell cycle, transformation, micronuclei in cultured cells
Details	
Reference	Ongoing
Principal Investigator	Simko, M.
Funding Agency	BfS
Country	GERMANY
Accession No	

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International **EMF** Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	298
Title	Effects of Weak 50 Hz Electric and magnetic Fields on Electrically Hypersensitive People
Study Type	Human / Provocation
Model	50-60 Hz/provocation study using hypersensitive people
Details	
Reference	Ongoing
Principal Investigator	Mueller, C.H.
Funding Agency	BfS
Country	GERMANY
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	299
Title	Clastogenicity of 50 Hz Electromagnetic Field on Chromosomes of Tradescantia
Study Type	In Vitro
Model	50-60 Hz/micronuclei in Tradescantia
Details	
Reference	Ongoing
Principal Investigator	Martin, U.
Funding Agency	BfS
Country	GERMANY
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	300
Title	A Study to Evaluate health Risks Associated with ELF-EMF
Study Type	Human / Provocation
Model	50-60 Hz/melatonin & HRV
Details	
Reference	Ongoing
Principal Investigator	Kabuto, M.
Funding Agency	NIES-Japan
Country	JAPAN
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	301
Title	A Study to Evaluate health Risks Associated with ELF-EMF
Study Type	In Vitro
Model	50-60 Hz/ELF inhibbition of melatonin effects on MCF-7 cells (replication of Liburdy et al)
Details	
Reference	Ongoing
Principal Investigator	Kabuto, M.
Funding Agency	NIES-Japan
Country	JAPAN
Accession No	

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EMF Study

(Database last updated on Jan 14, 2004)

ID Number	303
Title	[50-60 Hz/feasibility study for epidemiological study in Japan]
Study Type	Epidemiology
Model	50-60 Hz/feasibility study for epidemiological study in Japan
Details	
Reference	Ongoing
Principal Investigator	Takaku, F.
Funding Agency	NIES-Japan
Country	JAPAN
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	304
Title	[Residents near ELF sources (50-60 Hz) analyzed for leukemia incidence]
Study Type	Epidemiology
Model	Residents near ELF sources (50-60 Hz) analyzed for leukemia incidence
Details	
Reference	Ongoing
Principal Investigator	Kabuto, M.
Funding Agency	NIES-Japan
Country	JAPAN
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	1075
Title	Blood Flow to Brain Changes with EMF Exposure
Study Type	Human / Provocation
Model	mobile phone as well as 16 Hz and 1 MHz EMF exposure to hypersensitive individuals and evaluation of brain blood flow
Details	Human volunteers (n = 5 with self claimed symptoms of RF hypersensitivity), were exposed to mobile phones (? - signal type and dose - ?) as well as EMF excited by an AC current between 16Hz to 1MHz fed through a conductive wire that was worn around the volunteer's neck). The authors report different changes in brain blood flow in hypersensitive individuals with EMF exposure, but none were statistically significant due to the small sample size. The authors suggest EMF may have disrupted the nerve system, reducing the ability to maintain the brain's blood flow. The authors further state that "many people with irritations linked to electromagnetic waves have problems moving their eyeballs and have an abnormality in their pupils' reaction to light". The authors finally suggested that further research was needed.
Reference	Ongoing
Principal Investigator	Sakabe K
Funding Agency	?????
Country	JAPAN
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	1092
Title	SETIL: Case-Control Study on Etiological Factors for Childhood Leukemia, Non Hodgkin Lymphoma and Neuroblastoma
Study Type	Epidemiology
Model	Exposure to EMF (as well as ionizing radiation, chemicals, and other pollutants and the incidence of childhood leukemia
Details	Case control study of childhood cancers (leukemia, non-Hodgkin's lymphoma, and neuroblastoma) and exposure to physical (ELF-EMF, ionizing radiation), chemical (solvents, benzene, passive tobacco smoke, traffic pollution, insecticides, other related to parental occupation) and other factors (medical and personal history of child and parents, diet, crowding, infectious diseases, immunization).
Reference	Ongoing
Principal Investigator	Magnani C
Funding Agency	Italian Nat'l
Country	ITALY
Accession No	

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International **EMF** *Project*

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	1095
Title	Optimization, Management and Mitigation of EMF in Power Systems in Malaysia
Study Type	Epidemiology
Model	Analysis of potential effects of power frequency (50/60 Hz) exposure in the public
Details	Occupational exposure to ELF and various health implications in home and work environments in Malaysia
Reference	Ongoing
Principal Investigator	Farag AS
Funding Agency	UNITEN
Country	MALASIA
Accession No	

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International EMF Project

EMF Study

(Database last updated on Jan 14, 2004)

ID Number	1106
Title	Safe Distance between Power Lines and Homes
Study Type	Literature Review
Model	Literature review and modeling studies of ELF health effects
Details	
Reference	Ongoing
Principal Investigator	Khamees Belal A
Funding Agency	King Saud University
Country	SAUDI ARABIA
Accession No	

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Bioelectromagnetics Supplement 5:S32–S47 (2001)

The Potential Impact of Bias in Studies of Residential Exposure to Magnetic Fields and Childhood Leukemia

Daniel Wartenberg*

Environmental and Occupational Health Sciences Institute, UMDNJ—Robert Wood Johnson Medical School, Piscataway, New Jersey

Bias can have a major impact on the results of epidemiologic studies. In investigations of the possible association between residential exposure to magnetic fields and the occurrence of childhood leukemia, many have raised questions about selection bias, including participation bias and information bias. In this review, the data on these possible sources of bias are summarized and their likely impact is evaluated. Most data suggest that if a bias exists, it is a bias towards the lack of association between exposure to magnetic fields and childhood leukemia. In addition, given the wide variety of study populations and measurement protocols, it is unlikely that a single design flaw has resulted in consistent effects across all studies and can be the sole explanation for the reported associations. Bioelectromagnetics Supplement 5:S32–S47, 2001. © 2001 Wiley-Liss, Inc.

Key words: selection bias; participation bias; information bias; epidemiology; study design flaws; emf; leukemia

INTRODUCTION

Bias is generally defined as the presence of systematic errors in the results of an epidemiologic study, the finding of a false effect or the obscuring of a real effect for the wrong reason. Bias results from comparing subjects that differ in some important way. It is the failure to isolate, for a specific risk factor, an accurate measure of effect (separate from random error), and compromises the internal validity of a study. While many types of bias can be defined [Sackett, 1979], typically researchers focus on three specific types of bias: selection bias, information bias, and confounding [Rothman et al., 1998]. For the purposes of this manuscript, we focus on the first two types of bias and evaluate their importance with respect to studies of childhood leukemia and residential magnetic field exposures.

Selection Bias

In designing an epidemiologic study, it is important to assess the characteristics of the two groups to be compared and the possible impact of bias on study results. These characteristics depend on the design of the study. For case–control studies, all subjects (i.e., cases and controls) must be comparable and representative of the general population from which they are drawn. The investigator should select subjects based on each subject's disease status without knowledge of their exposure status. If there is a differential preference between cases and controls for selecting individuals with (or without) exposure, this may induce a bias in the measure of association between disease status and exposure status. For cohort studies, all subjects are disease free at the outset and are selected based on their exposure status without knowledge of their disease history. Provided that the investigator has no knowledge of the subjects' disease history (for historical cohort studies) and that follow-up is complete, there is no selection bias. However, it is essential that case ascertainment be complete and independent of exposure status. If the follow-up of individuals differs by disease status, follow-up bias may occur which can give erroneous results. In cohort studies, the representativeness of the subjects is relevant only for generalizing the study results to other populations (i.e., external validity).

Below are described specific aspects of studies of residential magnetic field exposure and childhood cancer studies that may have led to bias (Tables 1 and 2). This discussion identifies possible sources of bias.

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While such bias may exist, it is not possible to determine conclusively from published data whether the biases are large enough to explain the reported associations or lack of associations. Additional data and analyses would be required to determine this. Since all but one of the studies are case–control studies, I do not address issues of cohort studies in any detail. For case control studies, I focus on four main issues: representativeness of sources of cases, representativeness of sources of controls, participation rates, and differential mobility of subjects. Finally, I discuss a new and innovative approach that has been developed to assess possible control selection bias: the case specular method.

Representativeness of Cases

Three epidemiologic designs have been used in the studies of childhood cancer and residential exposure to magnetic field residential exposure studies (Table 1). The first type of study used a standard case–control design. That is, subjects with disease and subjects without disease were identified, and their exposures were estimated retrospectively. Cases were selected from population-based or hospital-based registries. Controls were selected from another register (e.g., birth certificates), through a random digit dialing procedure, or from friends of the cases.

The second type of study was a nested case–control design. In this design, a cohort of individuals was identified containing both cases and controls and both exposed and unexposed subjects, such as those living near electric power transmission lines. From this cohort, cases and controls were chosen independently of their exposure and compared with respect to their exposure as in a traditional case--control study. The advantage of this design is that, if designed properly, it enables the investigator to select a preferable exposure prevalence among subjects compared to the general population (in the case of residential magnetic fields, higher exposure prevalence), increasing the study's sensitivity for detecting an association between exposure and disease.

The third type of study was an historical cohort study. In this study, investigators identified all persons living near the electric transmission facilities as their cohort, and compared the incidence experience of these people with national incidence rates.

All the case–control studies utilized registry records to identify cases. They used all cases diagnosed or dying during a certain range of years, living in a specified geographic region and below a certain age (Table 1). Three different types of data sources were used to identify cases. Wertheimer and Leeper [Wertheimer et al., 1979] used death certificates. One concern with this source is that severity of disease may have affected reporting (i.e., non-fatal leukemias do not result in death certificates). Diagnosis, treatment and access to care can affect disease severity and may be related to socioeconomic status. And, socioeconomic status, in turn, could be related to proximity to power lines, which could have resulted in a bias. Fulton [Fulton et al., 1980], Fajardo-Gutierrez [Fajardo-Gutierrez et al., 1993] and Petridou [Petridou et al., 1997] used hospital incidence registries or physician registries. Socioeconomic status may influence physician and hospital choice. Referral patterns also can affect hospital choice. Unless the controls are drawn from the same population as the cases, i.e., the same hospital or physician, bias may result. The rest of the case–control studies used population-based registries to identify cases [Tomenius, 1986; Savitz et al., 1988; Coleman et al., 1989; Myers et al., 1990; London et al., 1991; Feychting et al., 1993; Olsen et al., 1993; Verkasalo et al., 1993; Linet et al., 1997; Michaelis et al., 1997; Tynes et al., 1997; Dockerty et al., 1998; Green et al., 1999a,b; McBride et al., 1999] These are optimal provided that ascertainment of cases is sufficiently high. Four studies supplemented these registries with other data [Savitz et al., 1988; Myers et al., 1990; Dockerty et al., 1998; McBride et al., 1999]. Overall, while there are minor variations in case selection, published data are not sufficient to assess possible bias. I believe these variations are unlikely to produce a largely unrepresentative sample or a bias large enough to explain the observed results.

If exposure to magnetic fields had an age-specific effect on the incidence of leukemia, studies using children of ages outside those affected could bias the reported effects toward showing no association. The age ranges of cases in studies reviewed here varied, from allowing only subjects under 11 years of age to allowing all those under 21. These ranges all are representative of children. Most studies used children under 15 as those eligible. Age variation is unlikely to have caused a substantial bias since there was such a large overlap between the age ranges, although it would be worthwhile to investigate the sensitivity of the results to maximum age cutpoint. Similarly, the calendar year ranges of eligibility vary across studies but should not result in substantial bias. Again, a sensitivity analysis could produce some insight. These sensitivity analyses cannot be conducted thoroughly without the original data.

Representativeness of Controls

In case–control studies, controls should provide an estimate of the exposure distribution in the population from which the cases were drawn [Rothman et al.,

TABLE 1. Subject Selection in Residential Childhood Cancer Studies

Design	Reference	Source of subjects: Cases	Source of subjects: Controls	Eligibility: Years	Eligibility: Location	Eligibility: Ages	Matching criteria
Case–control	Wertheimer	Death certificates	Next birth certificate unless a sibling	1950–1973	Colorado birth and Greater Denver Resident 1946–1973	<19	Either month and county of birth (File 1) or alphabetical, 5–20 year range (not sibling) (File 2)
	Fulton	State hospital incidence registry	Birth certificate	1964–1978	Rhode Island resident for 8 years prior to diagnosis	<21	Birth year
	Tomenius	Population-based cancer registry	Nearest birth certificate in Parish records	1958–1973	Born and diagnosed in Stockholm County	<19	Age, gender, church district of birth, and church district of diagnosis (if same as birth for case)
	Savitz	Population-based cancer registry and hospital records	Random digit dialing	1976–1983	Denver SMSA	<15	Age ±3 years, gender, telephone exchange at time of diagnosis of case
	Coleman	Population-based cancer registry (leukemias only)	Solid tumors (not lymphomas)	1965–1980	4 London Boroughs	All ages	Age, gender, year of diagnosis, residence borough
	Myers	Population-based cancer registry and other sources (mortality)	Nearest birth certificate	1970–1979	Yorkshire Health Region	<15	Gender, birth in same local area or health district, year of diagnosis
	London	Population-based cancer registry (leukemia)	Friends (first 65) and random digit dialing	1980–1987	Los Angeles County	<11	For most, age ± 1–3 years depending on age, gender, ethnicity
	Olsen	Population-based cancer registry (leukemia, CNS tumor, lymphoma)	Population registry	1968–1986	Denmark	<15	Gender, date of birth ± 1 year
	Fajardo-Gutierrez	Hospitals (3rd level)	Hospitals (3rd level)	—	Mexico City	—	Same hospital (in patient or out patient); no neoplasm
	Linet	Population-based cancer registry	Random digit dialing	1989–1994	9 U.S. States (IIL, IN, IO, MI, MN, NJ, OH, PA, WI)	<15	Phone number (8 digits), age, race
	Michaelis	Population-based cancer registry	Population registry	1991–1994	Berlin, Germany; Lower Saxony	<15	Gender, data of birth, city district at diagnosis
	Petridou	Physicians network	Hospital records	1993–1994	Greece (Greek nationals)	<15	Gender, age, town (urban) or region (rural), hospitalized at same time

(Continued)

TABLE 1. (*Continued*)

	Dockerty	National cancer registry hospital admission/ discharge data children's cancer registry	National birth records	1990–1993	Born and diagnosed in New Zealand	<15	Gender, age, resident in New Zealand
	McBride	Pediatric oncology treatment centers population-based cancer registry	Provincially-based government health insurance rolls	1990–1994	Within 100 km of principal cities of British Columbia, Alberta, Saskatchewan, Manitoba, Quebec	<15	Gender, age, area
	Green	Hospital for sick children via the pediatric oncology group registry	Randomly selected from telephone marketing lists	1985–1993	Resident within metropolitan Toronto or counties of York, Durham or Peel	<15	Gender, year of birth
Nested case–control	Feychting	Population-based cancer registry	Population registry	1960–1985	Residence within 300 m of any 220 kV or 400 kV power line in Sweden	<16	For most, in registry during year of diagnosis, birth year, gender, residence in same parish in year of diagnosis or move, near same power line
	Tynes	Population-based cancer registry	Population registry	Selected years 1960–1989	Residence in a census ward crossed by a high voltage power line during at least one of: 1960, 1970, 1980, 1985, 1987, 1989	<15	Vital status at time of diagnosis, sex, year of birth, municipality (except a few selected from neighboring municipality)
Historical cohort	Verkasalo	National cancer registry	National population registry	1970–1989	With 500 m overhead power lines	<20	5-year age groups

TABLE 2. Numbers of Subjects in Residential Childhood Cancer Studies

Reference	Number of subjects originally identified		Excluded/refused		Moved		Comments
	Leukemia cases	Controls	Cases	Controls	Cases	Controls	
Wertheimer and Leeper	344 (155 leukemia?)	344 (155 controls)	16—no death address; 72—no birth address	16—no death address; 72—no birth address	147	128	21% HCC in File 1; 23% HCC in File 2
Fulton et al.	119	240	9	15	53	—	Cases had to live in RI for 8 years prior to diagnosis; Controls had to be born in RI
Tomenius	746 (56 benign)	716	29—bad data; 1—not primary tumor; 43 of 1172 dwellings	46 of 1015 dwelling	316 of 746		
Savitz et al.	103	278	30 interviews; 67 measurements; 6 wire codes	56 interviews; 71 measurements; 19 wire codes (78.9% response rate in RDD)	37?	0	Controls had to be resident in Denver at time of recruitment and time of diagnosis of case; mobility of cases greater than that of controls
Coleman et al.	811 (84 under age 18)	1614 (141 under age 18) 254	40	182 23	—	—	Resident at time of selection (or 1975 for 2nd controls) used; mobility not assessed
Myers et al.	419	656	45	68	NR	NR	Analyses based on birth residence; control residence at time of diagnosis not reported
London et al.	331	257	99 interviews; 162 measurements; 112 wire codes	24 interviews; 108 measurements; 50 wire codes (82% response rate for RDD)	57%	66%	4,424 phone numbers resulted in 113 eligible controls
Olsen et al.	1707	4788	0	0	1050	3125	
Fajardo-Guiterrez	81	77	—	—	—	—	Little ancillary information reported
Linet	942	1,292	304 no interviews	672 no interviews	66%	68%	Used complete residential histories; mobility similar between cases and controls

(*Continued*)

TABLE 2. (*Continued*)

Michaelis	283	919	43 questionnaire; 64 measurement	339 questionnaire; 166 measurement	—	—	No historical residency requirement
Petridou	117	202	0	14 (8 replaced)	—	—	Require to be at same residence for at least 4 years
Feychting and Ahlbom	142	558	1 calculations; 53 measurements	4 calculations; 214 measurements	—	—	Residence history used in exposure assessment
Tynes	532 (148 leukemias)	2112 (579 controls)	32	108	NR	NR	Had complete residential history; excluded those not living in wards prior to diagnosis
Verkasalo	32	—	—	—	—	—	Cohort study
Dockerty	344 (131 leukemias)	—	121 interviewed; 115 measured	121 included (secondary controls); 117 measured	75	77	40 matched pairs resident for at least 2 years prior to diagnosis date analyzed separately
McBride	449	675	4 not located: 46 not contacted: about 75% measured	149 not located; 127 not sued; about 85% measured	NR	NR	Mobility of cases was higher than that of controls
Green	256	645	22 physician refusal; 22 relocated outside study area; 36 no response; 17 refused; 2 discarded	45 no response; 168 refused; 13 discarded	NR	NR	Mobility of cases was higher than that of controls

1998]. They should provide an estimate of the exposure rate that would have been observed in the cases if there were no association between the exposure under study and the disease [Schlesselman, 1982]. Controls (or comparison populations) were selected in a variety of ways. Some studies used regional birth certificate files [Wertheimer et al., 1979; Fulton et al., 1980; Tomenius, 1986; Myers et al., 1990; Dockerty et al., 1998]. This limits subjects to those who were both born and diagnosed (or selected) in the same region. In general, this is advisable to increase the likelihood adequate duration of residence (i.e., exposure) at the specified house.

Fulton [Fulton et al., 1980] conducted a hospital-based case–control study but used the general population listed in the birth certificate records as the source for controls. This population likely was larger than the hospital population from which the cases were drawn, which could have led to bias. Further, Wertheimer and Leeper [Wertheimer et al., 1980] have argued that because matched control homes were selected by birth addresses while case homes (often more than one per case) were homes occupied any time 8 years prior to diagnosis, there is a deficit of suburban addresses in the control population (or an excess of urban addresses). This resulted in a bias towards higher exposure for controls. In addition, only address at birth was used for controls while complete case address histories were obtained and used.

Other studies used random digit dialing to identify controls [Savitz et al., 1988; London et al., 1991; Linet et al., 1997]. Random digit dialing is a method designed to identify a set of controls for a study that come from a defined geographic region [Waksberg, 1978; Robison et al., 1984; Ward et al., 1984; Greenberg, 1990; Olson et al., 1992; Voigt et al., 1992; Lele et al., 1994; Psaty et al., 1994; Brick et al., 1995; Sakkinen et al., 1995]. For each case identified, the investigator takes the case's phone number, discards the last two digits and replaces them with two randomly chosen digits. This number is called. If it is not a residence, another pair of random digits is used. If it is a residence, the interviewer asks if a subject meeting the matching criteria resides there. If so, this person is recruited as a subject. If not, another pair of random digits is used. This process, applied to a childhood study with gender, age and ethnic matching, typically requires between 25 and 75 phone calls per case to identify an eligible control.

One limitation of random digit dialing is that it samples only homes with telephones. It is important to determine what proportion of residences have telephones and, if possible, to compare those residences with those that do not with respect to exposure and confounding variables. Poole and Trichopoulos [Poole et al., 1991] argue further that people of very low socioeconomic status are harder to reach by this method and are underrepresented in the sample. Another limitation of random digit dialing is that there is limited ability to assess non-response. Investigators rarely have information about residents at telephone numbers that never respond. More recently, as the use of telephone lines for fax machines, computer lines and cellular phones has increased, the effort required to reach the owner of the phone line has increased dramatically and the representativeness of those reached as a random sample has become increasingly questionable.

Gurney and colleagues conducted a study in the Seattle area to evaluate the potential bias of random digit dialing with respect to a possible association between socioeconomic status and wire codes [Gurney et al., 1995]. That study found that high wire code homes were more likely to be of low income families, although the association was weak. Since high income is associated with increased risk of childhood leukemia, the finding is consistent with a downward bias of the true odds ratio. If, however, the control homes selected were of higher socioeconomic status, due to more variation between than within dialing regions, an upward bias would be seen. Documenting this bias is complicated although the effect is unlikely to be large.

Another possible source of bias in using random digit dialing is that the sampling unit is the residence rather than the individual. That is, the investigator tries to reach each residence via telephone rather than each individual child, as one does in a registry sampling procedure. Individuals are the unit used in the final analysis. But if a residence does not have a telephone, none of the children in that residence can be considered for use as a control or, if a home has more than one eligible child, typically only one is considered eligible for the study. Exclusion of homes without phones likely results in greater similarity among potential subjects, while limiting subjects to one per household decreases similarity among potential subjects.

One study selected some controls using random digit dialing and others who were friends of cases [London et al., 1991]. The latter approach involves asking a case to name a friend who could be approached for inclusion in their study. One of the problems in using friend controls is that they may be overmatched [Kelsey et al., 1996]. That is, friend controls may be more similar to the cases in terms of a factor that is not a confounding variable, but is associated with exposure, compared to population-based controls. This reduces the statistical efficiency, meaning that a larger sample size might be needed to detect the association of interest, because the exposures tend to be more similar than expected (under a random control selection scheme) due to the friend-matching [Rothman et al., 1998]. It also can induce confounding which, if not adjusted for, can create bias. In addition, since the name of the friend is solicited from the case (or surrogate), it is possible that the case (or surrogate) has exercised some type of selection bias, such as selecting the friend that is most talkative or out-going, which may in turn be related to some risk factors. If one wishes to use friends as controls, one could solicit a list of friends from each case and select the controls for a case at random from such a list. Even so, there may be some bias. In addition, selecting some controls by one method and others by another method may lead to heterogeneity among controls. The rationale of combining the two different methods had to do with logistical considerations. It still may have led to differences between controls (i.e., different chances for selection depending on the method). Analyses of the data stratified or separated by control selection method could help investigators evaluate this.

Another study selected controls randomly from a marketing list and then contacted them by phone [Green et al., 1999a, b]. This is even more problematic than random digit dialing as it starts from a selective and likely biased list (at least in terms of socioeconomic status) and then encounters many of the same access limitations as random digit dialing.

One study used two complete sets of controls. One was composed of cancer cases other than leukemia and lymphoma, and the other set of controls was drawn from the local electoral roll [Coleman et al., 1989]. Both of these control populations are problematic. Other cancer cases may lead to a negative bias (reduction in the possible association) if cancers other than those excluded (i.e., brain cancers) are associated with exposure to magnetic fields. Fortunately, in this case, there are scant data to support an association of childhood cancers other than leukemia or brain cancer with magnetic field exposures. The electoral roll, which was not used for the childhood portion of the study, may not include all persons living in the region and may be ethnically and socioeconomically biased.

Still another study selected controls for a government health insurance listing [McBride et al., 1999]. Issues regarding completeness would have to be considered.

The cohort study, two case–control studies, and both nested case–control studies used population registries to identify controls [Feychting et al., 1993; Olsen et al., 1993; Verkasalo et al., 1993; Michaelis et al., 1997; Tynes et al., 1997]. Again, if ascertainment is adequate, this is ideal as samples are drawn at random from the entire population that one wishes to sample. Often, the investigator does not have access to such a convenient database.

Finally, two studies used the residence as the unit of analysis [Fulton et al., 1980; Tomenius, 1986]. This may introduce bias because the number of residences per subject may vary by disease and/or exposure (i.e., residence at birth, residence at diagnosis or death). Further, if the total number of residences is used in any of the analyses, the apparent sample size is increased artificially (i.e., more than one home per subject) inappropriately increasing the precision.

Participation Rates

Having identified the source of subjects, the next major concern in the case–control studies is the possible bias due to non-participation. If non-participation rates differ by exposure status only or by disease status only, there is no bias in the odds ratio. However, if these rates differ by both exposure and disease, a substantial bias may exist. One can conduct a sensitivity analysis for such an effect to determine the maximum amount of bias that could be present.

The potential for this problem is shown in Table 2. Some of the studies show substantial numbers of exclusions or refusals to participate. Without characterizing these individuals, it is not possible to determine the degree of bias imparted. However, if one were to do a sensitivity analysis to determine how large an effect there might be for these exclusions, in worst case, it is likely that the exclusion adjusted odds ratios would be substantially different from those reported. While this problem is not unusual in epidemiologic studies, it can have a large impact.

Gurney and colleagues, in their study of the potential bias from the use of random digit dialing for control selection, also evaluated the possible role of participation bias. They assumed that low income controls were less likely to participate in the study than other controls. Using their data on wire code distributions and income and assuming that all cases participated, they estimated that if 80% of controls with incomes over $15000 participated in a study and 0% with incomes under $15000 participated, it would produce a bias in the odds ratio of 1.24. If participation were better in those of low income or worse in those of high income, the effect would be even smaller. Again, these data suggest a possible bias, but not one large enough to explain the observed results.

The problem of participation bias is of particular concern across the range of measurement methods used. In most studies, far more houses were assessed in terms of wire codes than magnetic field measures. It would be instructive to get the data on the homes in all of these studies and determine if there was a bias associated with the type of exposure measurements made. For example, Savitz [Savitz et al., 1988] reports that homes with missing measurement data were more likely to have high or very high current configuration wire codes than those with measurements (28.8% vs. 22.1%), and there were more homes missing measurements among cases than controls. Thus, for that one study, the missing data likely resulted in an underestimation of the size of the association. Similarly, Hatch [Hatch et al., 2000] reports that subjects who had front door magnetic field measurements but not indoor magnetic field measurements, had higher magnetic fields (15.6% vs. 12.7%) and more of the highest category of wire codes (8.8% vs. 6.3%) than those with both measurements. Based on limited data from these two studies, subjects in homes with fewer types of measurements had higher exposures.

Mobility

Differential mobility of cases and controls has been raised as another possible source of bias in these studies. While generally data needed to evaluate this possibility are not published, some of the studies do present information on how many residences have been occupied by each study subject (Table 2). Jones and colleagues argue that the observed associations between wire codes and childhood cancers may be due to bias induced by differential mobility (for example, in the Savitz study, controls were required to be residentially stable but cases were not), and mobility has been found to be associated with higher wire codes [Jones et al., 1993]. Mobility differences were evident in the studies of Tomenius [Tomenius, 1986], Savitz [Savitz et al., 1988], McBride [McBride et al., 1999], and Green [Green et al., 1999a, b].

In most studies where it was reported, cases were more mobile than controls. In part, this may be due to different stability restrictions on the eligibility of cases versus controls. The purpose of a residential stability restriction in one study design was to eliminate from potential controls those who were not resident at the time of case diagnosis and who thus would not have been a case even if they had developed disease [Savitz et al., 1988]. In a study to investigate the possibility of this phenomenon, Jones found 31% more high wire codes in non-stable than in stable populations [Jones et al., 1993]. Again, while plausible, the quantitative impact is limited. Only if one assumes that the 31% excess of high wire code found by Jones [Jones et al., 1993] were true for virtually all of the Savitz study cases and none of the controls [Savitz et al., 1988], would removing this excess lower the odds ratio towards showing no association. Further, the applicability of the Jones data to the Savitz data is questionable since the Jones et al. study had substantially more high wire codes overall (30.1% vs. 24.5% total; 34% vs. 28% cases; 26% vs. 20% controls) [Jones et al., 1993].

Reviews

Issues of selection bias have been raised in various reviews of these residential childhood cancer studies. For example, the NRPB Report [National Radiological Protection Board, 1992] raised issues of bias in the use of random digit dialing for both the Savitz [Savitz et al., 1988] and London [London et al., 1991] studies. They suggested that this results in an undersampling of controls with low income and in differential mobility between cases and controls for these two studies.

The ORAU Report [Oak Ridge Associated Universities, 1992] reviewed control selection bias first for studies they viewed as most important [Wertheimer and Leeper, 1979; Savitz et al., 1988; London et al., 1991] and then for the others [Fulton et al., 1980; Tomenius, 1986; Coleman et al., 1989; Myers et al., 1990]. The authors argued that the control selection procedure used by Wertheimer and Leeper [1979] was not defined with sufficient clarity for critical evaluation, although they acknowledged it contained no obvious bias. They also noted that, for the Savitz et al. study [Savitz et al., 1988], if exposure were related to residential mobility or the chance of being sampled as a control, control selection bias would have been introduced. The underrepresentation of those of lower socioeconomic status in random digit dialing was raised with reference to the Savitz and London studies [Savitz et al., 1988; London et al., 1991]. They also questioned the representativeness of using friends as controls in the London et al. [1991] study.

For those studies deemed less important, the ORAU report also identified issues of control selection bias. For Fulton, they pointed out that cases had to have residential stability (residence near a specific hospital) while controls did not (residence anywhere in Rhode Island) [Fulton et al., 1980]. Coleman et al. used cancer controls in their study, which may have biased the result downward since brain cancer cases, which are the second most common childhood cancers, were acceptable controls and may have been associated with exposure to magnetic fields [Coleman et al., 1989].

The NRC and NIEHS Working Group reports raised many of the same issues as stated here [National Research Council, 1997; NIEHS Working Group, 1998]. Their conclusions were that, "empirical efforts to characterize the potential bias yielded plausible and testable hypotheses regarding social class, nonresponse and residential stability, but little direct support that the bias actually occurred." In addition, the NIEHS report noted that if higher socioeconomic status was associated with leukemia and random digit dialing was used to select controls, the study was likely to have overestimated risk. Similarly, if controls were more residentially stable than cases, the study may have overestimated risk.

Case Specular Method for Assessing Control Selection Bias

Control selection bias has been cited by many as a possible explanation for the observed association between wire codes, magnetic fields and childhood cancer. While many aspects of this issue have been discussed, as noted above, the data available preclude a convincing assessment. To examine this issue from another perspective, Zaffanella and colleagues developed an innovative approach using existing data and new wire code evaluations of properties near those of the study subjects [Zaffanella et al., 1995, 1998a]. The method was designed to discriminate between two hypotheses: (1) childhood cancer is associated with magnetic fields and wire codes are a surrogate for magnetic fields; and (2) childhood cancer is associated with neighborhood factors other than magnetic fields, such as socioeconomic status or environmental agents such as air pollution, and wire codes are a surrogate for these neighborhood factors. In this method, a control home is defined as a hypothetical (virtual or specular) home directly across the street from each case home. The hypothetical control house is a mirror image of the case house, thus matching on many neighborhood characteristics but not necessarily with the same wire code configuration. The wire codes are assessed for the case and specular homes and a summary measure of effect is calculated. The underlying concept of this method is that if high wire codes are an independent risk factor for cancer, there should be more cases living on streets with higher wire codes, and more cases living on the side of the street where the power lines are located. If, on the other hand, the cancers arise from some other neighborhood risk factor, the wire codes of the case and specular homes should be similar.

There is one major assumption underlying this method, as noted by the authors: that residences on one side of the street are not systematically different from residences on the other side of the street except possibly for wire codes. This assumption is not validated. One commenter [Maclure, 1998] explains that he, "thinks of a city as a mountainous region in which the peaks, valleys and slopes are the levels and gradients of socioeconomic and unknown factors that influence where houses are located and who lives in them. The streets are like rivers with relatively symmetrical banks." Therefore, houses directly across the street from each other, he asserts, are more like each other than houses one or two doors up or down the street. Again, this is an assumption and is not validated.

The case specular method has been applied in conjunction with data from two studies [Zaffanella et al., 1997; Zaffanella et al., 1998b; Ebi et al., 1999]. The results depend on the discordance of the specular pairs, i.e., when the wire code of the residence is different from the wire code of its specular. For the Denver data, the discordance rate was 34% while for the Los Angeles study it was 50%. The results, summarized in Table 3, showed that the odds ratios using the speculars as controls were higher than with the original controls, suggesting that there was not another neighborhood factor, such as socioeconomic status, responsible for the observed associations. Further, the observation that odds ratios increased when specular controls were used instead of random digit dialing controls is consistent with the hypothesis that cases tended to live on streets with higher wire codes.

It is important to note that this analysis did not address this issue of whether there was control selection bias in the data. That bias may still have been present, but this analysis was inconsistent with confounding by a neighborhood factor.

In summary, while various aspects of potential control selection bias have been identified, the series of issues investigated herein have provided little data to support or validate the claim that they were responsible for the observed elevations in odds ratios.

Information Bias

Another type of bias, which I will treat more briefly, is information bias. Information bias occurs when there are errors in the information gathered about study subjects. Errors can be made in two ways: at

TABLE 3. Odds Ratio (95% Confidence Interval) From the Application of the Case Specular Method (HCC vs. LCC)

	Case–control	Case-specular	Case-specular control-specular
Savitz: childhood cancer	1.6 (1.1–2.3)	2.3 (1.3–3.9)	2.4 (0.9–6.1)
London: childhood leukemia	1.5 (1.0–2.2)	1.8 (1.1–3.0)	2.4 (1.2–4.9)

random or preferentially in one group of subjects. If made at random, the errors are termed non-differential, i.e., they do not differ in occurrence between the two groups. These errors dilute any observed effect, giving results that show less of an association between exposure and disease than actually exists. In contrast, errors may occur preferentially between cases and controls or exposed and unexposed subjects. This is called differential misclassification. Bias may cause either weaker or stronger associations to be observed than actually exist, depending on the direction of the misclassification.

For the studies under consideration, there are two main types of information: disease; and exposure. In most cases, disease data have been confirmed histologically and are unlikely to have resulted in such consistent results. Exposure, on the other hand, has been evaluated in several ways and is much more complex.

Exposure Assessment

Our concern in this study is residential exposure assessment. The basic issue with exposure assessment is whether exposure for individual subjects is measured accurately. If not, it is important to know whether the errors are non-differential, i.e., made irrespective of the disease status, or differential. While we cannot assess this directly, we can review the issue in general, noting specific limitations of the methodology used. Note that mention of measurements includes (1) magnetic field measurements, (2) measurements of the distance of the house from the power lines, and (3) calculated fields which are based on distance measurements and measurements of the electrical load on the lines of the power delivery system.

One major limitation of the exposure assessments of the magnetic field and childhood cancer studies is that exposure assessments were limited to the exposures which occurred in the home, with the exception of one study that looked at school exposures [Lin et al., 1994]. Exposures in the home come from several sources: electrical facilities outside the home; wiring to and in the home including current on water pipes, etc.; and electrical appliances, toys, etc. in the home. Based on available evidence, the same source is not dominant in all homes. Use of residential exposure only could result in misclassification. Large facilities outside the house often use large amounts of electrical power and may give rise to greater magnetic fields than typical residential wiring, e.g., feeder lines, elevators, large electrical equipment such as generators and industrial size appliances. Similarly, if children spend substantial amounts of time in daycare, at their parent's workplace, or elsewhere outside the home, exposures may vary greatly.

The second major limitation of the exposure assessments has been to limit estimates to magnetic fields from the electrical power distribution system. Most studies estimated the subject's exposure from external sources by examining proximity of the home to the electrical facility. Because observable markers like number of conductors and gross estimates of their size are very crude indicators of line current and because some important highly-variable parameters, such as net and ground currents have no observable marker, wire codes can only be viewed as a very crude indicator of magnetic field within a nearby home, as demonstrated by the wide dispersion in field levels measured in homes with similar wiring codes [Zaffanella, 1993]. Exposure to appliances and sources outside the house were rarely considered.

A third limitation of the exposure assessments is the lack of consistent data on the relative size and characteristics of estimation errors. Since we lack consistent data on those errors, there is little scientific basis on which to argue the relative merits of measurements and wire codes. One might intuitively expect measurements which quantify fields from all sources, to be a better indicator of overall residential exposure than methods which use crude estimates from only one source. But contemporary short-term measurements offer two more sources of error: the error between the short-term measurement and contemporary long-term average, and the error between contemporary average and the average field at the historical exposure time of interest. We also have no information about the relative size of errors in magnetic field measurements in comparison to distance measurements or line load measurements.

The fourth limitation of the exposure assessments is the other biases in the measurements that are not always apparent. Principally, these biases have involved measurements in the center of the room and measurements in "low power" conditions. Both of these tend to bias exposure estimates toward measurements of fields from exterior sources by avoiding more localized fields from wiring in the floors, walls, and ceilings or fields from appliances that tend to be arranged around the periphery of the room. Not surprisingly, therefore, "low power" center of room measurements correlate with wire codes better than measurements in more realistic locations under more realistic conditions. Similarly, distance measurements, which are used to estimate exposure directly and also in conjunction line load measurements, are based on distance of the line from the house and do not differentiate among the different locations within the dwelling.

The fifth limitation of exposure assessments is that electric and magnetic fields are ubiquitous.

Everyone is exposed to some degree, making it extremely difficult to define a reference or "no exposure" population. This likely results in a downward bias of any measured effect.

Finally, we must note that, in addition to how exposure is measured, the way in which investigators summarize exposure data can lead to bias. That is, when categorizing continuous magnetic field data investigators often make arbitrary decisions about category boundaries, and these boundaries may differ from study to study. This results in cutpoint bias, the use of a non-representative odds ratio due to the choice of exposure classification rule [Wartenberg et al., 1991a, b]. Elsewhere, we have shown that this occurs with magnetic field data and can lead to different interpretations of results [Wartenberg et al., 1993]. One approach to this problem is to use continuous exposure-response models to summarize the relationship [Greenland, 1995]. Short of that, one can strive to use the same or similar cutpoints for consistency. In that way, results of studies using similar cutpoints can be compared directly. But, any categorization of continuous decreases precision and can lead to bias.

In summary, it is important to remember there is no persuasive evidence that one approach to exposure assessment is necessarily better than another. There are some studies in which exposure assessment is carried out poorly and they can be identified. But, there is no basis to maintain that measurements are better than wire codes or vise versa. When reporting results, we should use continuous exposure-response models, when possible, and consistent exposure cutpoints otherwise. Finally, we have no evidence to suggest that errors in exposure assessment are differential. If not, errors will weaken any true association between exposure and disease.

CONCLUSION

This paper reviews the main sources of bias in studies of residential exposure to magnetic fields and childhood cancer. The issues addressed include study design, selection of cases, selection of controls, participation rates, mobility, and exposure assessment. All of these can affect the results of a study. Unfortunately, published data rarely allow readers to evaluate the role of most of these. What is most compelling is when a body of literature includes a wide diversity of designs and methods, so that one can look for consistency to evaluate possible bias. Unfortunately, this is not always the case. For example, this paper reports on 18 studies of childhood leukemia and exposure to magnetic fields, of which only one was not a case–control study. Thus, all the biases associated with case–control studies may be present. The lack of cohort studies is likely due to the rarity of both the disease and the exposure in the general population, making conduct of such a study extremely expensive and statistically under powered. It is fortunate that the studies were conducted in different regions of countries, in different countries, and in different years. Concordance of results from studies showing wide variation in the populations studied suggests only limited bias.

After study design, control selection bias is probably the next biggest concern in these studies. We have limited information on source of controls, mobility of subjects, and participation rates of subjects. While these data do not reveal any striking patterns that suggest strong bias, far more information is needed to be convincing. In addition, a newly developed method to assess possible control selection bias provides data that suggest that if a bias exists it is a bias toward the null.

Concerns over information bias are also important to evaluate. Information bias can occur through errors in disease reporting and exposure measurement. There are few publicly available data to assess this directly. Again, data exist to suggest some small effects, but nothing shows obviously large effects. These may result in some bias, and certainly result in a reduction in precision.

As with any epidemiologic study, the studies of residential magnetic field exposure and childhood cancer have many possible sources of bias. Unfortunately, these are very hard to quantify unless we systematically analyze the data, which generally are not available. While any of these biases could contribute to the size of the reported odds ratios, none is believed to be so substantial that in all of these studies it could be used to explain the results. Rather, each may contribute in a small way to the odds ratio, either increasing or decreasing its value. Since there is such variety in the populations studied and because there is no overriding flaw that encompasses all of them, it seems unlikely that selection bias cannot be the sole explanation for the reported associations between exposure to magnetic fields and childhood cancer incidence.

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APPENDIX: DISCUSSION AT WORKSHOP

Stolwijk noted that worries about bias first appear as the design of a study is developed. It is important to perform a pilot study, especially for a very expensive study, since one can thus identify problems that could be very difficult to fix once the study has begun. He also reminded us that the most important and common study restraints—i.e. those of resources, available population and power, and exposure assessment and distribution of exposure—continue to test the ingenuity of epidemiologists. He concurred with Buffler that these restraints especially plague studies that investigate very low risks, relatively low exposures, or relatively rare diseases. Stolwijk also said that some studies which will be reporting their results soon have their own problems, as well. The British study, for instance, will not have the usual problems due to random-digit dialing, but it will have its own problems due to dissimilarity of the hospital registries employed. On the other hand, researchers find the well developed Swedish registries an enviable resource, but Swedish epidemiologists wish they had a larger population from which to draw subjects.

In general, Stolwijk continued, it is difficult to identify any sources of bias in a study and to analyze the influence of such biases. Usually published studies do not permit outside analysis of the effect of biases, and sometimes the studies do not even discuss possible sources of biases or why they might have appeared in the study. He went on to say that biases occur inevitably because researchers must make tradeoffs in the design stage of a study, even though they know that some of these design choices will produce problems later. It is impossible to meet all the constraints that face researchers and still avoid all possible biases that may appear. Stolwijk also agreed with Wartenberg that one cannot find a study free of all possible sources of bias, but one can luckily find a few studies where a reader can actually assess how strongly biases may have affected the outcome.

Wartenberg added that data sets are normally kept by the principal investigators and that there is no central repository where one can find the data and investigate questions of bias. If one wants to investigate bias in a study, one must contact each investigator and get clearance to obtain the data, an involved and time consuming process.

Bringing up selection bias in particular, Savitz related how in the late 1980s, Louise Brenton presented a very cursory slide of experience with random-digit dialing over the years, and he found that the effectiveness of random-digit dialing has decreased since it was first introduced. This trend, caused mostly by cultural factors, seems to be continuing; unfortunately, we do not have a better technique available for most general populations in the United States. Savitz also said that selection bias probably does really occur and even though we don't know the magnitude of it, it must affect studies in important ways. If researchers systematically miss people who would have a certain wire code classification, he explained, the researchers would inevitably arrive at the wrong conclusions. Savitz added that he was very pessimistic about improving the present methods in the U.S. for selecting cases and controls. For example, if he were to repeat his Denver study, he is not confident that he could find controls that would illuminate the data from the original study.

Wartenberg suggested that using neighborhood controls might reduce selection bias. With advances in geographic information systems, he said, researchers can accurately map the area around a case residence and deduce important information about the population in that area. However, he added, this approach would introduce its own biases, such as over-matching. Langholtz replied that neighborhood controls have worked well in Los Angeles studies for a long time, and epidemiologists in that city have developed a very good system for finding and verifying neighborhood controls. He also said that he believes that researchers should use several different study designs to investigate a possible health risk, each of these studies inevitably having a different set of biases. The researchers can then compare the different studies and their results, informed by what they already know about the biases implicit in the study designs. Then an investigator would feel more comfortable with his or her conclusions if the different studies, with different biases, all yield similar results.

Ebi explained that in order to evaluate the hypothesis that wire codes are associated with a factor confounding the association with leukemia in certain neighborhoods, EPRI sponsored a study using the case-specular method. This method has a variety of assumptions, including the assumption that the distribution of wire codes in the controls and the distribution of wire codes in the speculars for those controls is symmetric. If that assumption is not met, an asymmetry would reveal control selection bias. They found that the control-specular matrices were not symmetric in Denver or LA, and they were clearly not symmetric in opposite ways, although the reason for this remained unclear. Wertheimer related that she did what was essentially a case-specular study for the California EMF Project's adult study of the Denver area sample. By using an actual house, randomly distributed within an eight block region around the case, they avoided the problem of a biased, fictional house.

Neutra noted that the proportion of VHCC in all these studies was down around 3%, a small number. However, when Pearson and Wachtel used a computerized method to wire code a large citywide sample, the proportion of VHCC homes became a little larger, approximately 7%. Neutra wondered if the difference, which is not very large, implies that there was selection bias in these studies, or if the difference is simply within the computer's margin of error. He also argued that in Wertheimer's case the researchers avoided selection bias by selecting controls from birth certificates. Wertheimer corrected this statement, reminding Neutra that in her childhood study they did not use the VHCC classification, so she could not say whether her prevalence of VHCC controls in that study was similar to Savitz's or Pearson's.

Ebi clarified that when GIS methods were used to automatically wire code Denver, the exercise was restricted to neighborhoods that existed when Savitz's study was conducted, and it only included census blocks that actually had children living in them. Furthermore, the case-specular study found a reasonably good correlation between the wire code assigned by direct observation and that assigned by the computer methods, but it did not find an exceptionally high correlation. However, there was one major unresolved issue: the power system had changed in undetermined ways between studies, and the researchers did not know how to account for those changes.

Wertheimer remarked that if distances were measured from the center of the roof in the computerized method, this would result in more VHCCs being found than would be the case if the original Wertheimer and Leeper protocol were used.

Neutra argued that if selection bias in the controls had led to a positive result in the London study, then we should be able to compare Preston-Martin's brain cancer cases to London's controls and find an effect. However, when we make that comparison, we do not find any effect. Similarly, researchers did not find a strong association in LA between mobility and wire code when they used the data reported by Jones.

Tarone expressed his conviction that bias has a greater effect on the quality of a study than does confounding. Because of the increasing difficulty of finding controls, he wondered if investigators are hurting themselves by trying to match too closely on too many things. Perhaps, he said, it would be better to match less closely and stress other things instead. Carpenter responded that there is a consensus that a couple of variables generally need to be matched. Originally, epidemiologists thought that matching successfully controlled for confounding. However, he said, on closer examination, it's not clear that matching does an adequate job. Even when there is confounding in a study, it's never clear whether confounding or bias is the biggest problem.

Savitz observed that geographic matching poses the most difficulties and that researchers have two options. On one hand, they can take all the cases from a given area of a city, such as Denver or Los Angeles, and try to create a random sample of the population by doing their best with RDD. On the other hand, they can change the last few digits of the case's phone number, in which case they are performing a variant of individual matching. Researchers should choose a method depending on how densely phoned the area under consideration is, which in turn affects how tightly matched the subjects will be on other variables. In Denver it appeared that the second approach would keep much of the meaningful variability in the wirecode. Then Savitz noted that in the Denver inner city area a single telephone exchange forms a tighter geographic group than it would in a more remote area, but he still did not think geographic proximity is one of the most important problems he confronted. Carpenter replied that the importance of geographic density depends on the geographical area under study. In some areas of suburban New Jersey, the phone number defines a more homogeneous region than a zip code in the same region. DelPizzo added that as the demographics of an area become more homogeneous, the wire codes become more homogenous as well. If a case is found in a new development, and all the phone numbers in the area have the same initial digits, it is very likely that all the possible controls have underground power as well. Moreover, over the past decade or so, the phone line density has become higher than the phone line density of households, now that many families have more than one line.

Langholtz agreed that we probably do not need close matching as much as we used to think, but he thought we should pay more attention to defining the study base. He wondered how we can begin to better define the demographics of the study base and their origin.

Identification and Characterization of Populations Living Near High-Voltage Transmission Lines: A Pilot Study

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Populations living close to high-voltage transmission lines often have residential magnetic field exposures in excess of 1 μT, and sometimes over 2 μT. Yet, populations studied in most epidemiologic investigations of the association between residential magnetic field exposure and cancer typically have exposures below 1 μT and frequently below 0.5 μT. To improve statistical power and precision, it would be useful to compare high exposure populations with low exposure populations rather than only studying small differences within low exposure populations. Toward this end, we have developed an automated method for identifying populations living near high-voltage transmission lines. These populations likely have more highly exposed individuals than the population at large. The method uses a geographic information system (GIS) to superimpose digitized transmission line locations on U.S. Census block location data and then extract relevant demographic data. Analysis of data from a pilot study of the populations residing within 100 m of a 29-km segment of one 230-kV line in New Jersey shows that when compared to populations in the surrounding census blocks farther than 100 m from this line, those populations close to the line have similar demographics but differ in terms of perceived housing value variables. We believe that the approach we have developed will enable investigators to rapidly identify and characterize populations living near high-voltage transmission lines on a statewide basis for considering the impact of exposures and for public policy and that these populations also can be used for epidemiologic study. *Key words:* electromagnetic fields, geographic information system, high-voltage transmission lines, population identification. *Environ Health Perspect* 101:626–632(1993)

Exposure to electric and magnetic fields has become a major area of research and concern over the past 10–15 years. With the publication by Wertheimer and Leeper of the seminal paper investigating the association between residential exposure to electric and magnetic fields and the incidence of childhood cancers in Denver, Colorado (*1*), there has been an explosion of concern by the press and the public and expanding study by the scientific community (*2*). Studies designed to replicate this seminal study in Denver and elsewhere (*3–10*) have had mixed results, generally finding associations between indicators of magnetic field exposures and cancer more often than not. Overall, in residential studies, elevated magnetic fields but not electric fields have been associated with excess cancer.

A complementary approach used to investigate the association between electric and magnetic fields and cancer has been the study of mortality patterns of workers with high occupational exposure to electric and magnetic fields. The excess rates of leukemia and brain cancer deaths observed in these studies [e.g., Theriault (*11*)] have substantiated concern about exposure to electric and magnetic fields. But because the actual magnitude of electric and magnetic field exposures has not been documented in these occupational studies (exposure estimates for most such studies are based on job titles) and because these workers may be exposed to other hazardous substances while on the job (leading to confounding), these studies are not considered conclusive.

One important observation about the residential studies is that, due to epidemiologic design characteristics, most exposures cited have been fairly low, nearly all below 1 μT (= 10 mG) and most below 0.5 μT (= 5 mG). However, numerous homes have exposures as high as 2 μT or more, and the principal source of this exposure is most often ascribed to proximity to high-voltage transmission lines. Further, prediction of the magnetic fields attributable to proximity to high-voltage transmission lines is far easier and more accurate than prediction of fields generated from other sources.

The goal of this study was to develop methodology to identify populations that are exposed to electric and magnetic fields from overhead high-voltage transmission lines. This will enable us to determine the number of exposed people and characterize their demographic attributes for risk assessment and public policy considerations. In addition, if sufficiently accurate, this method could be used to determine the incremental exposure to electric and magnetic fields that populations incur from high-voltage transmission lines, a possible exposure metric for use in epidemiologic investigations of excess cancer. By focusing on these highly exposed populations, we believe we would increase both the statistical power and precision of epidemiologic investigations.

We know of only two studies that previously attempted to identify and/or characterize populations residing near high-voltage transmission lines. Florig and Morgan (*12*) assessed the density of housing along transmission lines by reviewing aerial photographs. They found that the population density close to the lines was lower than elsewhere in the region and that the difference in density decreased as the distance of the residences from the line increased up to 200 m, the maximum distance they report. Salzberg et al. (*13*), in Melbourne, Australia, investigated the association of ambient magnetic fields with various indices of socioeconomic status. Using an arbitrary sampling grid in which 77% of the sampling locations were under overhead transmission or distribution lines, they found only weak associations between the strength of the magnetic field and specific aspects of socioeconomic status, and none with combined indices of socioeconomic status variables. They concluded that there was no overall association (*13*). While other epidemiologic investigators have considered transmission lines as confounders (i.e., factors associated with both exposure and disease, although not of primary interest), they generally have not analyzed demographic data with respect to these lines (*1,3–10*).

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In Scandinavia, it is possible to identify populations living near high-voltage transmission lines using public records. These records, which are far more detailed and/or accessible than those available in the United States, include cancer registries, population registries (which contain complete residence histories), and utility transmission line databases. Using these data to derive separate exposure estimates based on distance from the transmission line, current magnetic field strength, and reconstructed historical magnetic fields strengths (using historical annual average load data for each year of residence), epidemiologic studies have been conducted in Sweden (*14*), Denmark (*15*), and Finland (*16*). Although these studies evaluated the association of estimated magnetic field exposure with disease incidence, they did not look at indicators of socioeconomic status.

To demonstrate the feasibility of conducting an epidemiologic study in the United States using highly exposed populations, we chose to identify populations living within a few hundred meters of high-voltage transmission lines. To get a sufficient number of such individuals, it may be necessary to include hundreds of miles of such lines. Although high exposure populations could be identified using aerial photographs, it would be extremely time consuming and labor intensive. Our approach is to use a computer-based geographic information system (GIS) to combine independently developed transmission line location data with the most recent (1990) U.S. Census data to identify and characterize such populations. In addition, address ranges can be extracted for record matching with disease registries and for contacting individuals.

To demonstrate our approach, we have undertaken the pilot study reported here. To demonstrate that this approach will generate sufficient number of subjects at the appropriate scale of geographic resolution, a larger study would be needed. We plan to begin such a study to identify all populations living near 230-kV and higher voltage lines in New York State in fall 1993 in cooperation the Empire State Electric Energy Corporation.

Background: Electric and Magnetic Fields and Cancer

In general, measuring and assessing exposure to electric and magnetic fields have been problematic in epidemiologic studies. Growing concern about a relationship between electric and magnetic fields and cancer is driving research to improve exposure assessment. Investigators have estimated residential exposure in a variety of ways, basing exposure on proximity to high-voltage transmission lines, the configuration of electrical wiring outside each residence (i.e., the so-called wire codes), spot measurements of magnetic fields, 24-hr measurements of magnetic fields, and historical reconstruction of cumulative magnetic fields based on line load data. However, the consistency among these measures has been less than desired for epidemiologic studies. The goal of most exposure studies has been to capture relevant aspects of the hourly, daily, seasonal, and secular patterns of variation while accommodating historical changes in electric power delivery. However, because there is no known mechanism of disease causation from exposure to nonionizing radiation, it is not clear what aspects of exposure are biologically relevant. In occupational studies, job titles have been used to classify exposures, which likely results in much imprecision and substantial confounding. Kaune (*17*), in a recent review, notes that there are also many limitations to the spot measurement technique used in some residential studies, including short-term variability, spatial variability, and selection of a metric for time averaging.

One noteworthy observation is that homes near high-voltage transmission lines often receive a substantial but variable portion of their magnetic field exposure from those lines (Table 1). For example, Caola et al. (*18*) measured electric and magnetic fields in three New Jersey homes and found that electric fields produced by the house wiring were similar to those produced by the transmission lines, with shielding of external fields provided by walls without windows, while magnetic fields inside the houses were not affected by the walls (i.e., there was little shielding) and were about 0.25 μT. Maddock et al. (*19*) discuss the magnitude of electric and magnetic fields under high-voltage transmission lines in the United Kingdom and state that for a 400 kV line, electric fields at 25 m from the center line are less than 1 kV/m, whereas magnetic fields at 25 m rarely exceed 10 μT. Stuchly (*20*) reports calculated maximum magnetic fields of 13 μT at the center line for a 230-kV line, 33 μT for a 500-kV line, and 29 μT for a 765-kV line. Residential measurements, she reports, range from typical backgrounds of less than 0.1 μT to levels over 0.5 μT for houses with electric heaters. Levels for homes in Germany were substantially higher (*20*).

Heroux (*21*) investigated ambient, urban electric, and magnetic fields resulting from electric distribution lines between 49 kV and 735 kV and found magnetic fields generally below 1 μT and electric fields generally below 0.3 kV/m. Dlugosz et al. (*22*), reporting magnetic field measurements made at 33 street corners in Buffalo, New York, found flux densities as high as 1.6 μT. Three street corners had transmission lines within 46 m, and these were the three highest mean flux densities (1.08–1.44 μT).

Bracken (*23*) summarized exposures in public access areas by noting that both electric and magnetic field exposures are related to the proximity of transmission and distribution systems and, while generally similar to residential exposures, can be as high as 180 V/m and 10 μT. Commercial buildings, however, likely have different electric shielding properties. Kavet et al. (*24*) studied 45 adult residents in Maine and found that, for the 30 who lived near high-voltage transmission lines, the transmission lines were a significant source of exposure (more than 50% of the total exposure) and that in-home measurements were a reliable index of total exposure ranging from about 0.5 μT to 6 μT.

Proximity to Transmission Lines as an Exposure Metric

As homes with unusually high magnetic fields (e.g., greater than 1 μT) generally are close to high-voltage transmission lines, if there is an association between high magnetic fields and cancer incidence, residents of these homes should be at greatest risk. Yet, only a few epidemiological studies have emphasized the role of transmission lines in elevating exposures.

Table 1. Exposures near high-voltage transmission lines

Source of exposure	Magnetic field (μT)	Electric field (kV/m)	Reference
Homes near transmission lines	0.25		(*18*)
400-kV line			(*19*)
Center line	<40	<5	
25 m	<10	<1	
Center line			(*20*)
230-kV line	13		
500-kV line	33		
765-kV line	29		
Residence	0.1-0.5		
49-kV–735-kV urban line	<1	<0.3	(*21*)
33 Buffalo, NY street corners	<1.6		(*22*)
Residences	<10	<0.18	(*23*)
Homes 79 m–465 m from 345-kV line	0.08–0.58		(*24*)

Myers et al. (*6,7*) studied children living near overhead electric lines in Yorkshire, England, and did not find a significant association between distance of residence from overhead line or calculated magnetic field (based on maximum load during year of birth) and the incidence of childhood cancer. However, critics have pointed out that only 5 out of 962 subjects had exposures above 0.1 μT, suggesting unusually low exposures overall. McDowall (*25*) investigated the mortality experienced by persons living near electric transmission facilities in East Anglia, England, and found lower than expected mortality in the study population, with only female lung cancer being statistically significantly elevated. (The lung cancer observation was hard to interpret because the investigators did not have data on smoking habits.)

Tomenius (*8*), in a case–control study in Sweden, found that those living in proximity (within 150 m) to a 200-kV electric transmission line were at excess risk of cancer [relative risk (RR) of 2.1]. Coleman et al. (*26*) investigated the association between leukemia incidence and proximity to electricity transmission equipment in Southeast England and found elevated but not statistically significant effects (RR of 1.5 for residence within 100 m of an overhead transmission line, RR of 2.0 within 50 m). Johnson et al. (*27*) conducted a spatial analysis of leukemia and brain cancer incidences and transmission line location. Although the disease incidence patterns exhibited a nonrandom pattern, they found no association with transmission line location. Schreiber et al. (*28*) studied the mortality experience of the population living near two 150-kV lines and one transformer substation. They also did not find significant elevations of cancer mortality rates.

Most recently, a series of nested case–control studies has been conducted in Scandinavia. These studies used a variety of exposure metrics including measured distance to transmission lines, measured magnetic fields, and computed exposures attributable to electrical transmission connections and substations based on historical line loads and tower configurations. Feychting and Ahlbom (*14*) conducted a residential study among people living near high-voltage transmission lines. Elevated cancer rates were observed within 300 m of these lines [odds ratios (ORs) generally from 2 to 5 for leukemia for calculated magnetic fields]. When analyzed similarly, these data gave relative risks comparable to those of Savitz et al. (*9*) as reported by Wartenberg and Savitz (*29*). Olsen et al. (*15*) compared exposures of all children diagnosed with leukemia, tumors of the central nervous system, or malignant lymphoma from 1968 to 1986. They found a nonsignificant, elevated relative risk for all cancers studied using an *a priori* cutpoint (OR = 1.5 for cutpoint of 0.25 μT) and a statistically significant excess for a higher, *a posteriori* cutpoint (OR = 5.6 for cutpoint of 0.4 μT). Verkasalo et al. (*16*), studying children living within 500 m of a high-voltage transmission line in Finland, found elevated leukemia, nervous system cancers, and overall cancers, with the rate of nervous system cancers being statistically significantly elevated [standardized incidence ratios = 2.3), especially for gliomas (SIR) = 6.5.

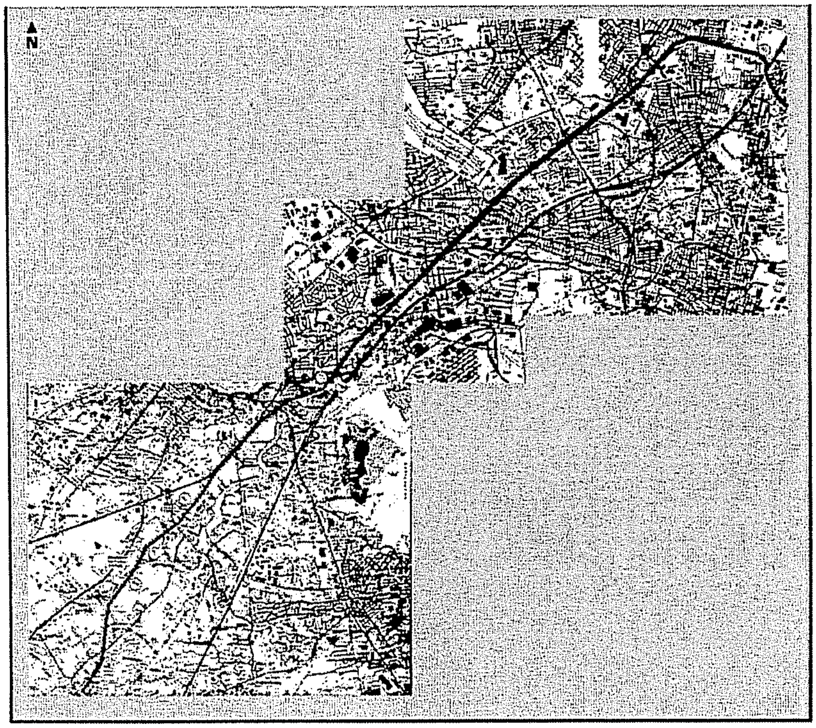

Figure 1. A route map of a 230-kV electric transmission line from Woodbridge, New Jersey to South Brunswick, New Jersey. Note that a USGS quadrangle is used as a base map.

Methods

The basic methodology we used was: 1) select a transmission line, 2) digitize it, 3) superimpose it on the U.S. Census TIGER files, 4) construct a buffer around the line, 5) identify all census blocks contained within or intersecting the buffer, and 6) extract the relevant demographics for these census blocks from the U.S. Census demographic files. We describe this process in more detail below.

To begin our pilot study, we wanted to use a high-voltage transmission line in the vicinity convenient to our research team. After consultation with the local utility, Public Service Electric and Gas, we selected a 29-km segment of a 230-kV line that runs from the Sewaren Switching Station in Woodbridge, New Jersey, to the Deans Switching Station in South Brunswick, New Jersey, circuit S-2219. We note that while this line may not be typical of the United States, it is not atypical of lines in eastern New Jersey, a very densely populated area.

The first step in this procedure was specification of the exact location of each transmission tower. Using a series of maps developed by the utility company (Fig. 1), we digitized the geographic coordinates of each transmission tower in a Universal Transverse Mercator coordinate system and stored the resulting data in a vector digital line graph format.

To locate the line and retrieve demographic data for the populations living near the line, we used the 1990 U.S. Census data. The Census Bureau has released a computerized set of detailed geographic map files known as TIGER (topologically integrated geographic encoding and referencing) files. These files contain details on the physical features and census tract (and block) boundaries for every county in the United States. These data are relatively fine-scaled, particularly in more densely populated areas, and enable researchers to reference these geographic locations to census tract (and block)-level demographic data (*30,31*).

We related the location of the transmission line to the U.S. Census data using the Arc/Info GIS package (Figs. 2 and 3). Then, we specified an arbitrary 100-m buffer zone on either side of the transmission line as the region of concern. The width of this buffer corresponds to a magnetic field exposure of approximately 0.2 μT (See appendix). Some studies have considered even wider buffers [e.g., 200 m (*8*), 300 m (*14*), 500 m (*16*)], but we believed a smaller buffer would provide a more rigorous test of the methodology.

We extracted the block numbers of all intersecting blocks, the total area contained within each census block, and the area of each census block contained within the buffer to enable us to calculate the percentage of each intersecting census block inside the buffer.

To obtain the demographic data for the identified census blocks, we matched the ID numbers for the blocks intersecting or contained within our buffer with the attribute data and extracted the relevant information. For comparison purposes, we also extracted summary data for each town (municipality) in our study. These data were further processed and summarized using our own software.

Results

Overall, we found 201 census blocks that intersected or were contained within a buffer of 100 m on either side of the center line, containing a population of 18,040 individuals and 7,154 housing units. Of these blocks, 21% (42 of 201) had no housing units and hence no population, as reported by the U.S. Census, and 30 blocks had no data reported because the population sizes within these individual blocks were so small that release of block data would have jeopardized individual confidentiality. These blocks represented a total of 2,865 (16%) individuals and 1,161 (16%) housing units. The remaining 129 blocks contain 15,175 individuals and 5,993 housing units. Two of the six towns along the path of the transmission line, New Brunswick and Milltown, did not have any blocks with enumerated populations. They are shown on the figures but omitted from the tables. All further calculations and tabulations in this paper are based on those blocks with fully enumerated data only. The demographics in these blocks were characterized and are summarized in Tables 2 and 3.

Table 2 categorizes the census block data by the proportion of the area of the block contained within the 100-m buffer we defined. The majority of the population identified lives in blocks in which only a small proportion of their area lies within the buffer. It is likely that most of the individuals residing in these blocks live outside the buffer. However, some of the blocks

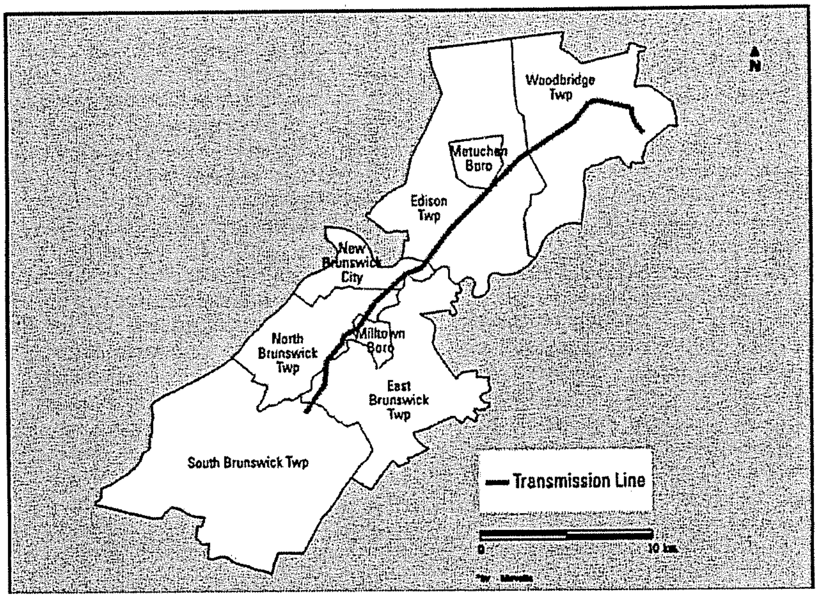

Figure 2. A map of the electric transmission line shown in Figure 1 digitized and superimposed on township boundaries generated using U.S. Census TIGER files.

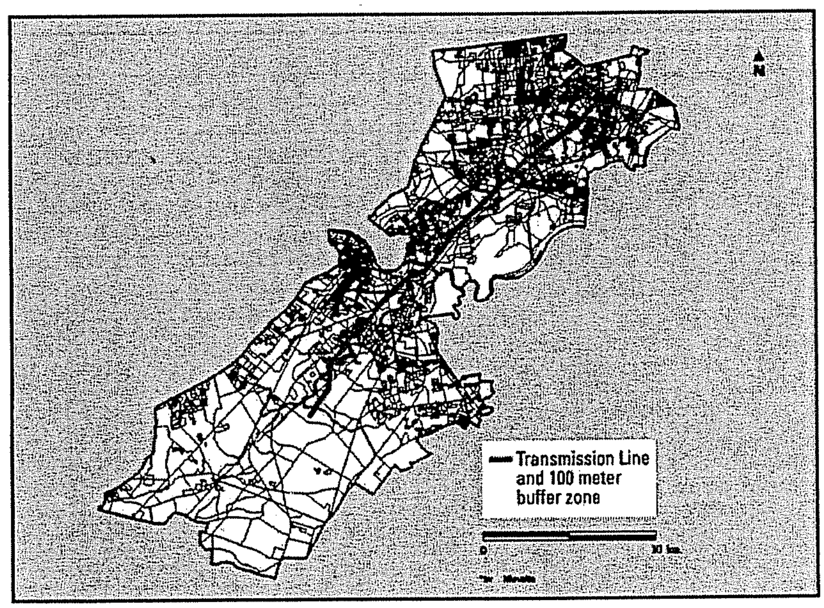

Figure 3. The map and line shown in Figure 1 digitized and superimposed on U.S. Census block boundaries generated from the U.S. Census TIGER files, with a 100-m buffer on either side of the line.

Table 2. Population and housing units with 100-m buffer

% of area of census block[a]	No. of census blocks included (%)	No. of people in census blocks included (%)	No. of houses in census blocks included (%)
100	7 (5.4)	358 (2.4)	183 (3.1)
95	11 (8.5)	530 (3.5)	255 (4.3)
90	12 (9.3)	535 (3.5)	257 (4.3)
70	15 (11.6)	678 (4.5)	311 (5.2)
50	37 (28.7)	2,724 (18.0)	1,128 (18.8)
30	62 (48.1)	6,681 (44.0)	2,977 (49.7)
10	91 (70.5)	11,001 (72.5)	4,447 (74.2)
0[b]	129 (100.0)	15,175 (100.0)	5,993 (100.0)

[a]Within buffer required for inclusion.
[b]All census blocks intersection buffer included.

are wholly contained, or mostly contained, within the buffer. Many of the individuals living in these blocks live within the buffer. Refinement of these data would require field evaluation or analysis of aerial photography to locate individual housing units with respect to the buffer border. We did not undertake such analyses in this study.

Table 3 compares some of the demographic and perceived housing value characteristics of the populations living within the buffer, or near the buffer, with the similar characteristics of the town in which the buffer is contained. In general, demographic values are similar among towns and inside and outside the buffer. For example, for the percentage of the population under age 18, the entire towns show between 19% and 26%, while blocks intersecting or contained within the buffer show between 13% and 25%. Similarly, the percentage of the population over 65 years of age is generally between 6% and 16%, the percent white is generally between 79% and 95%, and the percent black is between 0% and 12%. For these four demographic variables, the average differences among the towns are similar to the average differences between each town and that part of the town contained within the buffer except perhaps for percent white, which shows slightly larger variation within than between towns. Interestingly, the blocks within the buffers tend to have fewer people under 18 years of age, more whites, and fewer blacks.

Variables reflective of perceived housing value, however, differ more greatly within towns than between, as shown by the differences at the bottom of Table 3. Percent owner-occupied varies between 61% and 82% for towns as a whole, while it varies between 60% and 98% for blocks within the buffer. Average housing price varies between \$163,400 and \$204,500 among towns, while it varies between \$127,062 and \$274,979 for blocks within the buffer. Average rent varies between \$644 and \$725 among towns and between \$520 and \$1175 for blocks within the buffer. One association between the variables is noted: if the percent owner-occupied is greater for blocks within the buffer, so is the cost. In general, except for North Brunswick, rents tend to be lower for blocks inside the buffer.

Only one town, Woodbridge, has a sufficient number of blocks nearly wholly contained within the buffer for evaluation (Table 4). They are listed as those blocks with 90% of their area contained within the buffer. The patterns for these blocks are similar to those described above, with more white and fewer black people, and the average rent being even lower than in all the blocks intersected by the buffer.

Discussion

Previous epidemiologic studies of the association between exposure to magnetic fields and the incidence of cancer sought to quantify a relatively small risk for rare diseases. As such, epidemiologists used a case–control design to identify a population of individuals with the disease of concern and a control population and to characterize their exposures. Because the study subjects were selected on the basis of disease status rather than exposure status, their exposures reflected the most common levels of exposure, mainly those below 0.5 μT. Generally, individual studies compared populations whose mean exposures differed by only a few tenths of a microtesla. Taken as a whole, results of these studies are uncertain, show numerous inconsistencies, and conclusions tend to be controversial.

Given the widespread distribution of electrical distribution systems, there is a substantial number of people with exposures markedly higher than 0.5 μT. Although these individuals represent a small proportion of the entire U.S. population, we believe that they are common enough to represent a useful cohort for epidemiologic study. If there is an association between residential exposure to magnetic fields and cancer, and if the dose–response relationship is monotonic, then studies comparing populations with mean exposures that differ by 1–3 μT should have substantially more statistical power and precision than those comparing populations with mean exposures that differ by 0.1–0.5 μT.

Toward this end, we developed a method for identifying and characterizing these highly exposed individuals. We used a computerized procedure so that large regions can be assessed rapidly and easily and so that populations of sufficient size for epidemiologic study can be readily identified.

In our pilot study in New Jersey, we examined the demographics of the populations living near a single high-voltage transmission line in five towns and compared these data to comparable data for each town as a whole. We found that the

Table 3. Population characteristics by town: overall and within 100-m buffer

Township	No. of blocks	Population	Housing units	% under 18	% over 65	% White	% Black	% Owner occupied	Mean cost (\$)	Mean rent (\$)
East Brunswick	—	43,548	15,395	24.0	8.7	88.1	2.2	81.7	203,700	725
Blocks intersecting buffer	10	731	248	24.6	10.7	94.1	0.4	90.3	274,979	535
Edison	—	88,680	32,832	21.7	10.7	79.5	5.6	64.7	204,500	659
Blocks intersecting buffer	50	6,436	2678	19.5	9.4	86.1	4.1	62.7	177,405	588
North Brunswick	—	31,287	12,186	20.4	9.2	80.1	11.1	61.2	199,300	681
Blocks intersecting buffer	15	2,003	369	13.3	6.6	86.9	3.9	97.3	268,968	1175
South Brunswick	—	25,792	9,962	25.2	6.5	84.1	6.2	70.5	201,600	724
Blocks intersecting buffer	1	152	55	20.4	15.1	94.7	0.7	81.8	233,400	520
Woodbridge	—	93,086	34,498	19.3	13.0	86.6	6.5	70.7	163,400	644
Blocks intersecting buffer	53	5,853	2643	18.0	13.4	85.8	4.5	60.4	127,062	602
Mean difference among towns				3.1	3.0	4.7	3.7	9.4	17,320	45
Mean difference between town and buffer				3.2	3.0	6.2	3.6	13.7	47,236	200

Table 4. Population characteristics of Woodbridge: overall and within 100-m buffer

	No. of blocks	Population	% under 18	% over 65	% White	% Black	Housing units	% Owner occupied	% Renter Occupied	Mean cost (\$)	Mean rent (\$)
Town	—	93,086	19.3	13.0	86.6	6.5	34,498	70.7	26.3	163,400	644
Blocks intersecting buffer	53	5,853	18.0	13.4	85.8	4.5	2643	60.4	36.1	127,062	602
Blocks 90% within buffer	9	442	19.5	10.0	96.4	2.9	212	54.3	44.3	146,246	593

population characteristics (e.g., age, ethnicity) did not differ markedly between those close to the lines and those far away, although the perceived housing value variables (e.g., house value, rent, proportion owner-occupied) varied more so. Further, the perceived housing value variables differed not only within a town but also between towns. We note, however, that these observations are likely to be highly unstable due to the very small sample size.

To explain these variations, we visited the area in question. The reasons for the differences, we believe, are town specific. Although the towns are similar in terms of overall demographics and perceived housing value, the areas of the town through which the transmission line runs are different. For example, in one portion of Edison, the line runs along a major local road and borders on a low-income housing project. Thus, it is not surprising that the census blocks within the buffer are more frequently renter occupied and that housing and rental costs are relatively low. In North Brunswick, on the other hand, the transmission line runs through a fairly upscale region, as is reflected in the high owner-occupancy rate and the high rental and housing costs. This suggests that it is probably not possible to generalize about populations that live near high-voltage transmission lines but rather to note that, since all people need electricity, lines run through all towns and through all kinds of neighborhoods.

One interesting observation is that, based on this small and arbitrary sample of data, there is no evidence of environmental disparity with respect to ethnicity or socioeconomic status. That is, in spite of the possible undesirability of proximity to high-voltage transmission lines (for health or aesthetic reasons), we do not see them preferentially located in nonwhite or less affluent regions. Rather, their locations are town dependent. In most of the towns we studied, the populations living closest to the line were more white and had a wider age distribution than the towns that surrounded them. Housing values varied markedly by town, although values within the buffer were lower than the town as a whole more often than not, possibly suggesting a perception of lower value.

Conclusions

Our pilot study had two objectives: to demonstrate the feasibility of identifying populations living near high-voltage transmission lines for epidemiologic study and to characterize these populations. We have shown that we can identify these populations readily using a GIS and the 1990 U.S. Census databases. Although we cannot estimate the distance from the center line for each individual or housing unit, we can provide grouped estimates based on reasonable buffer sizes. Since we assessed the population along only a few miles of a single line in New Jersey and found hundreds of people living within 100 m, we believe that this methodology could be used, at least in New Jersey, to identify a cohort of sufficient size for epidemiologic study. Further, these populations are not different socio-demographically from the rest of the population, making them attractive for epidemiologic study.

In terms of the characteristics of these individuals, our pilot study demonstrates that for a single, arbitrarily chosen 230-kV line in New Jersey, the populations living close to the line have fewer people under age 18, are more white, and have less expensive rents. Housing costs depend more on the communities we examined than on the houses' proximity to the power line. These data support the notion of environmental equity for this potential health hazard in this pilot study area, although further study is warranted.

Appendix

Determining the Magnetic Field Strength at the Edge of the Right-of-Way

To determine the relevance of our arbitrary buffer width, we calculated a sample magnetic field strength at the edge of the buffer. To do so, one needs to know the geometric configuration of the three conductors on the tower, the distance between the conductors, and the current flowing through the line (*17*). Often, along a transmission line, the tower configurations will vary. For these calculations we selected an arbitrary tower to use in our calculations. The three conductors for this line were configured vertically (that is, one was directly above the other, which was directly above the third), and each pair was separated by 21 feet, or 6.4 m (F. Blahuta, personal communication). The normal current load on this line was 953 amps (J. Flynn, personal communication). This is not the maximal load, but rather a typical load used for rough calculations.

To calculate the ambient magnetic field attributable to this line, we used the following formula (*17*):

$$B = \frac{I}{5R^2}\sqrt{\frac{S_{12}^2 + S_{13}^2 + S_{23}^2}{2}}$$

where B is the field's total flux density in microtesla, I is the current in amperes carried by each of the three phase conductors, R is the distance in meters from the line to the point where the field is being calculated, and S_{ij} is the transverse distance in meters between the ith and jth conductors. Therefore,

$$B = \frac{953}{5(100)^2}\sqrt{\frac{(6.4)^2 + (12.8)^2 + (6.4)^2}{2}}$$
$$= 0.21\mu T$$

Thus, the magnetic field attributable to the transmission line at the edge of the buffer was 0.2 μT. At 50 m from the center line, the field would be 0.5 μT. At 25 m from the center line, the field would be 2.1 μT. And, at the center line, the field would be 1315 μT.

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Residential EMF Exposure and Childhood Leukemia: Meta-Analysis and Population Attributable Risk

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The controversy over the possible association between magnetic field exposure and childhood leukemia has led several researchers to summarize the literature using meta-analysis. This paper reviews these previous meta-analyses and extends them by adding results from four studies published since the most recent analysis. The analyses include odds ratio calculations based on both dichotomous and continuous exposure models, heterogeneity analysis including subgroup summaries and meta-regression, "leave one out" influence analyses, and publication bias assessments. In addition, there is a review of some of the considerations of the exposure assessments used in the studies and their implications for cross-study comparisons. Finally, the results of the analyses using dichotomous and continuous exposure model are combined with national exposure data to estimate the population attributable risk of childhood leukemia among children in the US. If an association exists, as many as 175–240 cases of childhood leukemia in the US may be due to magnetic field exposure. Bioelectromagnetics Supplement 5:S86–S104, 2001. © 2001 Wiley-Liss, Inc.

Key words: magnetic fields; meta-regression; EMF; meta-analysis; leukemia

INTRODUCTION

The purpose of a meta-analysis is to provide a systematic, rigorous and quantitative review of a body of literature. In the study of residential exposure to magnetic fields and the occurrence of childhood leukemia, several meta-analyses have been conducted [National Radiological Protection Board, 1992; Ahlbom et al., 1993; Washburn et al., 1994; Miller et al., 1995; Meinert and Michaelis, 1996; National Research Council, 1997; Wartenberg, 1998; Wartenberg et al., 1998]. This paper summarizes and critiques those evaluations, explores the implications of their results for making inferences about the possible association between residential exposure to magnetic fields and childhood leukemia, and predicts the magnitude of the population attributable risk in the United States (US).

What is a Meta-Analysis?

Meta-analysis is a statistical method designed to summarize and simplify a complex set of study results [Greenland, 1987, 1994, 1998; Petitti, 2000]. Typically, original studies are identified systematically from the literature, these studies are evaluated for suitability for summarization, data are extracted from each study in a consistent manner, and these data are subjected to a series of statistical analyses. Meta-analysis differs from other literature summaries in that other efforts typically are less systematic and less comprehensive and, most often, results are not reported quantitatively. To maintain objectivity when conducting a meta-analysis, it is important for investigators to specify *a priori* a set of criteria for acceptable studies. Once studies are selected, a protocol for data extraction must be developed and implemented. Finally, a set of statistical analyses must be chosen. Typically, these include average risk estimation, heterogeneity analysis, influence analysis, and assessment of possible publication bias.

When undertaking a meta-analysis, there are several issues one must grapple with. For example, to conduct the statistical analyses of a set of studies, one must first determine a common exposure metric across which studies can be compared. If not done rigorously, this can lead to concerns about the validity of the analysis. One also must determine the specific statistical methods to be used in analyzing the data. In addition,

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there is much concern over how the heterogeneity is assessed and interpreted and whether the tests for heterogeneity have ample statistical power [Greenland, 1983; Petitti, 2000]. One must determine whether all the studies can be combined together for a single effect estimate or whether one must restrict the analyses to specific subgroups. Another concern when summarizing effects is whether dichotomous or continuous exposure response models are to be used to quantify effect sizes and whether adjustments can be made for confounders and effect modifiers. Following these analyses, one must decide how best to assess their statistical robustness, such as by conducting sensitivity or influence analyses, and how to assess the possible publication bias.

Of all the issues in the application of meta-analysis to observational studies in environmental epidemiology, the largest methodologic controversy is the comparability (and heterogeneity) of studies [Greenland, 1987; Fleiss and Gross, 1991; Dickersin and Berlin, 1992; Colditz et al., 1995; Petitti, 2000]. Comparability can be a function of design, exposure assessment, and/or adjustment for confounders and effect modifiers. The controversy focuses mainly on how one ought to assess heterogeneity, given the low statistical power of traditional methods, and how one ought to describe it [Fleiss, 1981; Greenland, 1983; DerSimonian and Laird 1986; Hardy and Thompson, 1998; Poole and Greenland, 1999; Thompson and Sharp, 1999; Petitti, 2000]. Often, one evaluates whether the data are sufficiently homogeneous to warrant a single analysis or whether one ought to limit the analyses to assessment of homogeneous subgroups. Increasingly, one of the most important goals of meta-analysis has been to try to explain the observed heterogeneity, often through subgroup analyses and related methods [Olkin, 1994; Lau et al., 1997].

Another large issue in meta-analysis is the need to apply regression models (i.e., meta-regression) to assess trend and exposure response, in preference to simple dichotomous models and adjust for confounding and effect modification [Greenland, 1987; Maclure and Greenland, 1992; Greenland and Longnecker, 1992; Berlin et al., 1993]. Limiting analyses to dichotomous exposures can obscure some patterns in the data and limit interpretations.

Below I consider these issues with respect to meta-analyses of residential magnetic field exposure and childhood leukemia.

A Review of Meta-Analyses of Residential EMF Exposure and Childhood Leukemia

As noted above, several meta-analyses have been conducted to assess the association between residential magnetic field exposure and childhood leukemia. Because of the limited number of original epidemiologic studies conducted in this field to date and the close scrutiny the field is under, there is little controversy over the identification of studies potentially eligible for a meta-analysis. The selection of studies to include, however, has varied widely across meta-analyses. I briefly review these meta-analyses, highlighting differences, and report the estimated effect sizes in Table 1.

The first meta-analysis of residential magnetic field exposure and childhood leukemia was presented in a report of the National Radiological Protection Board of the United Kingdom [National Radiological Protection Board, 1992]. In that review, the authors excluded the first residential magnetic field and childhood leukemia study [Wertheimer and Leeper, 1979] from consideration because it was the sentinel study that raised the concern [Enterline, 1985]. They combined results from three other studies [Fulton et al., 1980; Tomenius, 1986; Savitz et al., 1988] in three separate analyses using the alternative exposure metrics of wire codes, distance from electric lines and measured magnetic fields. They found elevated average odds ratios (ORs) for each exposure metric.

In the following year, three studies of residential magnetic field exposure and childhood cancer conducted in Scandinavian were published [Feychting and Ahlbom, 1993; Olsen et al., 1993; Verkasalo et al., 1993]. In these studies, the calculated magnetic field exposures were based on proximity to electric power transmission lines and historical electrical loads on these lines and were based on nationwide cohorts. In a Letter to the Editor, the authors of these studies reported results of a meta-analysis of their three studies. They argued that these studies were more similar to one another than other studies and thus the meta-analysis would be more meaningful if limited to these studies [Ahlbom et al., 1993]. Weighting the results of each study by the inverse of its variance, they found a statistically significant doubling of the leukemia risk.

The next meta-analysis, conducted by Washburn et al. [1994], included several studies either not used or not available for previous meta-analyses [Coleman et al., 1989; Lin and Lu, 1989; London et al., 1991; Lowenthal et al., 1991; Fajardo-Gutierrez et al., 1993; Petridou et al., 1993]. The methodology in this meta-analysis differed from previous residential magnetic field meta-analyses in that individual study results based on different exposure metrics were combined into a single summary estimate of effect, rather than being stratified by exposure metric. Dichotomous cutpoints were developed for each exposure metric to facilitate this. Heterogeneity analyses were con-

TABLE 1. Summary Effect Measures From Meta-Analyses of Residential Magnetic Field Exposure and Childhood Leukemia

Reference* (no. of studies analysed)	Heterogeneity assessment	Publication bias assessment	Influence analysis	Wire codes	Spot measures	Distance	Historical calculations
					Dichotomous exposure		
'92 NRPB (3)	—	—	—	1.4 (1.1–1.8)	1.2 (0.7–2.1)	1.3 (0.7–2.2)	—
'93 Ahlbom et al. (3)	—	—	—	—	—	—	2.1 (1.1–4.1)
94 Washburn et al. (13)	Yes	—	Limited	—	—	~~1.5 (1.1–2.0)~~[c,d]	—
95 Miller et al. (1–4)	—	—	—	1.6 (1.3–2.0)	1.1 (0.7–1.7)	2.1 (1.2–3.7)	2.5 (1.0–6.0)
96 Meinert and Michaelis (13)	—	—	—	1.7 (1.1–2.5)	1.9 (1.1–3.3)	1.3 (0.9–1.9)	—
97 NRC/NAS (11)	Yes	Yes[a]	Yes	1.5 (1.1–2.1)	0.9 (0.5–1.6)	—	—
				~~1.4 (1.0–2.0)~~[d]	1.3 (0.8–2.0)	1.4 (1.1–1.8)	1.6 (1.0–2.7)
					Continuous exposure (increase in RR per 0.1 μT)		
98 Wartenberg et al. (5–11) dichot. (2–4) continuous	Yes[b]	Yes[a]	Yes	2.7 (0.8–8.7) (scored by spot)	1.1 (0.9–1.3)	—	1.2 (0.9–1.5)
				~~1.6 (0.5–4.6)~~[d] (scored by 24 hr)	—	—	—
					Dichotomous exposure		
01 This report (6–13)	Yes[b]	Yes[a]	Yes	~~1.2 (0.9–1.6)~~[d]	1.3 (1.0–1.7)	1.4 (0.7–2.7)	1.3 (0.8–2.0)

[a]Includes fail-safe N and sample size needed calculations.
[b]Includes stratified analyses to identify factors explaining heterogeneity.
[c]A variety of exposure metrics were combined in this summary.
[d]Values with a line through them indicate substantial heterogeneity ($P \leq 0.1$); these relative risks may not be representative.
—Not Reported.
*For full references, see text.

ducted and showed that the studies combined were heterogeneous ($P = 0.02$), although this was attributed largely to one outlier, the study by Wertheimer and Leeper [1979]. Analyses without that single study were moderately homogeneous ($P = 0.14$). To assess exposure response, these authors considered six studies with exposure-response data and compared the dichotomous OR derived when all exposed categories were pooled (OR = 1.2, 95% CI 1.0–1.6) with the dichotomous OR derived using the highest exposure categories reported in each study (OR = 1.4, 95% CI 1.0–2.0). From this they inferred that either there was nondifferential misclassification or that an exposure response relationship existed. They also conducted a series of sensitivity analyses to test all of the decision rules that they used in extracting the relative risk data. These analyses showed that the assumptions had minimal impact on the results. While this was a more comprehensive meta-analysis than the previous ones, disparate exposure metrics were combined and only limited attention was paid to the observed heterogeneity.

Miller and colleagues conducted a subsequent meta-analysis in which they sought, "to examine the methodological variation used in determining EMF exposure... and how this variation affects interpretation of EMF risk" [Miller et al., 1995]. They used a more restricted set of studies than Washburn et al. [1994] for analysis of leukemia risk [Wertheimer and Leeper, 1979; Fulton et al., 1980; Tomenius, 1986; Savitz et al., 1988; Coleman et al., 1989; London et al., 1991; Feychting and Ahlbom, 1993]. Then, rather than pooling results across exposure metrics, as was done by Washburn et al., these investigators conducted four separate analyses, one for each exposure metric (i.e., wire codes, distance, spot measures, calculated index of magnetic field exposure) in a manner analogous to two previous meta-analyses [National Radiological Protection Board, 1992; Ahlbom et al., 1993). This resulted in a small number of studies for each analysis. Specific cutpoints were selected for each exposure metric. Those for wire codes and distance were the same as Washburn et al., while those for magnetic fields differed. The use of subgroup analyses improved the consistency of the exposure metrics and cutpoints across studies but decreased sample size. Notably, analyses using exposure metrics of wire codes, distance, and calculated index all gave statistically significantly elevated ORs, while that using spot measures was slightly but not statistically significantly elevated.

Following this study, Meinert and Michaelis conducted a meta-analysis that was designed specifically, "... to investigate a potential dose-response-like relationship by comparing analyses for different cutoff points of exposure [Meinert and Michaelis, 1996]." They considered the same set of studies as Washburn et al., but excluded from the analyses two studies used by Washburn et al. [Lin and Lu, 1989; Lowenthal et al., 1991] and also excluded one study that they found which had not been identified by Washburn et al. [Lin and Lee, 1994]. They then analysed the data for leukemia, lymphoma, CNS tumors, and all tumors. Analyses using the only random effects method were conducted for all cutpoints for which data were available from at least two different studies, resulting in 26 different ORs. They also found elevated ORs for wire codes, distance and magnetic field strength, with the wire codes and magnetic field strength results both statistically significant. In terms of the trend tests, ORs increased with decreasing distance but the results were not statistically significant, magnetic field strength did not show a monotonic response, and wire codes were available for only one cut-off point. The authors did not address adequately the large heterogeneity among the individual study results.

In 1996, the U.S. National Academy of Sciences (NAS) Committee on the Possible Health Effects of Exposure to Residential Electric and Magnetic Fields released their report which included yet another meta-analysis [National Research Council, 1997], a revised version of which has also been published in the peer-reviewed literature [Wartenberg, 1998]. The explicit goal of that analysis was to determine the role of random error in the possible association between residential magnetic fields and childhood leukemia. This meta-analysis includes all but two of the studies used in Washburn's meta-analysis [Washburn et al., 1994], excluded due to issues of data adequacy, but included all the childhood leukemia studies used by the NRPB [National Radiological Protection Board, 1992], Ahlbom et al. [1993], Miller et al. [1995] and Meinert and Michaelis [1996].

The NAS group conducted a series of subgroup analyses and assessed both publication bias and the influence of individual studies on the summary results. In general, they found only limited to moderate heterogeneity among the studies and found elevated ORs for wire codes, wire codes and distance, calculated fields, and for all studies together when comparing the highest exposure category reported to all others. Spot magnetic field measurements, however, showed a slightly protective OR (i.e., less than 1.0). The influence analysis showed that no single study had a disproportionate effect, and the publication bias analysis indicated that many null studies would have had to have been unpublished to explain the observed results as due to random fluctuations.

When the meta-analysis included four additional studies that were published while the peer-reviewed version of the study was in process [Linet et al., 1997; Petridou et al., 1997; Tynes and Haldorsen, 1997; Michaelis et al., 1997a], only minor fluctuations in the summary ORs were found [Wartenberg, 1998]. A further analysis showed that these summary results would be changed further only if an extremely large study (several hundred to several thousand subjects, depending on exposure subgroup) reported strong negative (protective) results.

Finally, as part of its review of the EMF RAPID program for a report to the US Congress, the National Institute of Environmental Health Sciences (NIEHS) commissioned one more meta-analysis [Wartenberg et al., 1998]. This meta-analysis identified 22 studies of magnetic field exposure and childhood cancer, but excluded seven for inadequate data or design. The analyses were based on all the studies cited in the previous meta-analysis [Wartenberg, 1998] but more consideration was given to the comparability of exposures across studies, and individual study exposure-response analyses were used for the first time in a meta-analysis of exposure to magnetic fields. Efforts were made to isolate sources of heterogeneity by subgroup analysis, but no consistent pattern was detected. When exposure was dichotomized, the ORs for each exposure metric showed an elevated OR, with ORs for wire codes, calculated and measured fields combined, and proximity to electrical facilities showing statistically significant effects. The results for the dose-response analyses also showed all elevated ORs, although none were statistically significant (unless one used the fixed effects OR).

DATA AND METHODS

Since the completion of the meta-analysis conducted for NIEHS, [Wartenberg et al., 1998] four additional case-control studies of childhood leukemia have been published [Dockerty et al., 1998; McBride et al., 1999; UK Childhood Cancer Study Investigators, 1999, Dockerty et al., 1999; Green et al., 1999a, 1999b]. In this study, I extend the NIEHS meta-analysis to include these four new studies and conduct some additional analyses.

Selection of Studies

To conduct this meta-analysis, I identified all studies assessing the possible association between childhood leukemia and residential exposure to magnetic fields. Using the previous meta-analyses, I identified 22 studies. To this, I added the four most recent studies. My criteria for inclusion were that each study reported an effect measure for the possible association of childhood leukemia with residential exposure to magnetic fields and provided data on the exposure measure used. I reviewed each study to determine whether they met these criteria. From 26 studies originally identified, seven were omitted for the following reasons:

Coghill and Steward [1996]	Data on magnetic fields not presented
Li et al. [1998]	Exposure assessment based on community proximity to lines rather than subjects' proximity to lines
Lin and Lee [1994]	Exposure related to school rather than residence
Lowenthal et al. [1991]	No data on controls; no summary effect estimate
McDowall [1986]	Children not identified separately
Michaelis et al. [1997b]	Partial data only (these data are also reported by Michaelis et al. [1997a], which is included in the meta-analysis)
Schreiber et al. [1993]	Children not identified separately

The 19 studies included in the meta-analysis are listed in Tables 2 and 3.

Exposure Assessment

Different investigators studying the possible association between exposure to electric and magnetic fields and childhood cancer defined a variety of methods of exposure classification. In some instances, ostensibly similar modes of classification (e.g., wire codes in Denver and Los Angeles) may not be truly comparable, and in other instances, ostensibly dissimilar modes of classification (e.g., wire codes in Denver and proximity to transmission lines in England) may be comparable. After careful review, I focus on four exposures metrics: (1) calculated historical transmission line fields; (2) measured magnetic fields; (3) wire codes; (4) proximity to electrical facilities.

Calculated historical transmission line fields. Six studies used some form of calculated historical magnetic field exposures. A small number of children live close to high-vohage transmission lines, experiencing unusually high residential exposure—high enough to overshadow exposures from other sources. One can calculate with reasonable accuracy the field levels near the lines and can develop cumulative exposure estimates using historical line load data. This approach is accurate mainly for high voltage transmission lines (e.g., 230 kV) and not for lower voltage subtransmission and distribution lines. The main limitation of this metric is that few children live near such lines. Feychting and Ahlbom [1993], Olsen et al. [1993], Verkasalo et al. [1993], and Tynes and Haldorsen [1997] used this approach in similar electric power distribution systems in Scandinavia so that their estimates should be comparable. All four calculated historical time-weighted-average (TWA) field levels, although the specific cutpoints used for the epidemiologic analyses differed and the period over which the TWA was estimated varied. Generally, cutpoints closest to 0.2 μT were used in this meta-analysis.

Myers et al. [1990] used a similar approach to estimate exposure in England but summarized the data in terms of the child's calculated peak exposure over a several year period. Since peak loads are typically 1.5–4 times the annual average load, these exposure values based on peak loads were divided by 3 for comparability with other values based on average load.

The UK Childhood Cancer Study Investigators [1999, 2000] used a complicated set of measurements and calculations, including distances to circuits and line loads to determine the estimated arithmetic mean EMF exposure in the year preceding date of diagnosis. EMF exposure information was gathered from measurements at each child's home, measurements made at the child's school or other institution, a parental questionnaire on appliances in the home, the proximity and type of overhead power line nearby, and electrical company data on historical line loads and operating characteristics. These data were combined into a time-averaged estimate of the magnetic flux density. Again, a cutpoint of 0.2 μT was used for analyses in this meta-analysis.

Measured magnetic fields. Nine studies reported spot (or point-in-time) measurements [Tomenius, 1986; Savitz et al., 1988; Feychting and Ahlbom, 1993; Green et al., 1999a, b], 24- or 48-hour field measurements [Linet et al., 1997; Dockerty et al., 1998, 1999; McBride et al., 1999], both spot and 24- or 48-hour field measurements [London et al., 1991; Michaelis et al., 1997a], and two studies used personal monitors on children [McBride et al., 1999; Green et al., 1999a]. Personal monitors provide the most comprehensive assessment of a child's exposure, including for the first time measuring exposures outside the home. However, because these were available for only two studies, these data were not used in the meta-analysis. Next best are the 24- or 48-hour measurements, which can be used to average out diurnal variations and the increase in classification accuracy of 24- or 48-hour measurements over spot measurements. However, this difference is probably small compared to the assumed errors associated in relating either type of relatively short-term measurement to long-term average exposure sometime in the past. Given the limited number of measurement comparability studies, the likely similarity of these metrics to one another relative to the other metrics, and the limited number of studies, I do not separate the 24- or 48-hour measurements from the spot measures.

Again, the cutpoints used in the analyses in the different studies vary. Some studies report data based on cutpoints selected *a priori*, others selected the cutpoints *post hoc*, and some studies reported data for both. Results using *a priori* cutpoints likely have less opportunity for bias. Unfortunately, investigators often do not state how they have chosen their cutpoints. I give preference to 24- or 48-hour measurements over spot measures when both are available. The values used for the meta-analysis were the exposures closest to 0.2 μT.

Wire codes. Wire codes reflect a set of assessments designed to categorize likely magnetic field exposure based on the size of the electric power lines outside a residence, as a proxy for electrical load on the lines, and the distance these lines are from the residence. The original Wertheimer-Leeper wire code and its various derivatives are based on very basic principles of engineering and common sense. The original 2-level code and subsequent 4-level code developed by Wertheimer and Leeper for their childhood [Wertheimer and Leeper, 1979] and adult cancer [Wertheimer and Leeper, 1982] studies, respectively, were developed for use in the Denver metropolitan area. These same wire codes were used by Savitz et al., in their subsequent study of this issue in Denver [Savitz et al., 1988], and these wire codes also have been used in other US residential exposure studies, even though some data suggest that there is substantial geographic variation in the magnetic fields in particular wire code classes (see below).

Fulton et al. [1980] modified the Wertheimer-Leeper wire code for Rhode Island, using a data-based approach. They divided the "exposure" levels of control subjects into quartiles resulting in very low, low, high, or very high exposure categories. Because Fulton's method uses the same fundamental basis as the Wertheimer-Leeper, both systems should give similar ranking of exposures although exposure class boundaries differ. To combine Fulton's data with

Wertheimer's 2-level code data, I aggregate Fulton's three lowest categories (very low, low, and high) (75% of control homes) to compare to Wertheimer's LCC (78% of control homes) while comparing Fulton's "very high" category (25% of control homes) with Wertheimer's HCC category (22% of control homes).

The analyses reported by Petridou et al. [1997] used an "adapted wire code" that is based on basic electrical engineering principles for a different distribution system. These exposure data likely differ substantially from US wire code studies and should not be used in the same analyses without adjustment. Specifically, Petridou's categories 4 and 5 were compared to the VHCC and OHCC categories of Wertheimer and Leeper's wire codes.

The wire codes used in the Linet study [Linet et al., 1997] spanned nine states in the US and thus raised questions of internal as well as external comparability. For example, while Savitz et al. [1988] reported 60% of the VHCC homes in Denver had low power spot magnetic field measurements over 0.2 µT, the corresponding figure from [Linet et al., 1997; Tarone et al., 1997] only found 40%. This could, in part, reflect urban/rural differences [Zaffanella, 1993]. In the Linet study, which reported results for eight states, there was substantial geographic variation [Tarone et al., 1997]. Twenty four hour average magnetic field measurements in each state for VHCC homes differed by over 300%, ranging from 0.082 µT to 0.267 µT. Further, for some states, 24-hour average magnetic field measurements did not increase consistently across wire code categories. In short, wire coding protocols applied to different geographic regions may provide a useful rank ordering of exposure within each region but they do not necessarily correspond to similar magnetic field levels between regions.

Both McBride et al. [1999] and Green et al. [1999a, 1999b] used wire codes based on the Wertheimer-Leeper method. The exposure cutpoint used in this meta-analysis was VHCC and OHCC versus OLCC, VLCC, and UG.

Proximity to electrical facilities. Proximity to electrical facilities in general is an indicator of magnetic field exposure, albeit very imprecise. A distance metric was used by Feychting and Ahlbom [1993], Tynes and Haldorsen [1997], Myers et al. [1990], Coleman et al. [1989], and Fajardo-Gutierrez et al. [1993]. There is greater uncertainty in comparing proximity to different types of electrical facilities than to similar types. To combine all studies reporting proximity data, I used a distance cut point of 15–20 m for distribution lines and transformers, and 50 m for transmission lines and substations. Although wire codes are based on both distance from and type of distribution line, distance captures a large proportion of the information. To pool wire code studies with the cruder proximity studies, I included VHCC and OHCC (or HCC in the 2-level code) homes with homes within 20 m of distribution systems or 50 m of transmission systems and included OLCC, VLCC, and underground (or LCC) homes with those outside the above cut points.

Exposure Summary

There are many combinations of studies, exposure metrics, and cutpoints that could have been examined in this meta-analysis. I believe that the ones I have chosen are most valid because they were selected from an independent assessment of the exposure methodology. For measurement-based analyses, I used calculated fields over measured fields, and 24- or 48-hour measurements over spot measurements (Table 2). For proximity-based analyses, I used wire codes in preference to distance (Table 3). For consistency, for each exposure metric I selected exposure cutpoints that I believe are as close as possible to each other. For proximity to electrical facilities including wire codes, cutpoints used were VHCC + OHCC, 50 m from transmission lines and 25 m from other lines as noted in Table 2. For calculated and measured fields, cutpoints closed to 0.2 were used, as noted in Table 3.

Statistical Methods

Traditional methods for meta-analysis are used in this study [Petitti, 2000]. Calculated results include the combined effects measures, heterogeneity, influence analysis, and publication bias.

Combined effect measures and heterogeneity analysis. Meta-analysis summary statistics that incorporate the individual effect sizes use either of two statistical models: (1) fixed effects and (2) random effects. The fixed-effects model assumes that the observed ORs of the studies included are estimates of the underlying population ORs. Within-study precision (i.e., an overall treatment effect) is assessed by weighing individual study results by the inverse of the variance. The random-effects model assumes that the observed ORs are a random sample from the statistical distribution of the population ORs. An assumption of the model is that there is a sampling effect and there are differences in the true underlying ORs for each study [DerSimonian and Laird, 1986].

Model choice may be based on results of the Chi-squared (or Q-test) for homogeneity that assesses constancy of treatment effects [DerSimonian and Laird, 1986]. If the test does not reject the null hypothesis of homogeneity, then the fixed effects model is valid. If

TABLE 2. Meta-Analysis and Individual Study Results for Studies of Calculated and Measured Magnetic Fields Exposure and Childhood Leukemia*

Study*	Exposure definitions	Exposed cases	Exposed controls	Unexposed cases	Unexposed controls	Individual odds ratio	$OR_{fixed\ effects}$	$Pr(Q_{HOMOG})$	$OR_{random\ effects}$
All combined		241	298	3697	6000	1.31 (1.09–1.59)	1.32 (1.09–1.59)	0.29	1.34 (1.07–1.67)
Tomenius	0.3 μT spot	4	10	239	202	0.34 (0.10–1.09)	1.37 (1.13–1.65)	0.62	1.37 (1.13–1.65)
Myers	0.03 μT peak	6	6	174	271	1.56 (0.49–4.91)	1.31 (1.08–1.59)	0.23	1.34 (1.06–1.70)
Savitz	0.2 μT spot	5	16	31	191	1.93 (0.66–5.63)	1.33 (1.04–1.71)	0.13	1.38 (0.94–2.01)
London	0.27 μT 24 h	20	11	144	133	1.68 (0.78–3.64)	1.33 (1.03–1.71)	0.12	1.38 (0.93–2.06)
Feychting	0.2 μT calculated	7	46	31	508	2.49 (1.04–5.98)	1.29 (1.00–1.66)	0.20	1.32 (0.93–1.89)
Olsen	0.25 μT calculated	3	4	830	1662	1.50 (0.34–6.73)	1.36 (1.06–1.73)	0.11	1.41 (0.97–2.06)
Verkasalo	0.20 μT calculated	3	1.93	—	—	1.55 (0.29–3.81)	1.24 (1.05–1.73)	0.12	1.40 (0.95–2.08)
Linet	0.2 μT 24 h	83	70	541	545	1.19 (0.85–1.68)	1.55 (1.10–2.20)	0.16	1.49 (0.96–2.30)
Tynes	0.14 μT calculated TWA	1	14	147	565	0.27 (0.04–2.10)	1.39 (1.09–1.78)	0.23	1.47 (1.06–2.04)
Michaelis	0.2 μT 24 h	9	8	167	406	2.74 (1.04–7.21)	1.30 (1.01–1.67)	0.21	1.32 (0.93–1.88)
McBride	0.2 μT calculated	49	42	248	287	1.35 (0.86–2.11)	1.31 (1.07–1.62)	0.23	1.35 (1.04–1.75)
Dockerty	0.2 μT 24-hour interior average	5	2	35	38	2.71 (0.49–14.9)	1.31 (1.08–1.58)	0.27	1.33 (1.06–1.66)
Green	0.15 μT interior average	25	44	58	142	1.39 (0.78–2.48)	1.31 (1.07–1.60)	0.23	1.34 (1.04–1.73)
UK	0.2 μT calculated	21	23	1052	1050	0.96 (0.50–1.66)	1.37 (1.13–1.68)	0.32	1.40 (1.11–1.76)

Sample size needed to balance observed results = 8900.
Fail Safe $N = 23.72$.
*For full references, see text.

TABLE 3. Meta-Analysis and Individual Study Results for Studies of Proximity to Electrical Facilities and Childhood Leukemia

Study*	Exposure definition	Exposed cases	Exposed controls	Unexposed cases	Unexposed controls	Individual odds ratio	$OR_{fixed\ effects}$	$Pr(Q_{HOMOG})$	$OR_{random\ effects}$
All combined		527	610	1535	2906	1.64 (1.43–1.87)	1.18 (1.02–1.37)	0.03	1.24 (0.99–1.56)
Wertheimer	VHCC + OHCC birth address	52	29	84	107	2.28 (1.34–3.91)	1.12 (0.97–1.31)	0.13	1.15 (0.94–1.42)
Savitz	VHCC + OHCC	27	52	70	207	1.54 (0.90–2.63)	1.16 (1.00–1.35)	0.03	1.22 (0.95–1.55)
London	VHCC + OHCC	122	92	89	113	1.68 (1.14–2.48)	1.12 (0.95–1.31)	0.06	1.19 (0.93–1.50)
Linet	VHCC + OHCC	111	113	291	289	0.98 (0.72–1.33)	1.25 (1.06–1.48)	0.04	1.29 (1.00–1.67)
McBride	VHCC + OHCC	122	128	229	234	0.97 (0.72–1.32)	1.25 (1.06–1.48)	0.04	1.29 (1.00–1.67)
Green	VHCC + OHCC	12	25	67	100	0.72 (0.34–1.52)	1.21 (1.04–1.40)	0.03	1.28 (1.02–1.62)
Fulton	VHCC	42	56	131	169	0.95 (0.60–1.50)	1.21 (1.04–1.41)	0.03	1.28 (1.00–1.65)
Feychting	50 m transmission	6	34	32	520	2.87 (1.12–7.33)	1.16 (1.00–1.34)	0.06	1.19 (0.96–1.48)
Tynes	51 m transmission	9	55	139	524	0.62 (0.30–1.28)	1.22 (1.05–1.41)	0.05	1.29 (1.00–1.67)
Fajardo	20 m distribution	3	2	43	47	1.64 (0.26–10.29)	1.18 (1.02–1.37)	0.02	1.24 (0.98–1.56)
Coleman	25 m substation	3	3	81	138	1.70 (0.34–8.64)	1.18 (1.02–1.37)	0.02	1.23 (0.98–1.56)
Petridou	Categories 4,5	11	14	106	188	1.39 (0.61–3.18)	1.18 (1.02–1.37)	0.02	1.23 (0.97–1.57)
Myers	25 m	7	7	173	270	1.56 (0.54–4.53)	1.18 (1.02–1.37)	0.02	1.23 (0.97–1.56)

Sample size needed to balance observed results = 4483.
Fail Safe $N = 20.14$.
*For full reference, see text.

the test is statistically significant, homogeneity is rejected, heterogeneity is detected and the random effects model may be useful. However, often the random effects estimate does not make adequate adjustments for the heterogeneity and other methods may be need [Poole and Greenland, 1999]. To assess heterogeneity using the homogeneity test, investigators often use a cutpoint for the P-value as large as 0.2 because of the low power of the test and the typically small numbers of studies available for meta-analyses.

I also conducted meta-analyses of dose-response trends for each exposure metric for which two or more studies reported results for childhood leukemia in at least three exposure categories [Berlin et al., 1993]. First, a dose-response function was estimated within each study by weighted linear regression. The dependent variable was the natural logarithm of the relative risk estimate for each exposure category. The independent variable was a score assigned to each exposure category. The weights were inversely proportional to the estimated variances of the logarithmically transformed relative risk estimates. For categories of magnetic field other than the lowest and highest, I used the midrange as the exposure score. For the lowest category, the score was 0.7 times the upper category boundary. For the highest category, the score was 1.3 times the lower category boundary.

I next conducted a test of the homogeneity of the estimated dose-response functions from the separate studies. Finally, as indicated, I combined the study specific results into summary estimates by computing inverse-variance weighted averages with random effects. The results from both the study-specific analyses and the meta-analytic summaries are expressed as the estimated relative risk for a 0.1 μT increase in estimated exposure.

Influence analysis. Influence analysis was conducted for the dichotomous results by recalculating summary indices for a set of studies leaving out one study at a time, and doing so for each study. The difference between the average risk and the average risk with one study omitted indicates the influence of the omitted study on the overall average risk and enables the researcher to determine whether any of the studies has a dominant effect on the average risk [Olkin, 1994].

Publication bias. Publication bias is the differential publication of studies based on their results. The underlying concern is that there may be many studies showing no association (i.e., null studies) that investigators are not sufficiently motivated to publish, resulting in an upward bias in the average risk of published studies. One method for investigating possible publication bias is to combine z-scores of individual published studies to assess the sensitivity of the results to possibly unpublished null studies. This enables the investigator to determine the number of additional null unpublished studies needed to reduce an observed statistically significant combined effect to non-significance, the so-called Fail Safe N [Cooper, 1979; Rosenthal, 1979].

For an alternative means of assessing publication bias, one can assess how large a study would be required to balance the average of reported result if they were due to random fluctuations. To do so, one can calculate the size of a single hypothetical study that would be needed to give a null average risk across all studies (i.e., an OR of 1.0), if that hypothetical study had equal numbers of cases and controls, had an exposure prevalence equal to that observed in reported studies, and had an OR equal to the reciprocal of the reported average. Unlike the Fail Safe N, this calculation uses the size of the effect measure, weights each study result by the inverse of its variance, hypothesizes a study with a protective rather than null effect (a plausible result if the observed effects are due to random variation), and seeks a null rather than non-significant combined effect.

Investigation of heterogeneity. One goal of a meta-analysis is to see if characteristics of studies are related to their results, particularly if testing shows substantial heterogeneity. The characteristics may pertain to aspects of study design and conduct, the nature of the exposures, or population characteristics. When the number of studies is small and their characteristics are highly correlated, as in these analyses, the utility of stratification is somewhat limited.

In Tables 4 and 5, I report possible sources of heterogeneity separately for two groups of studies listed in Tables 2 and 3. For each of six characteristics (study design, country in which studies was conducted, year of publication, exposure metric, maximum age of subjects, and method of control selection), I divide the studies into two groups and compute for each group the random-effects OR and the P-value for the Q-test for homogeneity [Olkin, 1994; Lau et al., 1997]. If the ORs differ and each subgroup is homogeneous, then this characterization, in part, appears to explain the overall heterogeneity.

I also investigate the six characteristics simultaneously using meta-regression separately for proximity metrics and measurement characteristics. To do so, I define a binary design matrix for each of the six characteristics. Then, I regress the logarithm of the OR on the design matrix, weighing by the inverse of the variance of the logarithm of the OR. The resulting beta

TABLE 4. Stratification by Study Characteristics of Results for Measured and Calculated Magnetic Fields

Characteristic	Homogeneity	Odds ratio	Homogeneity	Odds ratio
All studies	0.3	1.34 (1.07–1.67)	—	—
	Case-control (11)		Cohort/Nested case control (3)	
Study design	0.2	1.27 (0.99–1.64)	0.7	1.90 (1.07–3.39)
	US (3)		Other (11)	
Country	0.6	1.30 (0.97–1.76)	0.2	1.36 (0.97–1.83)
	1993 and before (7)		After 1993 (7)	
Year of publication	0.3	1.48 (0.96–2.30)	0.3	1.27 (0.99–1.62)
	Measured (7)		Calculated (5)	
Magnetic field strength	0.2	1.39 (0.96–2.00)	0.4	1.31 (0.98–1.76)
	≤ 14 (11)		>14 (3)	
Maximum age of subjects	0.6	1.32 (1.08–1.61)	<0.1	1.17 (0.40–3.42)
	Random digit dialing (4)		Population-based data (10)	
Control selection	0.8	1.32 (1.01–1.72)	0.1	1.32 (0.96–1.93)

Number in parenthesis indicates number of studies in each group out of the 14 total studies considered.

coefficients are the logarithms of the ORs for the design variables and reflect their relative importance.

Estimating the population attributable risk. To determine the possible impact of the observed risk to US population, it is possible to conduct a quantitative risk assessment by calculating the population attributable risk and annual number of cases expected. This is done by combining the average study risk with the prevalence of exposure [Rothman and Greenland, 1998]. Using the random-effects OR, I calculate the attributable risk (or attributable fraction) as (OR-1)/OR. Then, by multiplying this number by the prevalence of exposure among children in the US, I estimate the population attributable risk, or the proportion of the total number of cases observed that might be due to EMF exposure and the number of cases expected annually in the US [Wartenberg, 1999].

RESULTS

Results for Dichotomous Exposure Classifications

Individual study and meta-analysis results using the exposure proximity and measurement calculation classifications described above are presented in Tables 2 and 3, Figures 1 and 2, respectively, and summarized in Table 11. In Tables 2 and 3, the first line of the table presents totals for all studies

TABLE 5. Stratification by Study Characteristics of Results for Proximity to Electrical Facilities

Characteristic	Homogeneity	Odds ratio	Homogeneity	Odds ratio
All studies	< 0.1	1.24 (0.99–1.56)	—	—
	Case–control (11)		Cohort/nested case control (2)	
Study design	0.1	1.24 (1.00–1.54)	—	1.10 (0.62–1.96)
	US (5)		Other (8)	
Country	< 0.1	1.37 (0.98–1.90)	0.2	1.09 (0.79–1.50)
	1993 and before (8)		After 1993 (5)	
Year of publication	0.3	1.59 (1.24–2.04)	0.6	0.94 (0.78–1.15)
	Wire codes (8)		Distance (5)	
Proximity metric	< 0.1	1.22 (0.96–1.56)	0.1	1.39 (0.71–2.70)
	≤ 14 (8)		>14 (4)	
Maximum age of subjects	0.1	1.12 (0.88–1.41)	< 0.1	1.71 (0.93–3.13)
	Random digit dialing (4)		Population-based data(9)	
Control selection	0.1	1.21 (0.84–1.71)	0.1	1.28 (0.92–1.78)

Number in parenthesis indicates number of studies in each group out of the 13 total studies considered.

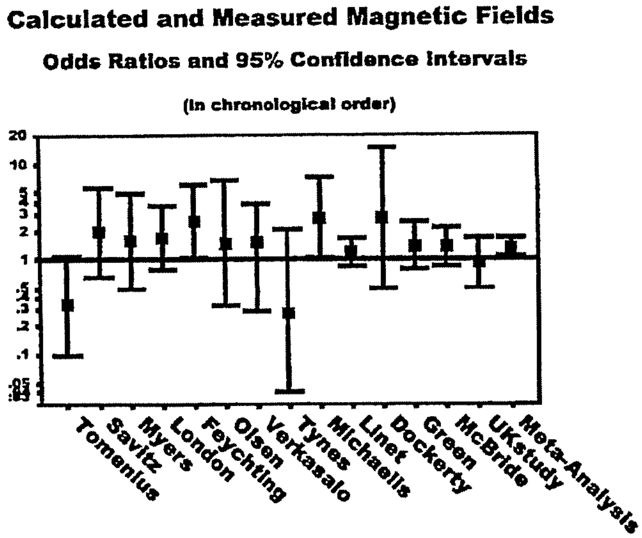

Fig. 1. Calculated and measured magnetic fields.

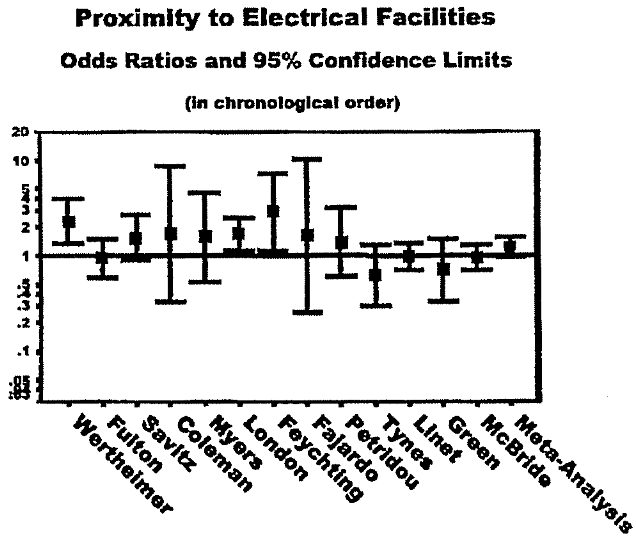

Fig. 2. Proximity to electrical facilities.

combined. That is, it shows the number of subjects, the crude OR for all studies pooled and the fixed-effects and random-effects estimates for all studies combined as well as the *P*-value for the Q-test for homogeneity.

Table 2 and Figure 1 present results for calculated and measured magnetic fields. The first line of the table shows the total number of subjects by disease and exposure status, the combined fixed- and random-effects ORs and the *P*-value for the Q-test for homogeneity. The combined OR is elevated and statistically significant (1.3, 95% CI 1.1–1.6), and the studies are homogeneous ($P = 0.4$). Each subsequent line of the table presents name of the primary study author the exposure metric and cutpoint, the number of subjects and study specific OR. Then, for the fixed effects, random effects and Q-test columns, the combined results are for all of the studies except the study named in that row (the leave one out statistics). Overall, the most influential study is the Linet study [Linet et al., 1997], which reduces the average OR by about 10%. Publication bias is unlikely given a Fail Safe *N*, the number of additional null studies needed to result in a nonstatistically significant average risk, that is greater than 23 and a needed sample size of 8900. A stronger effect is seen for the calculated magnetic field data than the measured magnetic field data only (detailed results not shown; some results are reported in Table 11).

For proximity to electrical facilities, in Table 3 and Figure 2, using the random effects model I found an elevated but not statistically significant OR (1.2, 95% CI 1.0–1.6) and moderate to strong heterogeneity ($P = 0.03$). Due to the heterogeneity, the average risk is not an adequate representation of the studies. Removal of the Wertheimer and Leeper study [1979], line 2 in Table 3, increases the homogeneity by the greatest amount, but the *P*-value is still only 0.13 and the OR decreases by less than 10%. Overall, these results were not sensitive to deletion of individual studies.

Publication bias seems unlikely, as shown by a Fail Safe *N* of greater than 20 and a needed sample size to negate the findings of over 4400 subjects. Results using only wire code data were similar (detailed results not shown) as were those for distance only (detailed results not shown).

Investigation of Heterogeneity by Stratification

Results of the heterogeneity analyses are reported for those using calculated and measures fields (Table 4) and for proximity to electrical facilities (Table 5). Studies with calculated and measured magnetic fields considered as a single group and unstratified show limited evidence of heterogeneity ($P = 0.3$). Only study design shows differences in the ORs between the two strata of at least 20%. For study design, one group is made up of the studies that are cohort or nested case control designs, that are Scandinavian studies, that use calculated rather than measured magnetic fields, that are similar to one another and that show higher ORs than the other studies. This is the most useful split in explaining the heterogeneity although it is not clear what aspect of the studies is most likely responsible for the difference.

Among the results for proximity to electrical facilities unstratified, there is substantially greater evidence of overall heterogeneity ($P = 0.03$). In the stratified analyses, there is evidence that the heterogeneity

TABLE 6. Meta-Regression Results

Characteristic (reference/alternative)	OR for measured and calculated fields	OR for proximity to electrical facilities
Intercept	0.66 (0.17–2.57)	1.48 (0.95–2.29)
Design (case–control/cohort or nested case control)	3.61 0.94–13.88)	0.79 (0.27–2.32)
Country (US/other)	1.11 (0.52–2.37)	1.07 (0.46–2.45)
Year ($\leq$ 1993/>1993)	0.84 (0.43–1.65)	0.59 (0.34–1.01)
Exposure Metric (measured/calculated; wire codes/distance)	0.62 (0.23–1.62)	1.24 (0.52–2.95)
Controls (other/random digit dialing)	0.74 (0.25–2.25)	1.10 (0.48–2.49)
Age limit (<15/$\geq$ 15)	3.05 (0.83–11.23)	0.99 (0.40–2.46)

may be attributable to study characteristics. However, even after stratification, many of the subgroups are still not homogeneous The one exception is stratification by year of publication in which both strata are homogeneous and there is a statistically significant elevation of risk for those studies published through 1993 but those after 1993 show no elevation of risk. This suggests that other than year of publication the stratification factors are not helpful in explaining the heterogeneity.

The results of the meta-regressions are shown in Table 6. When all characteristics were entered into the regression for either measured/calculated fields or wire codes/distance, none of the coefficients were statistically significant. In part, this reflects a limitation of the small sample size. The direction of most of the effects differ depending on which exposure metric is used, also suggesting that this approach is of limited value for these data.

Results for Exposure-Response Modeling

To conduct exposure-response modeling, one must extract results for each exposure category. The study specific data are reported in Tables 7–9 and the summary risk estimates in Tables 1 and 11.

Spot measurements of magnetic fields. Savitz [1987, 1988], Savitz et al. [1988], London et al. [1991], Feychting and Ahlbom [1993], and Linet et al. [1997] reported results for leukemia in more than two categories of magnetic field spot measurements. The results reported by Savitz et al. were the arithmetic means of the measurements taken near the front door, in the child's bedroom, and in the parents' bedroom in the residence occupied at the time of diagnosis. The results reported by London et al. were for the child's bedroom in the residence occupied longest in

TABLE 7. Results Extracted From Studies of Exposure-Response Trends for Childhood Leukemia and Spot Measurements of Magnetic Fields

First author	Exposure range (μT)	Assigned value (μT) (see text)	Cases	Controls	Relative risk (95% confidence interval)
Savitz	<0.065	0.0455	21	134	1.
	0.065–0.099	0.0825	4	28	0.91 (0.29–2.86)
	0.100–0.249	0.1750	4	33	1.35 (0.53–3.45)
	$\geq$ 0.250	0.3250	2	12	2.13 (0.63–7.22)
London	<0.032	0.0217	67	56	1.
	0.032–0.067	0.0495	34	28	1.01 (0.55–1.87)
	0.068–0.124	0.0960	23	14	1.37 (0.65–2.92)
	$\geq$ 0.125	0.1625	16	11	1.22 (0.52–2.83)
Linet	<0.065	0.0455	206	215	1.
	0.065–0.099	0.0820	92	98	0.96 (0.65–1.40)
	0.100–0.199	0.1495	107	106	1.15 (0.79–1.65)
	0.200–0.299	0.2495	29	26	1.31 (0.68–2.51)
	0.300–0.399	0.3495	14	11	1.46 (0.61–3.50)
	0.400–0.499	0.4495	10	2	6.41 (1.30–31.73)
	$\geq$ 0.500	0.6500	5	5	1.01 (0.26–3.99)
Feychting	<0.10	0.063	19	207	1.
	0.10–0.19	0.145	1	67	0.2 (0.01–0.9)
	$\geq$ 0.20	0.260	4	70	0.6 (0.2–1.8)

TABLE 8. Results Extracted From Studies of Dose-Response Trends for Childhood Leukemia and Wire Codes Scored by Spot Measurements of Magnetic Fields

First author	Wire code category	Assigned value (μT) (see text)	Cases	Controls	Relative risk (95% confidence interval)
Savitz	Buried + VLCC	0.030	33	106	1.
(Savitz, 1988;	OLCC	0.051	38	102	1.20 (0.70–2.05)
Savitz et al., 1993)	OHCC	0.090	20	44	1.46 (0.76–2.82)
	VHCC	0.216	7	8	2.81 (0.95–8.33)
London	Buried + VLCC	0.017	31	38	1.
	OLCC	0.022	58	75	0.95 (0.53–1.70)
	OHCC	0.029	80	68	1.44 (0.81–2.56)
	VHCC	0.060	42	24	2.15 (1.08–4.28)

a specified etiologic period, the definition of which varied with age at diagnosis. The results reported by Feychting were the average of the measurements in the room closest to the line, the room farthest from the line and a central room. The results reported by Linet were a weighted average of measurements taken in the child's bedroom, the family room, the kitchen, and the room in which the mother slept during the index pregnancy The extracted resuts are summarized in Table 7. The combined results are consistent when analyzed in this manner, as shown by the high P-value for the homogeneity test statistic ($P = 0.3$) and the identical values of the random-effects and fixed-effects summaries (OR = 1.1, 95% CI 0.9–1.3).

Wire codes scored by spot measurements of magnetic fields. Savitz [1987, 1988], Savitz et al. [1988] Savitz and Kaune [1993], and London et al. [1991] reported results for leukemia in more than two wire code categories and reported summary values of magnetic field spot measurements for those categories. Similarly, London et al. [1991] and Linet et al. [1997] report results for leukemia in more than two wire code categories and reported summary values of magnetic field 24-hour measurements for those categories. These data permit an analysis in which each wire code category is assigned an exposure score based on the field measurements in that category from the same study. This approach [Poole and Ozonoff 1996] takes advantage of the fact that there was far less missing data for the wire codes than for the measured fields. The extracted results are summarized in Tables 8 and 9.

Risks for all reported results are positive but none are statistically significant. The resulting relative risk for wire codes scored by spot measures (OR = 2.7, 95% CI 0.8–8.7) is considerably larger than the others but is far less precise and not very homogeneous ($P = 0.1$). The result for wire codes scored by 24-hour measures (OR = 1.6, 95% CI 0.5–4.6) is less homogeneous ($P = 0.02$) than others.

Calculated magnetic fields. Feychting and Ahlbom [1993], Verkasalo et al. [1993], Olsen et al. [1993], and Tynes and Haldorsen [1997] reported results for leukemia in more than two calculated magnetic field categories. Various algorithms used by the investigators to determine the calculated fields. The extracted data are reported in Table 10. The results are homogeneous ($P = 0.2$) and show a small but not statistically significant elevation of risk (OR = 1.2, 95% CI 0.9–1.5).

TABLE 9. Results Extracted From Studies of Exposure-Response Trends for Childhood Leukemia and Wire Codes Scored by 24-hour Bedroom Measurements of Magnetic Fields

First author	Wire code category	Assigned value (μT) (see text)	Cases	Controls	Relative risk (95% confidence interval)
London	Buried + VLCC	0.0475	33	106	1.
	OLCC	0.0650	38	102	1.20 (0.70–2.05)
	OHCC	0.0720	20	44	1.46 (0.76–2.82)
	VHCC	0.1150	7	8	2.81 (0.95–8.33)
Linet	Buried + VLCC	0.072	175	175	1.
	OLCC	0.118	116	114	1.07 (0.74–1.54)
	OHCC	0.136	87	87	0.99 (0.67–1.48)
	VHCC	0.207	24	26	0.88 (0.48–1.63)

TABLE 10. Results Extracted From Studies of Exposure-Response Trends for Childhood Leukemia and Calculated Magnetic Fields

First author	Exposure range (μT)	Assigned value (μT) (see text)	Cases	Controls	Relative risk (95% confidence interval)
Feychting	<0.100	0.070	27	475	1.
(0.2 μT upper cutpoint)	0.100–0.199	0.145	4	33	2.1 (0.6–6.1)
	≥ 0.200	0.260	7	46	2.7 (1.0–6.3)
Feychting	<0.100	0.070	27	475	1.
(0.3 μT upper cutpoint)	0.100–0.299	0.195	4	47	1.5 (0.4–4.2)
	≥ 0.300	0.390	7	32	3.8 (1.4–9.3)
Verkasalo	<0.01	0.007	—	—	1.
	0.01–0.19	0.100	32	—	0.89 (0.61–1.3)
	≥ 0.40	0.520	3	—	1.6 (0.32–4.5)
Olsen (0.25 μT	<0.10	0.070	829	1658	1.
upper cutpoint)	0.10–0.24	0.170	1	4	0.5 (0.1–4.3)
	≥ 0.25	0.325	3	4	1.5 (0.3–6.7)
Olsen (0.40 μT	<0.10	0.070	829	1658	1.
upper cutpoint)	0.10–0.39	0.245	1	7	0.3 (0.0–2.0)
	≥ 0.40	0.520	3	1	6.0 (0.8–44)
Tynes	<0.05	0.035	134	532	1.
	0.05–0.13	0.095	10	26	1.5 (0.7–3.3)
	≥ 0.14	0.182	4	21	0.8 (0.3–2.4)

Summary. In summary, exposure metrics of wire codes (scored by spot measurements and 24-hour measurements), spot measurements and calculated fields, all analyses but those of wire codes gave similar random effects ORs (2.7, 1.6, 1.1, and 1.2, respectively), as shown in Table 11.

Population Attributable Risk (PAR)

Finally, I conduct a quantitative risk assessment by calculating the population attributable risk. This is a prediction of the impact of residential magnetic field exposure predicated on the assumptions that: (a) the exposure causes leukemia in children; (b) the studies are accurate and representative; (c) the exposure-response follows a log-linear relationship. Using exposure data developed from surveys of homes throughout the US, I have both distributions of wire codes and spot measured magnetic fields [Zaffanella, 1993; Zaffanella and Kalton, 1998]. For wire codes, it was reported that 28% of homes have ordinary high (OHCC) or very high (VHCC) current configurations. For spot measurements, the data were reported to follow approximately a lognormal distribution with a mean of 0.09 μT and a standard deviation of 2.2 μT.

Using the relative risks of 1.4 for OHCC or higher wire codes and 1.1 per 0.1 μT for spot measured magnetic fields, as reported in the NIEHS meta-analysis [Wartenberg et al., 1998], and the reported annual 2,200 cases of leukemia cases to children under 15 years of age (source: Leukemia Society of America),

TABLE 11. Summary of NIEHS Meta-Analyses (Wartenberg et al., 1998)

		Measured/calculated Fields			Proximity to Source		
			Continuous			Continuous	
Criterion	Index	Dichotomy	Spot measurements	Calculated fields	Dichotomy	Wire codes scored by spot	Wire codes scored by 24 h
Strength	Summary RR[a]	1.4 (1.0–2.0)	1.1 (0.9–1.3)	1.2 (0.9–1.5)	1.4 (1.1–1.8)	2.7 (0.8–8.7)	1.6 (0.5–4.6)
Consistency	% of positive studies (number of studies)	80% (10)	75% (4)	75% (4)	73% (11)	100% (2)	50% (2)
	Homogeneity	0.2	0.3	0.2	0.1	0.1	0.02
Publication bias	Fail-safe N	7	—	—	30	—	—
	Subjects needed	>6000	—	—	> 3400	—	—
Influence analysis	Homogeneity	0.11–0.50	—	—	0.04–0.20	—	—
	Relative risk	1.2–1.6	—	—	1.3–1.5	—	—

[a]Random effects model (DerSimonian et al., 1986).

TABLE 12. Population Attributable Risk for Children in the United States

Stage of risk assessment		Wire codes	Measurements
Hazard ID		Group 2B carcinogen	
Exposure assessment		28% $\geq$ OHCC[a]	Lognormal (0.09, 2.2)[b]
Exposure response[c]		RR = 1.4	RR = 1.1 per 0.1 μT
Risk characterization	PAR	8%	11%
	#cases	~175	~240

[a]Zaffanella (Zaffanella, 1993).
[b]Zaffanella (Zaffanella et al., 1998).
[c]Wartenberg (Wartenberg et al., 1998).

one can calculate the number and proportion of cases attributable (PAR) to residential magnetic field exposure each year. Based on the wire code data, I predict about 175 cases, or 8%, attributable to residential magnetic field exposure in the US. Based on the spot measurement data, I predict about 240 cases, or 11%, attributable to magnetic field exposure in the US (Table 12). From a policy perspective, these are substantial numbers, if somewhat uncertain.

DISCUSSION

The goals of a meta-analysis are threefold. First, a meta-analysis is used to identify and review all studies conducted on a specific topic. Second, a meta-analysis is used to assess the consistency and comparability (homogeneity) of results of each of the identified studies. Third, if the studies are sufficiently similar, meta-analytic tools are used to combine estimates from individual studies into a composite estimate with greater statistical power than the individual studies. While the advantage of combining estimates to a "more reliable bottom line" is often seen as a primary objective of meta-analysis, careful attention has to be given to the review of the individual studies and the consistency of the contributing studies. If this is not done, the combined risk estimate may result in a false sense of reliability and closure even though the actual estimate of risk is very uncertain and unrepresentative.

First, results from the meta-analyses in which the exposure data are dichotomized generally are positive, and several are statistically significant. In most cases, none of the individual studies are particularly (or disproportionately) influential. This is important because many people believe there are no data to support an association between residential magnetic field exposure and childhood leukemia. To the contrary, the data strongly and relatively consistently support such an association, although the estimated magnitude of the risk is moderate. Limitations due to design, confounding, or other biases may suggest alternative interpretations.

There is moderate heterogeneity, statistically, in the results using a variety of measures of proximity to electrical facilities, but not for those using measured or calculated magnetic fields. When I attempted to isolate the source of the heterogeneity by stratification, I found that the year of study showed the greatest difference for the proximity analyses. That is, studies published up through 1993 showed a stronger association that those published thereafter. Age of subjects also differs greatly. For the studies with measured and calculated fields, the differences by year of publication were small, as were difference by age, although there is a substantial difference by study design not seen in the proximity/distance studies. None of the factors investigated showed consistent and substantial confounding. Thus, after sacrificing detail on any apparent exposure–response relationship by using a dichotomized analysis, there appears to be a fairly consistent association of leukemia risk with (dichotomized) residential exposure.

My analyses also provide little evidence for publication bias. The number of unpublished null studies needed to balance the average risk of those published (the Fail-Safe *N*) generally were considerably greater than the number published. However, for studies in which the results were not statistically significant, this index is not meaningful. Similarly for the statistic concerning the number of subjects needed, only an extremely large and negative (protective) study could reverse the observed results.

The exposure response meta-analyses represent a more sophisticated approach to assessing the consistency of study results and provide more specific information about effects of exposure. These analyses were conducted for exposure metric–disease outcome pairs. In order to be sure of combining only those studies with similar enough exposure assessment methods to be meaningful from an engineering standpoint, it was necessary to limit the number of studies that could be combined in any one comparison. In each such grouping therefore, there were only two to four studies. All ORs were elevated but none were statistically significant. Heterogeneity in all but the spot measurements was fairly large ($P < 0.2$). Information provided in these studies was too limited to allow me to determine the reason for heterogeneity in wire codes and spot measures, other than suggesting the obvious effects of seasonal and other temporal variations in energy use patterns. Similarly, there were no systematic differences in wiring practices in different geographical locations that would permit application of a simple correction factor to make wire code determinations more comparable in different regions.

When heterogeneity is present, it should be reported, and average risk estimates are unrepresentative. Explanation of the heterogeneity in terms of characteristics of the studies may provide more insight than the summary estimate itself. If there are a sufficient number of studies, a thorough analysis of study characteristics and results can provide particularly useful insights possibly relating these characteristics directly to the results. In such a study–rich meta-analysis, the homogeneity P values and comparisons between fixed effects and random effects estimates are preliminary analyses, conducted as a prelude to a serious analysis of the study characteristics and their associations with the studies' results. Our efforts in this direction were limited by only a few studies with exposure–response information and substantial heterogeneity across exposure metrics. Detailed analysis of factors contributing to outcome is precluded due to lack of data. In these situations, one often relies on indirect indicators of sources of error in the data.

In reaching final conclusions about the interpretation of these studies, one must consider four factors: the number of studies in an analysis, the heterogeneity, the effect size, and the sensitivity (robustness). Overall, I see largely positive results with small to moderate effect sizes. The results are robust to study deletion but there is considerable heterogeneity. These summaries are unlikely to be change by additional studies unless those studies are extremely large and produce markedly different results. If one chooses to use these summary estimates for interpretation, given the widespread exposure to magnetic fields they suggest perhaps as much as a 15–25 % increase in the childhood leukemia rate, which is a large and important public health impact.

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APPENDIX: DISCUSSION AT THE WORKSHOP

Neutra asked how the attributable risk of 23% translates to individual childhood accumulated risk. Wartenberg estimated that the childhood risk would be about 10% more than the base risk, i.e. between one in 1,000 and one in 10,000. Stolwijk objected that this kind of assessment assumes that there is a zero threshold and that most of the risk is actually accumulated by people or children receiving EMF exposures below 1 mG (0.1 μT). Wartenberg replied that he also performed a dichotomous estimate, classifying subjects as either unexposed or exposed, and the risk increased by a factor of two in this new analysis. Wartenberg thought that when one considers all the uncertainties involved in these estimates, the two results essentially agree.

Stolwijk remarked that there were very important mitigation consequences depending on which of the two models one accepts—either a model that assumes a threshold of zero or a model that assumes a threshold of around 2 mG, because mitigation generally addresses EMF sources on above 2 mG. People often propose to mitigate these levels of exposure, he said, but most of the EMF attributable risk would not be eliminated with this type of mitigation if, in fact there was a threshold of zero. Neutra agreed that this is a really important point that needs to be clarified. DelPizzo noted that in the Swedish study the cumulative distribution of the exposure of cases and controls living in single family homes diverged from a very low cutpoint (0.1 mG). He argued that if there were a clear threshold higher than about a fraction of one mG, the two curves would overlap up to the threshold and then diverge.

Bowman commented that if one were estimating the wrong metric, heterogeneity between studies using a quantitative assessment of exposure, would not imply inconsistency with a causal association. He said he was not sure the same could be said for studies using wire codes, since wire codes are so poorly understood. He also pointed out that, since the logistic model assumes no intercept, using a partially exposed population as the reference group underestimates the slope (he drew a graphic example). In their meta-analysis for occupational studies, Bowman continued, he and his colleagues subtracted the exposure of the reference group from each point. Using this approach, they get a fit with no intercept and a bigger slope.

Langholtz asked if, by integrating under Bowman's curve to calculate the population attributable risk (PAR), one implicitly makes the assumption that all childhood leukemia is attributable to electromagnetic field exposure. DelPizzo remarked that the quantity plotted on the vertical axis represents the odds ratio rather than the incidence. Therefore, he said, the incidence is not zero even if exposure is zero. Wartenberg agreed and explained that the area under the curve represents the total number of cancers attributable to EMF exposure and that therefore the intercept represents the rate among nonexposed subjects.

Buffler questioned the wisdom of attempting PAR estimates before having resolved all the doubts, which still linger, about EMF epidemiology. Wartenherg reminded her that he had prefaced his presentation by saying, "if one believes it's causative." Savitz said that this exercise, though performed with the scanty information that now available, should be remembered and considered a begining at generating a pooled estimate. However, he continued, this exercise relies heavily on assumptions that may or may not be good, and the result may or may not be right either. He thought that Wartenberg's work in carrying the meta-analysis through all the logical steps to the estimate of attributable cases was useful.

Savitz also said that he understood the National Academy of Sciences rules require making a dichotomous decision regarding hazard identification before procceding to the next stages. However, he thought that this procedure was not helpful if the answer to the hazard identification question was neither "yes" or "no," but rather "maybe," as he believed to be the case with EMF. He thought that by assuming varying degrees of possibility one can find a range of estimates, and finding such a range, he believes, is a useful exercise. However, he also recognized that once estimates are generated, people tend to forget the process that generated them and that the estimates are tentative, no matter how emphatically the researchers emphasize it. Therefore, he sympathizes with Buffler's concern over generating PAR estimates when one is not sure that the risk exists, especially since such estimates can fuel hysteria. In order to address the problem of potential hysteria, he agreed with Wartenberg that one should keep stating the same caveats over and over and keep describing the nature of the exercise. These sorts of estimates are generated all the time, he continued, in committees and behind closed doors, but he believes that the process should be explicit and discussed openly.

Wartenberg noted that experts continue to receive questions from the public concerned about EMF exposure, such as whether or not to buy a house near power lines. He thought that attempting a rough estimate of PAR helps to put the EMF question into context by allowing some comparison with other risks, even if a straight numerical comparison cannot be done. Rather than fuel hysteria, Wartenberg said, these estimates suggest that EMF is not one of the risk factors that require aggressive response. He thought that it is useful to be able to say that, even if EMF is causally related to by leukemia, we certainly cannot conclude, based on the information we have, that the majority of all leukemia cases are due to EMF exposure.