Current Status of Scientific Research, Consensus, and Regulation Regarding Potential Health Effects of Power-Line Electric and Magnetic Fields (EMF)

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Prepared for

State of Connecticut
Connecticut Siting Council
10 Franklin Square
New Britain, CT 06051

Prepared by:

Gradient Corporation
20 University Road
Cambridge, MA 02138

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1 Objectives of this Report

The State of Connecticut, Connecticut Siting Council ("CSC," New Britain, CT) retained Gradient Corporation ("Gradient," Cambridge, MA) to gather current materials on the various scientific lines of research regarding potential health effects of utility power-line electric and magnetic fields (EMF). The goal was to provide information relevant to developing CSC guidelines on rendering energy-related siting decisions. The CSC plans to incorporate the information identified from EMF research articles, the conclusions from EMF scientific reviews, and the analyses by public-health consensus groups into updated "EMF Best Management Practices" that address possible health effects of 60 hertz (Hz) EMF exposures from electric generation, substation, and transmission facilities in the State of Connecticut.

The contents of this Report to the CSC include (a) an overview of EMF and the issues that surround it, (b) a summary of the current status of EMF research, and (c) conclusions from scientific consensus groups around the world that have addressed the EMF issue. The information provided in this Report has been gathered through a variety of means, not only through computerized scientific literature search procedures, but also through Internet searches, and by examination of commercial and non-profit databases on EMF health effects.[1] Emphasis was placed on integration of the three main lines of scientific evidence, as described more fully below: Epidemiology, Animal Studies, and Mechanistic Analyses. The central focus of this Report is on EMF and health endpoints related to cancer, specifically childhood leukemia.

The scientific literature shows that, for EMF, the separate lines of evidence disagree as to the EMF exposure levels that may be of concern. Integration of the different types of scientific knowledge requires examination of the strengths and weaknesses of each approach. Analyses in this Report suggest bases for weighing the different lines of evidence on potential EMF health effects. Ultimately, an informed decision is required to select the most plausible interpretation of available data.

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1 Peer-reviewed articles were identified through a variety of sources to identify the recent research literature. Search engines such as Pub Med (National Library of Medicine) and Science Citation Index were used. In addition, the large EMF database, assembled by Information Ventures, Inc. was extensively queried. Gradient also accessed reference lists available online from the World Health Organization (WHO) that are compiled as part of their International EMF Project (http://www10.who.int/peh-emf/emfstudies/database.cfm) and from Dr. John Moulder's website on "Electromagnetic Fields and Human Health: Power Lines and Cancer Frequently Asked Questions (FAQs)" (http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ/toc.html#1).

2 Nature of EMF

2.1 Definitions of Electric and Magnetic Fields (EMF)

All matter contains electrically charged particles. Most objects are electrically neutral because positive and negative charges are present in equal numbers. When the balance of electric charges is altered, electric fields are created that act on other electric charges. Common electric-field effects are the static-electricity attraction between a comb and our hair, or the "static cling" of clothes in a dryer. Electric charges in motion, such as the current produced by a flashlight battery, produce magnetic fields. The magnetic fields of permanent magnets or electromagnets (such as in electric motors) are also caused by charges in motion, either at the atomic level, or in wires. Electricity both in nature and in society's use of it produces EMF.

To change a neutral object into an electrically charged one requires work, and work put into electrically charging something is measured by the "voltage." Voltage is the "pressure" of the electricity, and can be envisioned as analogous to the pressure of water in a plumbing system. Numerically, voltage is the "work-per-unit-charge" and the units are "volts" (V) or "kilovolts" (kV; 1 kV = 1,000 V). Electric charges push and pull on each other. Opposite charges (*i.e.*, + and –) attract and like charges (*i.e.*, + and +, or – and –) repel. Scientists explain these forces by saying that each electric charge generates an electric field, and the presence of this electric field exerts force on other nearby charges. **The electric field is a measure of force-per-unit-charge, and its units are "volts per meter" (V/m)**.

When electric charges move, an electric current exists, and the current generates a magnetic field. The units for electric current are "amperes" (A), which measures the "flow" of electricity – amount of charge per second. Electric current can be envisioned as analogous to the flow of water in a plumbing system. The current of moving electric charges produces a "magnetic field" that exerts force on other moving charges. Scientists explain this force by saying that the moving charges generate a magnetic field, and this magnetic field exerts force on other moving charges. "Magnetic field" is usually expressed in units of gauss (G) or milligauss (mG), where 1 G =1,000 mG. Another unit for magnetic field levels that is often used is the microtesla (µT), where 1 µT = 10 mG. **Fundamentally, the magnetic field is a measure of force-per-unit-current, and its units are milligauss (mG).**

Just as electric charges exert force on one another, so also current-carrying wires exert force on each wire. This fact can be seen in electric motors, where magnetic-field forces convert electric-current energy into mechanical work. Conversely, electricity-generating turbines exert force to rotate loops of wire through magnetic fields to convert mechanical energy to electric current.

2.2 Sources of EMF

We are all continually exposed to a wide variety of natural and man-made electric and magnetic fields. EMF can be slowly varying or steady (often called "DC fields"), or can vary in time (often called "AC fields"). When the time variation of interest corresponds to that of power line currents, *i.e.*, 60 changes per second, the fields are designated as "60-Hz" EMF.

Everyone experiences large electric fields in the phenomenon of "static electricity," where charged objects attract and repel each other. The earth's atmosphere produces slowly varying electric fields (about 100 to 10,000 V/m), and high field levels occasionally discharge as lightning strikes. Some living organisms, such as the electric eel, can produce very strong electric fields. Our bodies produce weak electric fields that manifest themselves in the "electrocardiogram" or "electroencephalogram."

Magnetic fields are common in everyday life. Many childhood toys contain magnets that generate strong, steady magnetic fields. Typical toy magnets (e.g., "refrigerator door" magnets) produce 100,000 – 500,000 mG. Magnetic resonance imaging ("MRI") is a medical diagnostic procedure that puts humans in much larger fields (20,000,000 mG). Magnetic fields are produced by the earth's core, and can be easily demonstrated with a compass needle. The size of the earth's magnetic field in the Northeast U.S. is about 570 mG. [2] These fields change slowly in time, and are often called "DC" fields. However, these magnetic fields are fundamentally the same as the magnetic field produced by steady or alternating currents in power lines. Magnetic fields do not all have the specific time variation characteristic of power-lines, *i.e.*, 60-cycles-per-second ('cycles per second' are often expressed as 'Hertz' or Hz), but they are otherwise identical entities. For example, a magnet spinning at 60 rotations per second will produce a magnetic field indistinguishable from the magnetic field produced by 60-Hz power-line current.

Electric power transmission lines, distribution lines, electric wiring in buildings, and electric appliances carry AC currents and voltages that change size and direction at a frequency of 60 Hz. These 60-Hz currents and voltages are accompanied by 60-Hz EMF. At any distance, the size of the magnetic field is proportional to the current, and the size of the electric field is proportional to the voltage. The EMF produced by electrical wires and electrical equipment decrease rapidly as the distance away from

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[2] United States Geological Survey: http://geomag.usgs.gov/intro.html

the electrical wires increases. When EMF are produced by different sources (*e.g.*, adjacent wires) the result can be larger or smaller than the EMF from each source. That is, the size of the net EMF produced will be somewhere in the range between the sum and difference of EMF from the individual sources.

Inside residences, typical baseline 60-Hz magnetic fields (away from appliances) range from 0.6 to 3.0 mG. [3] 60-Hz EMF in the home arise from electric appliances, outdoor distribution wiring, indoor wiring, and grounding currents. Moreover, for any magnetic field exposure, *e.g.*, for residences near power lines, the AC magnetic fields add or subtract to the steady (DC) field of the earth (570 mG), so that the sum total magnetic field in a home has both a steady and a time-varying part.

Higher magnetic field levels are found near operating appliances. For example, can openers, mixers, blenders, refrigerators, fluorescent lamps, electric ranges, clothes washers, toasters, portable heaters, vacuum cleaners, electric tools, and many other appliances produce magnetic fields ranging in size from 1,500 to 150 mG at distances of ½ to 1 foot. [4] Magnetic fields from personal care appliances (*e.g.*, shavers, hair dryers, massagers) produce 600 – 700 mG at ½ foot away. In the school and work environment, copy machines, vending machines, video-display terminals, electric tools, lights, and motors are all sources of 60-Hz magnetic fields.

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3 NIEHS, 50% and 95% levels for homes: http://www.niehs.nih.gov/emfrapid/booklet/youremf.htm#common

4 NIEHS, fields from appliances: http://www.niehs.nih.gov/emfrapid/booklet/youremf.htm#electrical

3 Research Studies on EMF Exposure and Risk of Cancer

A large volume of research and analysis on the question of health effects related to EMF exposure has been generated over many decades (with an increase of interest over the past 25 years), representing the accumulation of many decades of laboratory work, epidemiologic analyses, and human experiences with EMF. Although EMF from a variety of sources has been studied in biological systems for a long period of time, a significant impetus to power-line EMF research studies occurred in 1979, when an epidemiology study by Wertheimer and Leeper [5] reported a statistical association between "wire codes" and childhood cancers in certain residential neighborhoods of Denver, Colorado. This statistical correlation triggered laboratory investigation as well as further epidemiological studies.

Since 1979, a multitude of laboratory and correlative studies have investigated the questions raised by the Wertheimer and Leeper hypothesis that power-line configuration was linked to risk of childhood cancers. In 1992, the U.S. Congress authorized the Electric and Magnetic Fields Research and Public Information Dissemination Program (EMF-RAPID) in the Energy Policy Act (PL 102-486). In the RAPID program, the National Institute of Environmental Health Sciences (NIEHS), National Institute of Health (NIH) and the Department of Energy (DOE) were designated to fund, direct, and manage research and analysis aimed at providing scientific evidence to clarify the potential for health risks from exposure to power-line EMF. EMF scientific data have been reported, assembled, reviewed, analyzed, and often re-reviewed by many independent scientific consensus groups of research, government, and public-health experts.

Because more recent investigations have consolidated the scientifically valid parts of the earlier EMF research record, it's neither needed nor helpful to review the vast number of hypothesis-generating and suggestive articles in the literature. A more fruitful approach, adopted in this Report, relies in part on comprehensive reviews already completed by public health agencies (consensus documents), supplemented by a review of findings of central scientific importance, based either on relevance or recent publication. The targeted review in this Report aims to assemble those research data and conclusions expected to be the most helpful in decisions and deliberations on how to apply the current state of EMF knowledge to crafting guidelines for an EMF management policy that is appropriately health-protective without endeavoring to protect against risks that have not been established to exist.

[5] Wertheimer N, Leeper E. 1979. Electrical wiring configurations and childhood cancer. *Am J Epidemiol*. 109:273.

Of the thousands of published EMF studies, a large fraction examined limited and peculiar hypotheses, and often, the suggested EMF effect of one study was contradicted or superseded by the conclusion of another study. This is a consequence of researchers working in a novel area, developing new protocols, and pressing the limit of detection, *i.e.*, conditions under which chance positive findings are likely. Moreover, in published, peer-reviewed research papers, not all avenues of investigation are reported. Researchers tend to publish data that support a scientific hypothesis and leave unpublished those data that are inconsistent, seem less relevant, show a null result, and/or are difficult to interpret as an "effect." This phenomenon is known as "publication bias," and helps explain why many seemingly "positive" studies are published and "no effect" results are not. Thus, many initial findings ultimately lead nowhere.

Many published EMF research studies are characterized by the phenomenon that investigators attempting to replicate what appeared to be key findings were unable to do so, in spite of using more careful, better-designed, "blinded," follow-up research. On the other hand, solid and relevant EMF results were generally obtained under the research supported by the NIEHS (through the EMF-RAPID program), which initiated and funded a series of studies at the National Toxicology Program (NTP), carried out under rigorous scientific protocols. The NIEHS funding program supported researchers in the task of determining what, if any, aspects of EMF interactions with biological systems were (1) real and reproducible, and (2) had the potential to increase the risk of cancer. A number of well-designed, long-term, and life-time duration animal studies were done by the NTP (and others) as part of this research effort. The NTP results, and similarly solid research, merit significantly greater priority in a weight of evidence summary than findings which suffer from possible artifacts.

In 1999 the NIEHS submitted its report to the U.S. Congress: "*NIEHS Report on Health Effects from Exposure to Power-Line* Frequency *Electric and Magnetic Fields*." The report concluded the following:

> "*The scientific evidence suggesting that ELF-EMF exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults….In contrast, the mechanistic studies and the animal toxicology literature fail to demonstrate any consistent pattern across studies….No indication of increased leukemias in animals have been observed….. Virtually all of the laboratory evidence in animals and humans and most of the mechanistic work done in cells fail to support a causal relationship between ELF_EMF at environmental levels and changes in biological function or disease status. The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but it cannot completely discount the*

epidemiological findings. The NIEHS concludes that because of…. weak scientific evidence…exposure may pose a leukemia hazard. In our opinion, this finding is insufficient to warrant aggressive regulatory concern….The NIEHS does not believe that other cancers or non-cancer outcomes provide sufficient evidence of a risk to currently warrant concern." (NIEHS, 1999, 9-10)

No amount of scientific research can definitively prove or disprove a causal link between EMF exposure and, say, cancer risk. Absolute assurance of safety is not possible in any human, societal, or technological endeavor. The more important conclusion to be drawn is where on the spectrum between "unacceptable risk" and "entirely safe" does our current understanding place us. As embodied in the NIEHS statement, and as discussed further in Section 8, the most coherent picture to be drawn from available EMF studies and consensus analyses is that the evidence weighs in the direction of "disproof" much more heavily than in the direction of "proof." Key elements to this summary picture will be described in this Report.

4 Three Lines of Scientific Evidence

Understanding the toxicology of any type of human exposure (including EMF) requires integrating the information available in separate studies that fall into several independent lines of evidence. Each study can be evaluated on the basis of quality factors that relate to the type of evidence it provides. Typical factors include study population size, adequate design, dose-response, reproducibility, and strength of results. Next, the weight of evidence from the separate lines of investigation needs to be compared and contrasted. The three major avenues of toxicology investigation to be compared and contrasted are:

1. Epidemiologic and statistical analyses,
2. Laboratory animal experiments and clinical studies on humans, and
3. Biophysical and *in vitro* studies of mechanism.

Each of these sources of information has strengths and weaknesses. Approach (1) studies human beings in their natural environment, but statistical analyses of cancer risk patterns in residential and occupational populations can be difficult to interpret. This is because epidemiology utilizes indirect (surrogate) measures of an individual's past EMF exposure and also cannot reconstruct the role of all other potentially important influences on human health, such as lifestyle, demography, and exposures other than the one of interest. In epidemiology, these uncertainties are given names such as "exposure misclassification," "effect modifiers," "confounders," "selection bias," and "observer bias."

Approaches (2) and (3) involve experimental studies, and if the investigator accurately sets the EMF exposure, randomizes the subjects between exposed and control groups, and assesses the results in an unbiased, "blinded," fashion, such studies can provide insight into cause-and-effect relationships. Laboratory studies, however, require interpretation regarding their relevance to humans in their natural environment. For example, laboratory-animal experiments (2) allow well-characterized EMF exposures at elevated levels, followed by careful assessment of pathology. Animal models, however, may not faithfully mimic the complex mixtures of EMF to which humans are exposed over a lifetime.

Volunteer studies [clinical studies under approach (2)] allow definitive determination of EMF exposure levels, but are limited to short-term outcomes. However, volunteer studies have been used to investigate levels of EMF much higher than residential levels. Mechanistic and "*in vitro*" studies (3) build on the solid principles of chemistry, biology, and toxicology, but interpretation of exactly how the mechanistic model results carry over to a living organism may sometimes be uncertain.

Because the epidemiology associations do not require extrapolation from animal species or from laboratory test-tube systems, the media and some health professionals have focused on these results in isolation. But even considered in isolation, the EMF epidemiology yields weak and inconsistent results. For example, the low levels of EMF characteristic of residential exposure seem to more often yield a positive association than the much higher EMF levels characteristic of occupational exposure. And, as many scientific review groups have noted, positive epidemiology results have not found adequate support from either the study of cancer in animals or from mechanistic analysis of EMF effects on molecules and cells. Scientists have vigorously attacked the problem of finding supporting laboratory evidence for the epidemiologic associations in animal experiments or in analyses of biophysical mechanism. However, this effort has not been successful, and the current research continues to suggest that the elevated odds ratios reported by some epidemiology studies have an explanation aside from the suggested EMF exposure *per se*.

Because scientific understanding of EMF research results has evolved over time, the most helpful approach is to focus on scientific consensus reviews and more recent key research results. Also important are coherence and consistency with established toxicology and plausible mechanisms. Results that contradict generally accepted science, are not replicated, and represent sporadic findings, while potentially intriguing, cannot be used for a rational EMF policy. The epidemiologic studies are too weak to be interpreted as causal, and moreover, do not shed light on what component of EMF exposure might be relevant to cancer risk and hence relevant to mitigation efforts (*e.g.*, frequency of oscillation, the electric fields, the magnetic fields, continuous exposure, intermittent exposure, peak fields, time-average fields, or transients in EMF).

The following sections provide more detail on the current status of EMF evidence. The listing of validity criteria provides a structured framework for articulation of the bases on which an overall scientific judgment can be made.

5 Epidemiologic Correlations

Epidemiology is the study of the distribution of diseases in human populations, and the correlation of disease patterns with possible factors that may influence the occurrence of that disease. For example, epidemiologists may examine statistical measures of disease occurrence such as prevalence (how many diseased individuals there are per unit population), incidence (new cases of disease per year per unit population), and mortality (disease-specific deaths per year per unit population). They then collect information on population characteristics, work exposures, and environmental exposures that may correlate with differences in the measures of disease occurrence.

If a particular factor is suspected to influence disease probability, epidemiologists typically calculate a "relative risk" (RR) factor that expresses the degree of correlation. For example, if there is no correlation between exposure and risk, then RR = 1.0, and if the risk of disease among exposed people is twice as high as among unexposed people, then RR = 2.0. There is considerable uncertainty associated with these calculations, and one source of uncertainty that is often provided with the RR relates to the size of the population being studied. The smaller the study population, the greater the role of random chance effects, and this uncertainty is given in the form of a "confidence interval" (CI) that expresses the confidence that the result is not due to chance alone. For example, if RR = 2.0, and the confidence interval is ± 1.3, *e.g.* RR = 2.0 (CI: 0.7 – 3.3), then, even though an elevated risk was found, the possible role of chance could not be ruled out, because the CI overlaps the no-risk level of RR = 1.0. Even if the RR risk is elevated and the CI does not overlap 1.0, it remains unclear whether the association seen is due to a causal link to the exposure being studied. Many factors need to be considered, as outlined below.

Criteria originally presented by Austin Bradford Hill [6] (sometimes called the Bradford Hill "viewpoints") have been used for evaluating the plausibility of a causal link for reported epidemiologic associations. Some of the same criteria have also been deemed useful for evaluating the strength of animal and cell studies. The Bradford Hill "points of consideration include:"

- statistical significance of the study, (*i.e.*, the size of the population, and the size of the effect compared to random effects). Statistical significance *per se* should not, however, be mistaken for evidence of a clinically meaningful association;

6 K.J. Rothman and S. Greenland. 2005. "Causation and Causal Inference in Epidemiology." *Public Health Matters.* 95 (Supplement 1): s144-s150. See also: http://www.epi-perspectives.com/content/1/1/3

- strength of the study / association, (*i.e.*, the size of risks compared to background). However, mere strength should not be mistaken for causality (selection and participation bias, uncontrolled shared confounders, and non-random errors can play a part);
- specificity of the result / association, (*i.e.*, the exclusivity of the relationship between the agent and the disease). The specificity of the result depends crucially upon whether the parameter used to quantify "exposure" is valid and measures personal exposures for the population studied (*i.e.*, not subject to exposure misclassification);
- the biological plausibility of the result / association, (*i.e.*, repeated finding of an association does not prove causation, and all other evidence must be considered). Reliance on results outside of epidemiology is particularly important when correlations are weak, inconsistent, and of an unusual nature;
- the existence of an exposure-response trend, (*i.e.*, more exposure leads to higher odds ratios or relative risks). That is, occupational and residential populations show increased risks in proportion to the estimated exposure; and
- the cohesiveness of all the available data when considered as a whole, (*i.e.*, the associations demonstrate a consistent pattern that is coherent with what is known about the disease in other contexts, and the associations become stronger as methodology improves).

Because epidemiology is a non-experimental science, ascertaining the meaning of epidemiologic associations is very difficult. While a laboratory scientist can manipulate exposure conditions and randomly allocate groups to be exposed or non-exposed, and can read the results blindly (*i.e.*, without knowing the exposure history), epidemiology is an observational science and cannot apply such methods. As can be seen from the key epidemiology articles and the consensus group reviews, EMF epidemiology data have many weaknesses and fare poorly in the light of most of the above Bradford Hill criteria. That is, even though a number of studies have found an association between EMF and childhood leukemia, epidemiologic uncertainties and a lack of mechanistic and laboratory animal support prevent drawing a conclusion that the EMF associations with childhood leukemia are causal (See Appendix B). In fact, a recent analysis of bias in the EMF studies concluded that the results allowed for no other sources of uncertainty other than random error (*i.e.*, population size). [7]

[7] Sander Greenland. 2005. Multiple-bias modeling for analysis of observational data. *J. Royal Statistical Society*. 168(Part 2):267-306.

6 Laboratory-Animal Studies

A large fraction of our knowledge of substances and agents with potentially harmful effects in humans derives from studies with laboratory animals. Animals can be exposed to elevated levels of an agent for long periods of time (often for a lifetime), and then can carefully examined for an increase in tumors, pre-cancerous effects, and cancer. The usefulness of laboratory animal work for assessing toxicity depends on how well the work is done, and whether other investigators have reported similar results under similar exposure conditions. Some of the aspects of laboratory work with EMF that bear on whether the outcomes are valid and representative of potential human risk include the following factors:

- characterizing the animal's EMF exposure as to magnitude, duration, stability, homogeneity, *etc*.;
- identifying which aspect of EMF exposure (electric field, magnetic field, frequency, polarization, transients, intermittency) is being studied;
- using an appropriate number of EMF exposure levels to develop a dose-response curve;
- inclusion of control animals (zero EMF exposure) with identical noise, temperature, environment, handling, and housing;
- testing for abnormal animals, diseases, and pathogens within the animal population;
- assessing the results in an unbiased ("double-blind") fashion, with attention to completeness and accuracy in the outcomes measured; and
- adherence to good laboratory practice.

The results of laboratory studies may be interpreted as to their relevance to human EMF exposure, that is, whether the results can be plausibly generalized or extrapolated from the laboratory setting to the setting of interest, *i.e.*, general public exposure to EMF from transmission-line corridors. Ideally, the laboratory work would be useful for quantitative exposure-risk assessment. Key aspects of validity in this regard are (a) known similarities or differences between the test species and humans for the endpoint in question (*e.g.*, cancer).

Although many animal studies have reported "effects" from EMF exposure, the majority of these studies have not been consistent or reproducible. The studies undertaken by the National Toxicology Program are accepted as the most solid in design and execution. Over the past 10 years, more than a dozen studies have been published that evaluated tumors in animals that were exposed to EMF for most of their lives, including the pre-natal period in some cases. These major studies have found no evidence that power-frequency fields cause any specific types of cancer in the animal species tested (rats and mice).

7 Mechanisms of EMF Interaction with Organisms

7.1 Ionizing versus Non-Ionizing Electromagnetic Radiation

Power frequency EMF are at the very lowest end of an electromagnetic spectrum that encompasses frequencies that range from very high in the case of "ionizing energy," such as X-rays with frequencies of a billion-billion of cycles per second (Hz), to very low non-ionizing energy including, in descending order, microwaves (100 billion Hz), radio waves, and power frequencies (60 Hz) (Table 1). Visible light is also in this spectrum, at the threshold between ionizing and non-ionizing electromagnetic waves. The term "ionizing" refers to the ability of the electromagnetic waves to disrupt molecules, and "non-ionizing" means an absence of this disruptive effect. The higher the frequency of the electromagnetic energy source, the shorter the wavelength and the higher the energy. Lower frequency sources have longer wavelengths and correspondingly lower energy. Power frequency EMF are very low frequency fields (60 Hz) with extremely long wavelengths of 5,000 km (3,100 miles). Because of the extremely long wavelength, EMF associated with power frequency are experienced as separate electric and magnetic fields and are therefore not considered radiation or emissions. They carry very little energy away from the power lines, and the energy of the waves is very weak and cannot break chemical bonds or heat living tissue.

Table 1 identifies the key regions of the electromagnetic spectrum. More details about the electromagnetic spectrum (wavelengths, frequencies, photon energies) can be found in Appendix C.

Table 1: The electromagnetic spectrum includes 60 Hz EMF, radio waves, light energy, ultraviolet light, and x-rays in a continuum

ELF	AM Radio	FM / TV	Microwave and Radar	Radiant Heating, Infrared	Sun Lamps, Visible Light	Medical X-Rays	α-, β-, γ-Rays
♦ Power lines 50 – 60 Hz		♦ Cell phones, ~ 1 – 2 GHz		♦ Human body heat ← ← ← ←	♦ Vision Non-ionizing←	→ Ionizing	♦ Cosmic rays → → → →
(*induced*	*currents*)	(*RF heating*	*currents*)	(*photo* —	*chemistry*)	(*molecular*	*damage*)

The crucial dividing point on Table 1 is between electromagnetic waves that can disrupt chemical bonds (ionizing) and those that cannot (non-ionizing). This division occurs in the vicinity of the frequency of ultraviolet light, above UV range, above this range is "ionizing" and below visible light is the "non-ionizing" range. These terms refer to the energy of electromagnetic waves on a per-photon basis, because this tells us how the individual packets of electromagnetic radiation (known as "photons") can affect the molecules of life. Ionizing radiation can break up molecules like DNA, and hence cause mutational changes that might lead to cancer. However, non-ionizing radiation cannot break up molecules, and hence cannot directly affect the information content of DNA. EMF in the range of power-line frequencies are far too weak to damage molecules

7.2 Assessing EMF Effects through Mechanism and Physics considerations

The EMF health effects question can be examined *via* what is known about the physics of the interaction of electromagnetic fields with matter. The applicability of fundamental physics to all systems, and to biology in particular, permits conclusions to be drawn about the interaction of EMF with ions, molecules, cells, and organisms. **The basic interactions of electromagnetic fields with matter involve force on fixed and moving charges**, with the possibility of classical energy transfer (thermal energy) and quantum interactions with molecules (photon effects – see Appendix C).

Living organisms rely upon the same laws that govern all systems, and hence, mechanistic considerations are crucial. As shown in Fig. 1 below, physics forms the basis of chemistry, which forms the basis of biology, which forms the basis of medicine. Hence, even though there is an increase in complexity as you move up this progression, each successive layer must obey the fundamental laws found to be valid for the layer below. At the most fundamental level are the laws of physics, which have been exhaustively validated by experiment and through internal consistency. The principles behind radiofrequency waves, namely Maxwell's laws of electromagnetism, are accepted to be invariant in time and space, and their accuracy in describing the interactions between electromagnetic fields and matter underlies the functioning of virtually all technology. No exceptions have been found, in spite of constant challenges and tests. Likewise, physics has been found to be valid in complex systems, encompassing chemistry, biology, technology, and medicine. Simple conservation laws (*e.g.*, energy, motion, charge, momentum) are universally applicable, and biology is no exception.

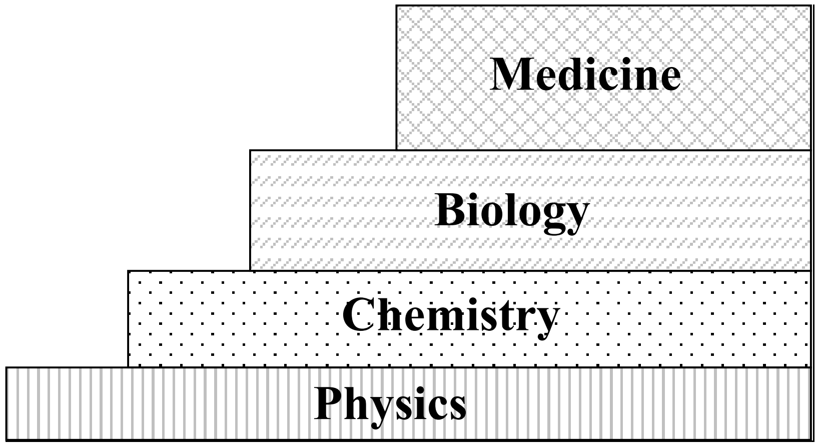

Figure 1: Each scientific discipline rests on the underlying laws of a more basic discipline

In order for the electric and magnetic fields from power lines and electrical appliances to exert an influence on living cells, the fields must in some manner modify molecules or structures in the organism. By their very definition, electric and magnetic fields interact with matter only by exerting force on stationary or moving electric charges. At sufficiently high levels of EMF, these forces can add small amounts of thermal energy or change the configuration of a charged biological molecule or structure. However, the magnitudes of natural forces that cells use and are sensitive to have been measured, and the results demonstrate that biological structures can withstand forces far larger than can be generated by power-line EMF. Failure to observe mechanistically plausible biological effects from EMF exposure is likely due to the fact that effects of EMF on biology are very weak (Valberg et al. 1997). Cells and organs function properly in spite of many internal sources of interfering chemical and force effects, which exceed by a large factor the effects caused by EMF (Weaver et al. 2000).

In summary, for power-line EMF to change physiological function, initiate dysfunction, or cause the onset of disease in humans or animals there must exist a mechanism by which EMF alters molecules, chemical reactions, cell membranes, or biological structures. EMF is a physical, not chemical, agent, and biological plausibility must be assessed with this in mind. The initial physical step is illustrated in the following causal chain, by which EMF interaction effects could hypothetically occur:

EMF $\Rightarrow$ Matter (physics) $\Rightarrow$ Molecules (chemistry) $\Rightarrow$ Organisms (biology) $\Rightarrow$ Disease

A necessary condition for EMF impact on human or ecosystem biology is that the EMF-induced changes have to exceed chemical changes from natural or background influences. Changes in biology are coupled to EMF through changes in forces on charged structures, which in turn, must be coupled to metabolically important chemical processes (reaction or transport rates). The size and direction of the electric field predicts the size and direction of force on electric charges. Likewise, the magnetic field predicts force on moving charges. Thus, any EMF bioeffects must solely and ultimately be the result of forces exerted on electric charges. There are no other actions of EMF.

The failure to observe consistent and reproducible laboratory effects from EMF exposure is likely due to the fact that typical power-line EMF do not affect biology in a manner detectable above the many natural disturbances in biological systems. This inability of power-line EMF to cause reproducible effects in biological systems supports the conclusion that EMF does not play a causal role in the epidemiologic associations.

8 Public Health Consensus Groups: Conclusions and Guidelines

In defining the current status of scientific understanding about EMF, it is helpful to consider the assembly of conclusions provided by "blue ribbon" scientific consensus groups that have reviewed EMF results. Among the authoritative groups that have examined the EMF issue (a more complete listing is given in APPENDICES A and B), the following are a representative list:

American Cancer Society (ACS)
American Conference of Governmental Industrial Hygienists (ACGIH)
American Industrial Hygiene Association (AIHA)
American Medical Association (AMA)
American Physical (Physics) Society (APS)
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)
British Columbia Center for Disease Control (BC-CDC)
European Union (EU)
Health Canada (HC)
Institute of Electrical and Electronics Engineers (IEEE)
International Agency for Research on Cancer (IARC)
International Commission on Non Ionizing Radiation Protection (ICNIRP)
National Academy of Sciences / National Research Council (NAS / NRC)
National Cancer Institute (NCI)
National Institute of Environmental Health Sciences (NIEHS)
National Radiation Protection Board (NRPB) (UK) (now Health Protection Agency)
Netherlands Health Council (NHC)
Swedish National Health and Welfare Board
World Health Organization (WHO)

Because of the extensive effort that has been devoted to reviewing "EMF science" by such diverse groups of scientific experts, an overview of their conclusions provides support for the conclusion that any effect of EMF on elevating cancer risk is hypothetical at best. The Tables included in this Report in APPENDICES A and B provide information available for these consensus groups on (i) date of most recent EMF review, (ii) Internet web page or source document, (iii) health endpoints considered, (iv) general conclusions on EMF, (v) numerical guidelines offered, if any, and (vi) suggestions for further research and / or uncertainties identified.

There are differences among the various consensus groups and their review criteria. Some review groups put more emphasis on the statistical associations from epidemiology, while others place weight on the laboratory studies, *i.e.*, animal and test tube experiments that have probed for an EMF mechanism, or a specific health problem. Overall, the absence of robust findings from careful, replicated laboratory studies causes most health agencies to be cautious about the reported epidemiological links. The statistical results are suspected to be due to such factors as selection bias and unmeasured or uncontrolled confounding.

The consensus groups uniformly note that a significant flaw in a causal interpretation of the EMF epidemiology is that, to date, there is no known biological mechanism or animal model by which power line EMF can be shown to initiate or exacerbate carcinogenesis. An animal model has not been established in which exposure to elevated 60-Hz magnetic fields consistently produces a disease or a pre-disease condition. Such animal *models* are the foundation (or "gold standard") in the regulatory or guideline arena, because it is in this way that regulators can determine what aspect of an exposure (*e.g.*, "EMF") should potentially be limited. Even under the hypothesis that the epidemiology relates to a causal link, scientists presently have no firm basis on which to decide if the greatest potential harm can be attributed specifically to, for example, electric fields or to magnetic fields, to the fundamental frequency or to harmonics, to continuous exposure or to intermittent exposure, to time-average fields or to peak fields, to constant amplitude EMF or to transients in EMF. Although ideas have been proposed in this area, and many analyses have been performed, years of diligent attention by scientists have not yielded answers on what aspects of EMF exposure, at what levels, and for what durations might increase cancer risk.

9 Summaries of Key Recent Literature Articles

9.1 Epidemiology Results

In the area of health effects of power-line EMF, most scientific and public scrutiny has centered on a possible link with childhood leukemia. The initial epidemiologic study that raised this question, and most of the follow-up studies have been of a design called a "case-control" study, wherein children with leukemia (cases) are matched to similar children without leukemia (controls). Then, questionnaires, interviews, and observations are used to investigate how the background (residence, lifestyle, EMF and non-EMF exposures, *etc.*) of the two groups might differ. A number of studies have reported that their investigations suggested that the "case" children may have had greater exposure to power-line EMF, as surmised from various indirect measures of EMF such as "proximity of distribution wires and transformers to the home," "distance to transmission lines," or "present-day measurements of EMF in the home." The results in epidemiology are expressed as an "association," or statistical link, which states that the occurrence of the surrogate measure of EMF was found to be somewhat more likely in the "cases" than in the "controls." In several EMF studies the role of chance *per se* was small, and when the role of chance is less than 5%, the outcome is called "statistically significant." Of course, as discussed earlier, the interpretation of epidemiology associations is problematic, because many significant uncertainties are not captured in the random-chance statistics alone, and other possible reasons aside from a causal basis could underlie the reported EMF link.

The epidemiological data are generally interpreted as "negative" to "weak." This is illustrated in the in the graphical tabulation in Figure 2 below (Dr. John Moulder, Medical College of Wisconsin, http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ). The central line marked "1.0" is the point at which there is neither an increase or decrease in reported risk, and to the right is increasing risk, and to the left is decreasing risk. The individual symbols (solid dots, or circles) mark the results reported by the studies identified, and the horizontal lines extending our from these dots show the range of uncertainty due to random chance alone. Figure 2 illustrates that the childhood leukemia studies show no consistent association between power-line exposure and the incidence of leukemia, and as a whole, they cluster around the RR = 1.0, or "no effect" line. The two open circles at the top and bottom represent a summary of the studies reported in the years specified, and because the horizontal lines extending from these open dots also cross the RR = 1.0 line, the summary statistics suggest "no effect," even when limiting the measure of uncertainty to random chance alone.

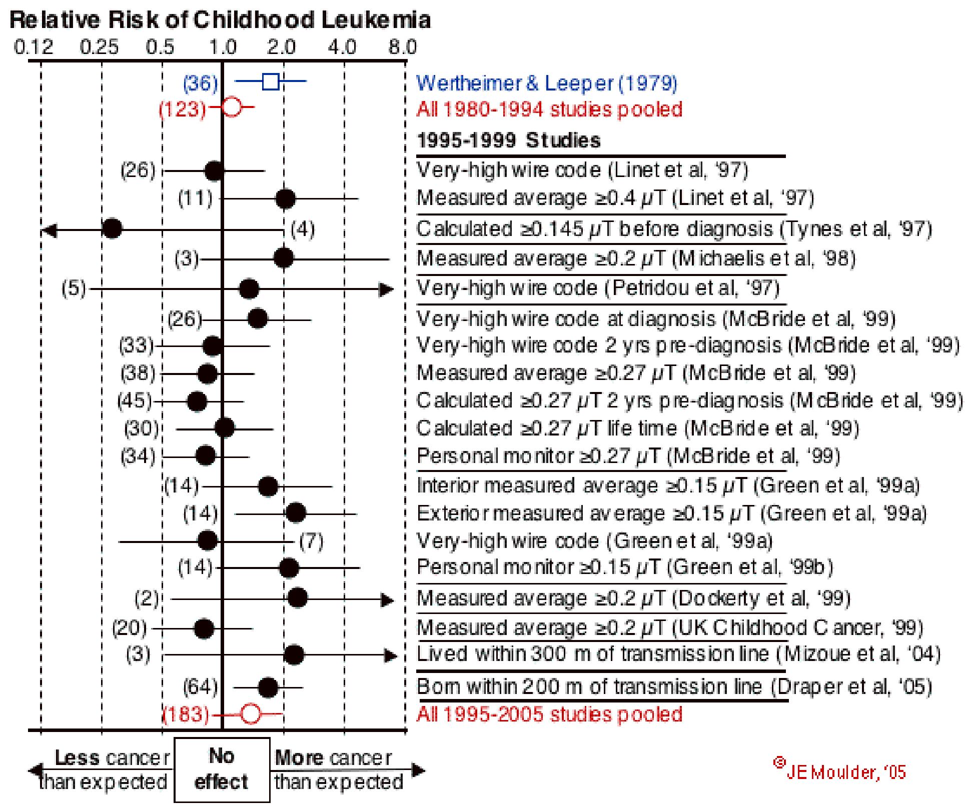

Figure 2. Relative risks (RR) from epidemiology studies of childhood leukemia and exposure to power-line EMF. RR's are shown with 95% confidence intervals. In parentheses are the numbers of expected EMF-exposed cases (*i.e.*, the size of the study). The pooled RR's (open circles) weigh each study on its population size (a measure of the statistical power of the study), and treats all EMF exposure-assessment methods of equal validity.

The interpretation of the EMF epidemiology remains uncertain because of the small RRs observed and the likely effect of bias in the studies. The types of non-causal explanations that have been offered are selection bias (cases and controls are not equivalent), EMF exposure misclassification (causing the confidence interval for the result to be larger than suggested by population-size considerations alone), and confounding (the EMF exposure surrogate used selects for some other, non-EMF population characteristic causing the observed result). Design limitations to any epidemiology study adds considerable uncertainty in the risk estimates, and it appears that little added information of value would come from future epidemiology studies with similar designs.

If EMF were responsible for increased leukemia risk in the residential studies, it would stand to reason that the increase in risk should be much greater in occupational studies of workers who are exposed to much higher levels of EMF. In fact, the trend is in the opposite direction. In its 2002 review of EMF, IARC (an agency of the World Health Organization) noted that considerably greater EMF exposure occurs in some occupations, yet the agency concluded that for workers: "There was no consistent finding across studies of an exposure–response relationship and no consistency in the association with specific sub-types of leukaemia or brain tumors." [8] Since that time, several large European studies (which have the advantage of being based on complete cancer registries) have reported that neither leukemia nor brain cancer risk is elevated among people exposed to EMF at work. [9] Another large study in the occupational setting evaluated whether EMF had an effect on breast cancer risk in women workers. After comparing the EMF exposure of 20,400 women with breast cancer to that of 116,227 women without breast cancer, the authors concluded that "The size of this study allowed for estimates with good precision in subgroups where previous studies have suggested increased risk, but the findings do not support the hypothesis that magnetic fields influence the risk of female breast cancer." [10] Thus, for people with the greatest potential for exposure to significant levels of EMF, the epidemiologic data do not support the existence of an increased cancer risk.

9.2 Laboratory-Animal Studies

The most comprehensive studies of the possible cancer-causing potential of power-line EMF have been lifetime studies in laboratory animals. Under the direction of the U.S. National Toxicology Program, lifetime exposure of rodents of high levels of power-line fields (20 mG; 2,000 mG; and 10,000 mG), followed by careful post-mortem analysis of all organ systems, have provided no significant evidence of carcinogenicity (or any other serious health effect). Figure 3 below illustrates the results of major laboratory animal experiments (http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ, Dr. Moulder, Medical College of Wisconsin), and it can be seen that the results cluster around the RR = 1.0, or "no effect" line.

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8 International Agency on Research in Cancer: http://www-cie.iarc.fr/htdocs/monographs/vol80/80.html

9 (a) Willett, EV; McKinney, PA; Fear, NT; Cartwright, RA; Roman, E. 2003. Occupational exposure to electromagnetic fields and acute leukaemia: analysis of a case-control study. *Occup Environ Med* 60: 577-583.

(b) Tynes T, Haldorsen T. 2003. Residential and occupational exposure to 50 Hz magnetic fields and hematological cancers in Norway. *Cancer Causes Control.* 14:715-20.

(c) Johansen C. 2004. Electromagnetic fields and health effects--epidemiologic studies of cancer, diseases of the central nervous system and arrhythmia-related heart disease. *Scand J Work Environ Health*. 30 (Suppl 1):1-30.

10 Forssen UM, Rutqvist LE, Ahlbom A, Feychting M. 2005. Occupational magnetic fields and female breast cancer: a case-control study using Swedish population registers and new exposure data. *Am J Epidemiol*. 161:250-9.

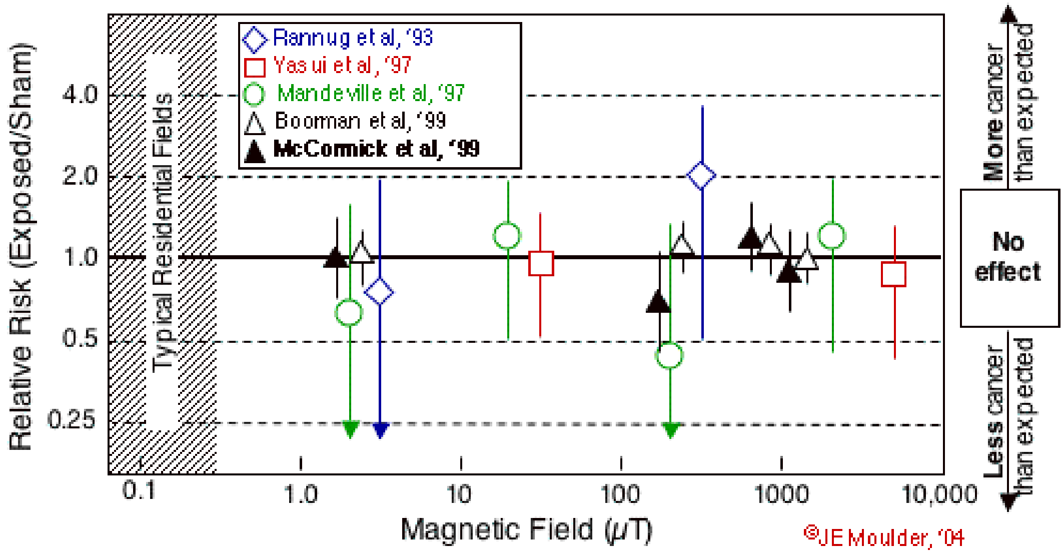


Figure 3: Results from Animal Carcinogenesis Studies following Lifetime Exposure to the Levels of EMF Indicated. These animal studies assessed total malignant tumors or overall survival. The figure shows the ratios (exposed/sham) of the number of animals with tumors at the end of the experiment, or the number of deaths during the experiment. All data are shown with 95% confidence intervals. On the left hand side of the chart, the shading shows a comparison to typical 24-hour average residential fields.

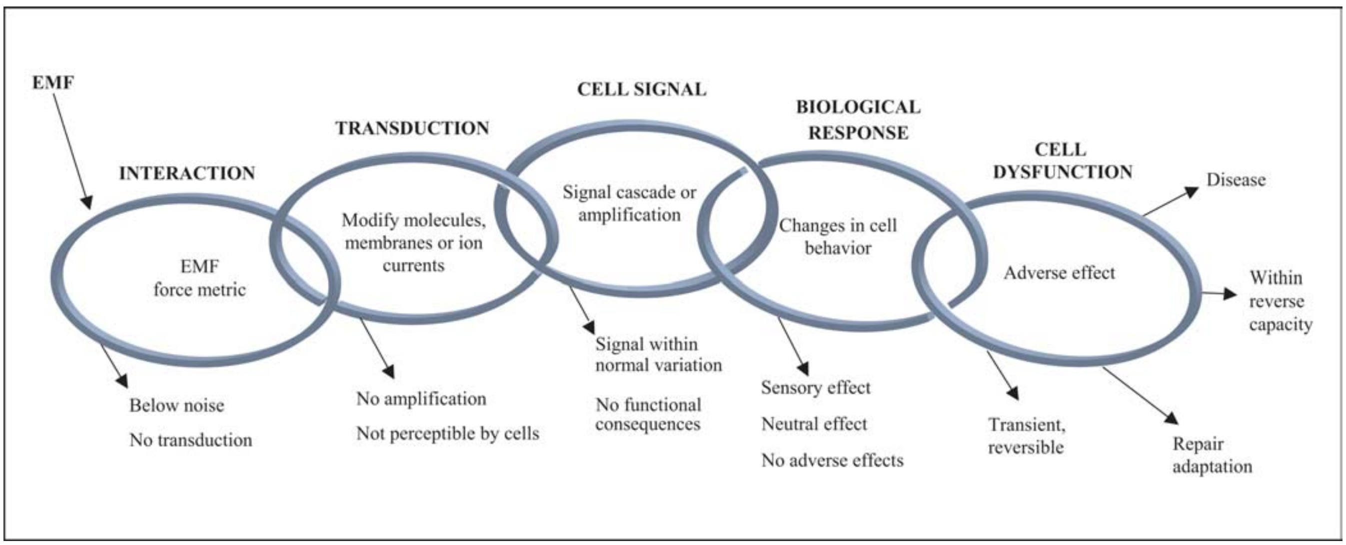
Laboratory evidence with animal exposures to power-line EMF have been consistent in failing to provide support for the epidemiologic associations. That is, even though the highest EMF exposure levels corresponded to fields more than 1,000 times that of the higher human residential exposures (which correspond to electromagnetic field energy densities one million times larger), experiments exposing rats and mice to these levels have not identified any type of cancer risk. However, some groups of scientists conducting more narrowly directed experiments have reported that very weak EMF do affect biology. The reason for this is not clear, but in cases where replication of such results was assiduously pursued, the replication failed, and the biological effects could not be reproduced. Overall, the numerous experiments with animals that report subtle results of EMF exposure do not fit into a coherent pattern of response.

9.3 Mechanistic Considerations

The hypothetical causal chain must be initiated by a mechanism of action

Biological processes in our bodies include many interactions among electric charges (on ions, molecules, proteins, and membranes). Hence, one can imagine that exposure to EMF, which exert forces on fixed and moving charges, may have the potential to modulate biological function. For EMF to cause or exacerbate disease in humans, EMF would have to trigger a series of sequential steps that leads to the disease outcome. The causal chain (see Figure 4) would begin with human exposure to some particular (as yet undefined) aspect of power-line EMF. To complete the first step, EMF must interact with biological molecules (or structures) in such a way as to alter their size, shape, charge, chemical state, or energy. In this energy "transduction" step, some absorption of EMF energy must occur or there can be no effect.

Figure 4: Mechanism(s) of Action is(are) the First Link in the Causal Chain



The hypothetical causal chain may be interrupted at any one of many required links

As shown in Figure 4, for observable biological (and possibly health adverse) effects to follow transduction, a cascade of sequential events at the molecular, cellular, and tissue level would be required, leading without interruption to the final outcome. The outcome "Disease" in the upper right hand corner is only one possible outcome of many, and it is an outcome that requires successful completion of many intermediate steps. Figure 4 illustrates multiple points in the causal chain where the signal produced by the preceding step might be within normal variations and, therefore, would have no further functional consequences beyond this point in the causal chain.

The first, mechanistic or transduction step in the multi-step pathway illustrated in Figure 4 has been completely elusive. In fact, even identifying the correct measure of EMF exposure, sometimes called the "EMF Metric," requires identifying specific biological effects at a molecular level. Since the health and viability of the human body depends in a fundamental way on the normal structure and function of large molecules (*e.g.*, proteins, nucleic acids, carbohydrates, and lipids), any theoretical EMF mechanism must predict how EMF could interfere with or modify the normal synthesis, function, or degradation of these molecules. A theory of EMF interaction mechanisms would then predict thresholds of exposure effectiveness in terms of EMF amplitudes, frequencies, time of onset, intermittency of exposure, homogeneity / heterogeneity of amplitudes and frequencies, exposure duration, transients, polarization, *etc*. [11] That is, because the mechanism is unknown, the aspect of EMF exposure that should possibly be mitigated is also unknown.

For power-line magnetic fields below about 500 mG, there are no identified and plausible mechanisms by which biological effects can be caused in living systems. [12] Even above this level, the small induced currents are not know to cause deleterious effects (see Appendix C and Adair, 2000). [13]

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11 Valberg PA. 1995. Designing EMF experiments: what is required to characterize "EMF exposure?" *Bioelectromagnetics*. 16:396-401.

12 Swanson J, Kheifetz L. 2006. Bio-physical mechanisms: a component in the weight of evidence for EMFs. *Radiation Research*. (in press).

13 Adair RK. 2000. Static and low-frequency magnetic field effects: health risks and therapies. *Reports on Progress in Physics*. 63:415-454.

10 Conclusions on the State of the Science

10.1 Strengths and Weaknesses of the Lines of Evidence

Laboratory animal and mechanistic studies of MF bioeffects do not support the existence of an increased cancer risk. Epidemiologic studies of power-line fields have reported weak, but somewhat consistent, associations between MF and risk of childhood leukemia. However, uncertainties in the interpretation of these associations prevent a conclusion that a causal effect of MF *per se* is involved. A recent overview of childhood leukemia (Brain *et al*., 2003) concluded that:

> "*Epidemiological associations between [MF] and childhood leukemia have made [power-frequency fields] a suspected risk factor. Animal data on the effects of exposure, however, are overwhelmingly negative regarding [power-frequency field] exposure, per se, being a significant risk for [leukemia]. We may fail to observe laboratory effects from exposure, because typical power-line [fields] do not give a 'dose' detectable above the many sources of 'noise' in biological systems. We may fail to detect effects in bioassay systems because the [power-frequency fields] themselves are not the causal exposure in the epidemiologic associations.*"

Hence the weak epidemiology, and the lack health-effect evidence from either laboratory animal work or *in vitro* / mechanistic studies, tend toward the conclusion that exposure to the low levels of 60-Hz MF typical of the home, most occupational, and most electric transmission environments is highly unlikely to lead to adverse health effects.

10.2 Identifying "Effect" Levels from Epidemiology, Animal Studies, and Mechanistic Analyses

The "effect" levels from the epidemiologic associations have been stated to be in the 3 to 4 mG range.[14] However, this low range of MF levels results from the categories of MF exposure levels characteristic of the studied residential populations, and, due to the many uncertainties discussed above, cannot be accepted as a causal factor.

As can be seen from Figure 3 (Section 9.2), the laboratory animal experiments give no suggestion of carcinogenic effects in the range of exposures that have been studied, which extends upwards to 10,000 mG (10 G). This is considerably above the range to which the general public might be exposed, even

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[14] Kheifets L, Sahl JD, Shimkhada R, Repacholi MH. 2005. Developing policy in the face of scientific uncertainty: interpreting 0.3 microT or 0.4 microT cutpoints from EMF epidemiologic studies. *Risk Anal.* 25:927-35.

from short-term exposure to MF produced by operating electric appliances held in close proximity to the body.

From the mechanistic line of evidence, the three mechanisms judged to have borderline plausibility at elevated MF levels are magnetite particles, free radicals, and induced currents (Appendices C and E). The first two mechanisms, however, would also be responsive to static magnetic fields. There no established data suggesting that these mechanisms lead to adverse effects in the case of exposures to the Earth's magnetic field (~500 mG) or to the vastly higher exposure of humans to magnetic resonance imaging (MRI) procedure, which involve fields of the order of ~ 20,000 G (20,000,000 mG). Established effects of low-frequency time-varying induced currents at low levels are few in number, and include the induction of slight "flickering" in the visual field, which appear when the eyes are exposed to sufficiently large time-varying magnetic fields. Such magnetically-induced visual effects are called magnetophosphenes. [15] Magnetophosphenes disappear as soon as the magnetic field is no longer present, and the phenomenon is not known to have any long-lasting or adverse health effects. Neither short-term or long-term consequences have been reported in the individuals who have experienced magnetophosphenes. The threshold for such effects is in the vicinity of 100 G (100,000 mG) applied to the head in the frequency range of 20 to 60 Hz. These levels are also considerably above the range to which the public may be exposed.

10.3 Synthesis of a Guideline or Screening Level

Scientists have not identified a specific and established adverse health effect from typical levels of power-line EMF exposure, and hence the normal procedure of identifying an "adverse-effect level" and extrapolating downwards to no-effect levels cannot be followed. Scientific-consensus-group guideline levels based on assuring an absence of biological effects *pre se* vary from about 800 mG to 9,000 mG (See Appendix B). If avoidance of cancer risk is the central concern, it is logical to look to the laboratory-animal experiments, because such data form the basis for many of the Environmental Protection Agency's (EPA) established guidelines for limiting potential cancer risks from chemical exposures. [16] Here, the standard EPA procedure is to find a dose at which the lifetime incidence of tumors in animals is increased by exposure, and then to extrapolate backwards in dose (in a linear

15 Taki M, Suzuki Y, Wake K. 2003. Dosimetry considerations in the head and retina for extremely low frequency electric fields. *Radiat Prot Dosimetry*. 106:349-56.
Bailey WH. 2002. Health effects relevant to the setting of EMF exposure limits. *Health Phys*. 83:376-86.

16 See Integrated Risk Information System: http://www.epa.gov/iriswebp/iris/index.html

fashion) until an acceptable cancer risk level is reached. However, since even the most elevated levels of MF exposure have not been shown to increase the risk of tumors in laboratory animals (Fig. 3), such a standard linear-extrapolation procedure cannot be applied in a straightforward fashion.

The usual approach used by regulatory bodies in the face of missing or less-than-satisfactory dose-response data is to use the highest "no-effect" level [17] identified in careful, lifetime-exposure laboratory animal experiments (if available), and then apply several "safety factors" or "uncertainty factors" to ensure the absence of adverse health effects. The animal-carcinogenicity experiments undertaken by the National Toxicology Program (NTP), as well as those by other researchers, showed no increase in tumors at any MF exposure level. The highest levels of MF exposure thoroughly tested by the lifetime animal experiments were approximately 10,000 mG (1,000 μT) (Figure 3), and no increase in leukemias or other relevant tumors was identified. [18] Hence, 10,000 mG is a "no adverse effect level" or NOAEL in animals, applicable as a nearly-continuous, lifetime-average MF exposure level. As discussed in EPA guidance documents, [19, 20] animal data can be extrapolated to corresponding human NOAEL's, typically using uncertainty factors of 1, 3, or 10. Likewise, within-human variability of NOAEL's is

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17 Often identified as the "No Observed Adverse Effect Level" or NOAEL

18 Boorman GA, McCormick DL, Ward JM, Haseman JK, Sills RC. 2000. Magnetic fields and mammary cancer in rodents: a critical review and evaluation of published literature. *Radiat Res*. 153:617-26.

Boorman GA, Rafferty CN, Ward JM, Sills RC. 2000. Leukemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields. *Radiat Res*. 153:627-36.

Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, Kovatch RM, Sills RC, Haseman JK. 1999. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. *Toxicol Pathol*. 27:267-78.

McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, Pletcher JM, Sills RC, Haseman JK. 1999. Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice. *Toxicol Pathol*. 27:279-85.

McCormick DL, Ryan BM, Findlay JC, Gauger JR, Johnson TR, Morrissey RL, Boorman GA. 1998. Exposure to 60 Hz magnetic fields and risk of lymphoma in PIM transgenic and TSG-p53 (p53 knockout) mice. *Carcinogenesis.* 19:1649-53.

Boorman GA, Gauger JR, Johnson TR, Tomlinson MJ, Findlay JC, Travlos GS, McCormick DL. 1997. Eight-week toxicity study of 60 Hz magnetic fields in F344 rats and B6C3F1 mice. *Fundam Appl Toxicol*. 35:55-63.

19 USEPA. 2002. "A Review of the Reference Dose and Reference Concentration Processes." EPA/630/P-02/002F, December 2002. http://www.epa.gov/IRIS/RFD_FINAL[1].pdf

20 See USEPA 2005. "Guidelines for Carcinogen Risk Assessment" EPA/630/P-03/001F, and "Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens" EPA/630/R-03/003F http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=116283

accounted for by assigning an additional uncertainty factor of 1, 3, or 10. In order to develop the MF screening-value, we apply the maximum uncertainty factor (10) to each of these steps.

Incorporating one safety factor of 10 for animal-to-human extrapolation, and a second safety factor of 10 for the potential range of susceptibility within the human population, yields a screening level of 100 mG. An additional implicit safety factor would derive from applying this screening level as a maximum 24-hour-average MF, because lifetime-average MF levels (the relevant average exposure investigated in the animal studies) would be considerably lower, under such a 24-hr-average MF limit.

In summary, limiting MF levels under a screening-level of 100 mG (calculated as a 24-hour average) can be expected to assure an absence of undue risk of adverse health effects, even in a hypothetically more sensitive sub-population. This screening level is likely to be highly conservative (*i.e.*, health protective), because it is unknown how far above the reported NOAEL an actual frank, deleterious effect might be found in laboratory-animal experiments. Moreover, the safety factors applied to the animal NOAEL to calculate this MF value assumed that humans are greater than 100-fold more sensitive than animals, when in fact available data are just as consistent with an assumption of equivalent sensitivity or less sensitivity. Such alternative assumption would predict a screening level larger than 100 mG.

Appendix A

Public Health Scientific Consensus Groups: List and Sources of Information

List of Scientific Consensus Groups and Source Documents on EMF Health Effects

Scientific Group	Date last Reviewed	Title	Type of document	# of Pages	Source
American Cancer Society (ACS)	2002	Unproven Risks – Non-Ionizing Radiation	Summary paragraph	1	http://www.cancer.org/docroot/PED/content/PED_1_3X_Unproven_Risks.asp?sitearea=PED
American Conference of Governmental Industrial Hygienists (ACGIH®)	2005	Sub-Radiofrequency Magnetic Fields: TLV® Physical Agents 7th Edition (2001) *Documentation*	2005 TLV and BEI, ACGIH Booklet	11	http://www.acgih.org/Store/ProductDetail.cfm?id=1355
American Industrial Hygienist Association (AIHA)	2002	Position Statement on Extremely Low Frequency Fields	Position statement	2	http://www.aiha.org/GovernmentAffairs-PR/html/PosStatelf.htm
American Medical Association (AMA)	1994	Effects of Electric and Magnetic Fields (Website accessed 10-2005)	Report	12	http://www.ama-assn.org/ama/pub/category/13682.html
American Physical Society (APS)	2005	Electric and Magnetic Fields and Public Health	Position statement	1	http://www.aps.org/statements/05_3.cfm
Australian Radiation Protection and Nuclear Safety Agency (ARPNSA)	2003	The Controversy Over Electromagnetic Fields and Possible Adverse Health Effects	Fact sheet	4	http://www.arpansa.gov.au/is_emf.htm
British Columbia Center for Disease Control (BCCDC)	2005	Health Concerns of Power Frequency Electric and Magnetic Fields	Fact sheet	5	http://www.bccdc.org/content.php?item=57&PHPSESSID=5544d3b2f5d83c30568872fc0fa01854
British National Radiation Protection Board (NRPB) (now Health Protection Agency or HPA)	2004	Review of the Scientific Evidence for Limiting Exposure to (0 to 300 GHz) Electromagnetic Fields	Major review	223	http://www.hpa.org.uk/radiation/publications/documents_of_nrpb/abstracts/absd15-3.htm
Committee on Man and Radiation	2000	Possible Health Hazards from Exposure to Power-Frequency Electric and Magnetic Fields	Report	7	http://ewh.ieee.org/soc/embs/comar/elf.pdf
European Union (EU)	2001	Possible effects of Electro-magnetic Fields (EMF), Radio Frequency Fields (RF) and Micro-wave Radiation on human health	Report	13	http://europa.eu.int/comm/food/fs/sc/sct/out128_en.pdf

Scientific Group	Date last Reviewed	Title	Type of document	# of Pages	Source
Health Canada (HC)	2004	Electric and Magnetic Fields at Extremely Low Frequencies	Fact Sheet	2	http://www.hc-sc.gc.ca/iyh-vsv/environ/magnet_e.html
Institution of Electrical Engineers (IEE)	2001	Electromagnetic Fields and Health	Fact Sheet	10	http://www.iee.org/Policy/Areas/BioEffects/emfhealth.pdf
Institute of Electrical and Electronics Engineers (IEEE)	2002	Safety Levels With Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz (doc# ANSI/IEEE C95.6-2002)	Report/Standards	43	http://webstore.ansi.org/ansidocstore/product.asp?sku=ANSI%2FIEEE+C95%2E6%2D2002
International Agency for Research on Cancer (IARC)	2002	Static and Extremely Low-Frequency Electric and Magnetic Fields	Major review	390	http://www-cie.iarc.fr/htdocs/monographs/vol80/80.html
International Commission on Non Ionizing Radiation Protection (ICNIRP)	2004	Guidelines For Limiting Exposure To Time-Varying Electric, Magnetic, And Electromagnetic Fields (Up To 300 GHz)	Position statement	10	http://www.icnirp.org/documents/emfgdl.pdf
Medical College of Wisconsin (MCW)	2005	Electromagnetic Fields and Human Health: Power Lines and Cancer FAQs	Online questions and answers	119	http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ/toc.html#1
National Academy of Sciences / National Research Council (NRC)	1999	Research on Power-Frequency Fields Completed Under the Energy Policy Act of 1992	Book	112	http://www.nap.edu/catalog/9587.html
National Cancer Institute (NCI)	2003	Questions and Answers about the Electromagnetic Fields and Breast Cancer	Fact Sheet / Journal article	7	http://www.nci.nih.gov/newscenter/pressreleases/LIBCSPemfQandA/Schoenfeld et al. Electromagnetic fields and breast cancer on Long Island: A case-control study. American Journal of Epidemiology 158:47-58, 2003
National Cancer Institute (NCI)	1997	Residential exposure to magnetic fields and acute lymphoblastic leukemia in children	Journal article, results of major study	7	Linet *et al*. "Residential exposure to magnetic fields…" New England Journal of Medicine, 337(1): 1-7, 1997 (638 cases / 620 controls)

Scientific Group	Date last Reviewed	Title	Type of document	# of Pages	Source
National Institute of Environmental Health Sciences (NIEHS)	1999	1999 NIEHS Report on Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields/EMF Questions & Answers	Major review	80	http://www.niehs.nih.gov/emfrapid/home.htm
National Toxicology Program (NTP)	1999	NTP Technical Report on the Toxicology and Carcinogenesis Studies of 60-Hz Magnetic Fields in F344/n rats and B6C3FL mice	Report	170	http://ntp.niehs.nih.gov/ntp/htdocs/LT_rpts/tr488.pdf
Netherlands Health Council (NHC)	2004	Electromagnetic Fields: Annual Update 2003	Report	122	http://www.gr.nl/pdf.php?ID=886&p=1
Occupational Safety and Health Administration (OSHA)		Extremely Low Frequency (ELF) Fields: Standards	Standards	1	http://www.osha.gov/SLTC/elfradiation/standards.html
World Health Organization (WHO)	2001	Electromagnetic Fields and Public Health, Fact Sheet #263	Fact Sheet	5	http://www.who.int/docstore/peh-emf/publications/facts_press/efact/efs263.html
World Health Organization (WHO)	2003	WHO's Health Risk Assessment of ELF Fields	Journal article	3	Repacholi MH "WHO's Health Risk Assessment…" Radiation Protection Dosimetry, 106 (4) 297-299, 2003
U.S.A. State Reviews and Actions					
California Department of Health Services (Cal DHS)	2002	An Evaluation of the Possible Risks From Electric and Magnetic Fields (EMFs) From Power Lines, Internal Wiring, Electrical Occupations and Appliances	Major review and analysis of epidemiology only	401	http://www.dhs.ca.gov/ehib/emf/RiskEvaluation/ExecSumm.pdf
California Public Utilities Commission (CPUC)	2005	PUC Actions Regarding EMF	Actions statement	2	http://www.cpuc.ca.gov/static/energy/environment/electromagnetic+fields/action.htm
Connecticut Department of Public Health (CDPH)	2004	Electromagnetic Fields (EMF): Health Concerns	Fact Sheet	4	http://www.dph.state.ct.us/Publications/BRS/EOHA/emf_2004.pdf

Scientific Group	Date last Reviewed	Title	Type of document	# of Pages	Source
Florida Department of Environmental Protection (Fla DEP)	2003	2003 Annual Report on EMF Research	Report	6	http://www.dep.state.fl.us/siting/programs/electric_magnetic_rpt_2003.pdf
Maryland Department of Natural Resources (Maryland DNR)	1998/2001	Status Report on Investigations of Potential Human Health Effects Associated with Power Frequency Electric and Magnetic Fields	Report	32	http://esm.versar.com/pprp/bibliography/feb02bib/ppse-t-42.pdf (1998 Report) and http://esm.versar.com/pprp/bibliography/sec11.htm
Massachusetts, the Energy Facilities Siting Board (MA EFSB)	2005	Decision by the Energy Facilities Siting Board	Recent siting decision	1	http://www.mass.gov/dte/siting/efsb04-1/1223tendecp124-185.pdf
Minnesota Department of Health (MDH)	2002	A White Paper on Electric and Magnetic Field (EMF) Policy and Mitigation Options	White paper	50	http://www.health.state.mn.us/divs/eh/radiation/emf/emfrept.pdf
New Jersey Department of Environmental Protection (NJ DEP)	2004	60 Hertz Electrical Power	General Information	4	http://www.nj.gov/dep/rpp/nrs/powlines.htm
New York State Department of Health (NY DOH)	NA	Power Lines Project - Questions and Answers	Online questions and answers	NA	http://www.health.state.ny.us/nysdoh/consumer/environ/power.htm
Utah Department of Environmental Quality	2004/1993	ELF-EMF	Position statement	1	http://www.radiationcontrol.utah.gov/Drc_nion.htm and http://www.radiationcontrol.utah.gov/BOARD/emf_pos.htm
Vermont Department of Health (Vermont DOH)	2003	Position Paper on Electric and Magnetic Power Frequency Fields	Position statement	68	http://publicservice.vermont.gov/dockets/6860/6860-VDH-Exhibit3.pdf
Virginia Department of Health (Virginia DOH)	2000	Ongoing Research on the Health Effects of High-Voltage Transmission Lines	Report	26	http://www.vdh.state.va.us/HHControl/highfinal.PDF
Wisconsin Public Service Commission (Wisconsin PSC)	2001	EMF – Electric & Magnetic Fields	Fact sheet	22	http://psc.wi.gov/consumerinfo/brochures/electric/6002b.pdf

Appendix B

Public Health Scientific Consensus Groups: Summary Conclusions

"Blue Ribbon" Scientific Consensus Group Assessments of EMF, Health Effects and Exposure Guidelines

Scientific Group	Health Endpoints Considered	Overall Conclusions on Causal Role of EMF	Guidelines Proposed for Gen. Public	Guidelines Proposed for Workers	Recommendations	Level of Concern
American Cancer Society (ACS)	cancer	[EMF] not proven to cause cancer	none	none	none	low
American Conference of Governmental Industrial Hygienists (ACGIH)	health	there is insufficient information on human responses and possible health effects of magnetic fields in the frequency range of 1 Hz to 30 kHz to permit the establishment of a TLV for time-weighted exposures	none	10,000 mG (b)	none	low
American Industrial Hygiene Association (AIHA)	health	insufficient evidence of human health risk at EMF levels below ICNIRP guidelines	833 mG (a)	10,000 mG (b)	follow standards; characterize exposures; education; research	low
American Medical Association (AMA)	cancer / health	no scientifically documented health risk has been associated with the usually occurring levels of electromagnetic fields	none	none	education; lower field designs; awareness; research	low
American Physical Society (APS)	cancer / health	the conjecture relating cancer to power line fields has not been scientifically substantiated	none	none	none	low
Australian Radiation Protection and Nuclear Safety Agency (ARPNSA)	health	no evidence that prolonged exposures to weak EMF result in adverse health effects	1,000 mG	5,000 mG	minimize exposure; research	low
British Columbia Center for Disease Control (BCCDC)	health	evidence to date does not support the assumption that adverse health effects from exposure at current residential and occupational levels pose a risk to human health	833 mG (a)	4,200 mG (a) 10,000 mG (b)	none	low
British National Radiation Protection Board (NRPB), now Health Protection Agency (HPA)	health	recommend ICNIRP EMF limits; apparent increased risk of childhood leukemia >4 mG, but weak evidence does not justify causality; no evidence of other health effects	833 mG (a)	4,200 mG (a)	follow standards; research	low

Scientific Group	Health Endpoints Considered	Overall Conclusions on Causal Role of EMF	Guidelines Proposed for Gen. Public	Guidelines Proposed for Workers	Recommendations	Level of Concern
Committee on Man and Radiation	health	balance of evidence is against the fields encountered by the public being a cause of cancer or any other disease	9,040 mG	9,040 mG	no action needed	low
European Union (EU)	cancer / health	overall evidence for EMF to produce childhood leukemia is limited; no suggestions of any other cancer effects	833 mG (a)	4,200 mG (a)	none	low
Health Canada (HC)	health	no conclusive evidence of any harm caused by exposures at levels normally found in residential and work environments	none	none	no action needed	low
Institution of Electrical Engineers (IEE)	health	the balance of scientific evidence does not indicate that harmful effects occur in humans due to low-level electromagnetic field exposure	none	none	research	low
Institute of Electrical and Electronics Engineers (IEEE)	health	The LF-standard IEEE C95.6 is the leading standard worldwide on protection against ELF exposure to human beings. The basic restrictions are based on current biological knowledge. IEEE stds also adopted by International Committee on Electromagnetic Safety (ICES)	9,040 mG	9,040 mG	none	low
International Agency for Research on Cancer (IARC)	cancer	limited evidence in humans for childhood leukemia; inadequate evidence in humans for all other cancers	none	none	none	low / med
International Commission on Non Ionizing Radiation Protection (ICNIRP)	health	no convincing evidence for carcinogenic effects of EMF, thus data cannot be used to set guidelines re: cancer; ICNIRP guidelines are not based on cancer risks	833 mG (a)	4,200 mG (a)	adherence to standards; protective equipment when needed	low
Medical College of Wisconsin (MCW)	health	most scientists consider that the evidence that power line fields cause or contribute to cancer is weak to nonexistent	833 mG (a)	4,200 mG (a) 10,000 mG (b)	reference to various other organization listed on this table	low

Scientific Group	Health Endpoints Considered	Overall Conclusions on Causal Role of EMF	Guidelines Proposed for Gen. Public	Guidelines Proposed for Workers	Recommendations	Level of Concern
National Academy of Sciences / National Research Council (NRC)	cancer / health	body of evidence has not demonstrated that exposures to EMF are a human-health hazard	none	none	none	low
National Cancer Institute (NCI)	cancer (breast)	no association between exposure to EMF and breast cancer in Long Island	none	none	none	low
National Cancer Institute (NCI)	cancer (leukemia)	little support for hypothesis that EMF is related to risk of childhood leukemia	none	none	none	low
National Institute of Environmental Health Sciences (NIEHS)	health	weak evidence for possible health effects from EMF; but they cannot be ruled out, especially epidemiological associations with childhood leukemia	none	none	education; minimize exposures; lower field designs; check in-home wiring	low
National Toxicology Program (NTP)	cancer	in highly exposed rats and mice, there were no increased neoplasm incidences at sites for which epidemiology studies have suggested an association with EMF	none	none	none	low
Netherlands Health Council (NHC)	cancer	since the conclusion of the IARC is not different from that of the Committee, it adheres to its previously expressed view that, on the basis of the current level of knowledge, there is no reason to take such action [to reduce EMF levels]	none	none	further research (esp. prospective studies with adequate exposure assessment)	low
Occupational Safety and Health Administration (OSHA)	health	There are no specific OSHA standards that address ELF fields, however, there are national consensus standards which OSHA could consider (ACGIH and ICNIRP)	none	none	none	low
World Health Organization (WHO)	health	a cause-and-effect link between ELF field exposure and cancer has not been confirmed	833 mG (a)	4,200 mG (a)	adherence to standards; protective measures; education; open communication with public and health researchers	low

Scientific Group	Health Endpoints Considered	Overall Conclusions on Causal Role of EMF	Guidelines Proposed for Gen. Public	Guidelines Proposed for Workers	Recommendations	Level of Concern
World Health Organization (WHO)	health	The major concern is the epidemiological evidence that suggest and association between exposures to ELF MF and childhood leukemia. The reason is still unknown. There is much evidence from laboratory studies that these fields cannot induce or promote cancer.	none	none	further studies needed	
U.S.A. State Reviews and Actions						
California Department of Health Services (Cal DHS)	health	concern about possible health hazards- childhood leukemia, adult brain cancer, Lou Gehrig's disease and miscarriage, but evidence is incomplete, inconclusive and often contradictory	none	none	research; measurement; minimize exposures	low / med
California Public Utilities Commission (CPUC)	health	due to the lack of scientific or medical conclusions about potential health effects from utility electric facilities and power lines, the CPUC adopted interim measures	none	none	minimize exposure; low field designs ; measurement ; education; research	low
Connecticut Department of Public Health (CDPH)	health/cancer	despite extensive research over the past 20 years, the health risk caused by EMF exposure remains an open question; some studies show a weak link between EMF exposure and a small increased risk of childhood leukemia at average exposures above 3 mG; for cancers other than childhood leukemia, none of the studies provide evidence of an association.	none	none	reduce EMF exposures	low
Florida Department of Environmental Protection (Fla DEP)	health	no convincing evidence for carcinogenic effects of ELF fields	150 mG to 250 mG (c)	none	none	low

Scientific Group	Health Endpoints Considered	Overall Conclusions on Causal Role of EMF	Guidelines Proposed for Gen. Public	Guidelines Proposed for Workers	Recommendations	Level of Concern
Maryland Department of Natural Resources (Maryland DNR)	health	EMF exposures remain suspect, but remaining unknowns are the reason for continued lack of firm affirmation of health risks from EMF exposures	none	none	research	low
Massachusetts-Energy Facilities Siting Board (MA EFSB)	health	in reviewing proposed transmission line facilities, the Siting Board has informally adopted edge-of-ROW permissible levels of 85 mG for magnetic fields	85 mG	none	none	NA
Minnesota Department of Health (MDH)	health	body of evidence is insufficient to establish a cause and effect relationship between EMF and adverse health effects	none	none	minimize exposure; energy conservation; education; communication	low
New Jersey Department of Environmental Protection (NJ DEP)	health	it is not know at this point whether exposure to magnetic fields from power frequency sources constitutes a health hazard	none	none	research	low
New York State Department of Health (NY DOH)	NA	"webpage being updated" ROW document: http://www3.dps.state.ny.us/pscweb/WebFileRoom.nsf/0/9C381C482723BE6285256FA1005BF743/$File/26529.pdf	200 mG (d)	NA	NA	NA
Utah Department of Environmental Quality	health	there is no convincing evidence in the published literature to support the contention that exposures to extremely low frequency electric and magnetic fields (ELF-EMF) generated by sources such as household appliances, video display terminals, and local power lines are demonstrable health hazards	none	none	research; monitor literature	

Scientific Group	Health Endpoints Considered	Overall Conclusions on Causal Role of EMF	Guidelines Proposed for Gen. Public	Guidelines Proposed for Workers	Recommendations	Level of Concern
Vermont Department of Health (Vermont DOH)	health	data is insufficient to establish a direct cause and effect between EMF exposure and adverse health effects	833 mG (a) 150 mG to-250 mG (c, d) 9,040 mG (e)	4,200 mG (a)	"prudent avoidance"; minimize exposures; education ; communication with public	low
Virginia Department of Health (Virginia DOH)	health	tests for causality have not been satisfied for the implicit deleterious health effects	none	none	none	low
Wisconsin Public Service Commission (Wisconsin PSC)	health	potential for health risks for exposure to EMF is very small.	none	none	continue review of research	low

Footnotes:

"low" level of concern: very limited evidence of health effects; mitigation only if at very low cost

"low / medium" level of concern: limited evidence but precautionary principles apply and mitigation when possible

(a) ICNIRP: guideline for exposure to 60 Hz EMF
(b) ACGIH: guideline for exposure to 60 Hz EMF (an interim TLV, on 2005 list for "Notice of Intended Changes")
(c) Florida: Guideline levels *per se* are *status quo*, not health based: 150 mG (69-230 kV lines); 200 mG and 250 mG (500 kV lines), at ROW edge
(d) New York: Guideline levels *per se* are *status quo*, not health based: 200 mG at ROW edge. See: http://www3.dps.state.ny.us/pscweb/WebFileRoom.nsf/0/9C381C482723BE6285256FA1005BF743/$File/26529.pdf
(e) IEEE standard for general public: 9,040 mG

Appendix C

APPENDIX C:

Physics, Biophysics, and Plausibility of EMF Mechanisms of Interaction

Supplementary Information on Mechanistic Considerations

Details on the Electromagnetic Spectrum. The table below is a detailed version of Table 1, which appeared earlier in the text. Key relationships for Table C1 are:

> frequency (ν) × wavelength (λ) = speed of light (c);
> Energy (E) = Planck's constant (h) × frequency (ν)
> Example, for 60 Hz (= 60/sec), $\lambda = (3\times10^{8}$ m/sec) / (60 /sec) = 5,000 km;
> $E = (4.1\times10^{-15}$ eV-sec) × (60/sec) = ~ 2.5×10^{-13} eV = ~ 0.25 peV
> "eV" = "electron volt" = is an energy unit for atoms and molecules; peV = 10^{-12} eV
> 1 eV = 1.6 picoerg = energy acquired by a singly charged particle accelerated through 1 V

Table C1: The electromagnetic spectrum includes 60 Hz EMF, radio waves, light energy, ultraviolet light, and x-rays in a continuum

ELF	**AM Radio**	**FM / TV**	**Microwave and Radar**	**Radiant Heating, Infrared**	**Sun Lamps, Visible Light**	**Medical X-Rays**	**α-, β-, γ-Rays**
λ= 3000 km ν = 100 Hz E = 0.4 peV	3 km 100 kHz 0.4 neV	3 m 100 MHz 0.4 μeV	3 mm 100 GHz 0.4 meV	30 μm 10^{13} Hz 0.04 eV	300 nm 10^{15} Hz 4 eV	3 Δ 10^{18} Hz 4 keV	0.3 pm 10^{21} Hz 4 MeV
♦ Power lines 50 – 60 Hz		♦ Cell phones, ~ 1 – 2 GHz		♦ Human body heat ← ← ← ←	♦ Vision <u>Non-ionizing</u>←	→ <u>Ionizing</u>	♦ Cosmic rays → → → →
(*induced*	*currents*)	(*RF heating*	*currents*)	(*photo —*	*chemistry*)	(*molecular*	*damage*)

The amount of energy in individual photons of electromagnetic energy in the ionizing range can disrupt chemical bonds, whereas in the infrared region and below (radio waves and EMF), the photons cannot damage molecules. For quantum interactions, the amount of energy (in electron-volts) that individual photons can deliver to atoms and molecules is shown on Table C2. Because chemical bonds have strengths of the order of 1 electron-volt and higher, photons from any portions of the electromagnetic spectrum below visible light cannot disrupt chemical bonds. In fact, we know that the chemistry of life is not affected by thermal energies corresponding to 37°C (310 K), and the energy of thermal collisions among molecules is about ~0.03 electron-volt.[1] In body fluids molecules move at

[1] For molecules that are in equilibrium with an absolute temperature T (Kelvin units), the thermal energy of each mode of movement (translation, rotation, vibration) is approximately kT, where k is Boltzmann's constant. The size of Boltzmann's constant is such that the energy per degree Kelvin is (86 μeV / K). Hence 310 K (body temperature) corresponds to 27 meV or approximately 0.03 eV.

~1,000 m/sec, undergo about 10^{12} (trillion) collisions per second, and have a Brownian displacement in one second of about 15 µm. Hence, any energy added by EMF must compete against this robust background of energetic activity. Table 2 shows that photons below the infrared portion of the spectrum do not achieve even the threshold of ~0.03 eV energies from background thermal collisions at 37°C. The photon energy of power-line EMF is far below this level.

Table C2: Comparison of Photon Energy (eV) and Interactions with Molecules Across the Spectrum

Spectrum	Photon Energy [2]	Effect on Molecules
Soft x-rays	20,000 eV	ionize
Visible light	2.0 eV	bend (*i.e.*, isomerize)
Infrared waves	0.02 eV	disaggregate (*i.e.*, melt solids)
Millimeter radar	0.0002 eV	rotate, vibrate
Television RF	0.00000002 eV	no known molecular effects
60-Hz EMF	0.0000000000002 eV	no known molecular effects

One important caveat to the above discussion, based on the energy of EMF photons, needs to be considered. That is, an exception to the above "no-effect" conclusion occurs, of course, when the electric-field strength is sufficiently large to cause a "corona" discharge. That is, at field strengths in the 100 kV/m range, free electrons (or ionized molecules) in the air may be electrically accelerated during one-half of the 60-Hz cycle so as to achieve kinetic energy sufficient to disrupt chemical bonds upon collision with molecules. However such high field strengths do not occur except in very close proximity to high-tension transmission lines, and lower field levels are not able to accelerate electrons to ionizing energy levels either in air or in fluid.

The basic interactions of electromagnetic fields with matter involve force on fixed and moving charges, [3] with the possibility of classical energy transfer (thermal energy) and quantum interactions with molecules (photon effects – see above). At sufficiently high levels of EMF, these forces can add small amounts of thermal energy (*i.e.*, energy dissipation from accelerated ions) or change the behavior of a charged biological molecule or structure. For example, because of electric charges associated with proteins or membranes, and EMF force may change the shape of a protein anchored in the cell membrane, and possibly interfere with its ability to function as an enzyme, a receptor, or an ionic gate. However, magnitudes of endogenous forces that are known to act at the cellular level to modify protein structures have been measured, and the data demonstrate that biological structures can withstand

[2] The energy of a photon of an electromagnetic wave is $E = h\nu$. where ν is the frequency and h is Planck's constant. The size of Plank's constant is such that 60 Hz photons have an energy of 0.25 pico-electron volts (peV). As another example, millimeter radar has a wavelength of 6 mm (λ = 6 mm, ν = 50 GHz), and the photon energy is 200 µeV.

[3] The fundamental relationship between electric field and force is given in Coulomb's Law, which relates force (F) to charge (q) and electric field (E): $F = qE$. The direction of the force is parallel to the electric field.
The fundamental relationship between magnetic field and force is given by the Lorentz's Law, which relates force (F) to charge (q), the velocity of the charge (v), and magnetic field (B): $F = q (v \times B)$. The "×" symbol tells us that the force is perpendicular to the plane formed by the direction of the magnetic field and the velocity. For charges traveling in a wire, the magnetic field tells us the force-per-unit-length-of-wire per unit current.

forces far larger than can be generated by power-line EMF. That is, failure to observe mechanistically plausible biological effects from EMF exposure is likely due to the fact that effects of EMF on biology are very weak (Valberg et al. 1997). Cells and organs function properly in spite of many sources of intrinsic chemical "noise" (*e.g.*, stochastic, temperature, concentration, mechanical, and electrical noise), which exceed the effects caused by EMF by a large factor (Weaver et al. 2000).

Table C3 shows that, in terms of energy or force on the whole-body scale or on the molecular scale, the effect of even "large" EMF is many orders of magnitude below the typical forces and energies that accompany life processes. For example the energy of a 60-Hz EMF photon is vastly less than that of ionizing radiation, and EMF is too weak to alter molecular structures. The intensity of the electric field *per se* could be increased to levels where it accelerates individual free electrons to electron-volt energies, exceeding those needed to break a chemical bond (as for example, in corona discharge). However, the level of electric-field intensity required for this type of molecular damage is far above that to which any organism would be exposed in environmental, power-line EMF. Likewise EMF forces on biological structures can easily be calculated, but the force required to distort the shape of complex biological molecules, for example DNA or enzymes, is far larger than what the electric component of EMF can provide.

Table C3: Biological Process Strength Compared to EMF Interaction Strength

Interaction process	**Baseline strength in living systems**	**Interaction strength for typically "large" EMF levels** [*e.g.*, 1,000 V/m and 100 μT (or 1,000 mG), 60-Hz fields]
Heating	basal metabolism ~ 100 watts	absorbed 60-Hz EMF energy = ~ 0.000 01 Watts (*i.e.*, **10 μwatts** is ~10 million fold below basal metabolism)
Photon absorption	chemical bond energies of ~ 0.1 to 5 eV	60-Hz EMF photons = ~0.000001 electron-volt (eV) (*i.e.*, EMF ~ **1 μeV**, whereas X-Rays ~ 500 to 5,000 eV)
Force (electrical)	biological forces ~1 to 100 pN	Force on molecule with ±100 electric charges ~ **0.0002 pN** (pN = 10^{-12} N = 0.000 000 000 001 Newton)
Force (magnetic)	biological forces ~1 to 100 pN	Twisting force on microscopic ferromagnetic particles, (acting like compass needles), ~**2 pN**, but EMF force alternates direction every 1/120th s, and averages to zero
Biochemistry	free-radical recombination lifetimes ~ 2 ns	Free-radical chemistry requires >1,000 mG, and any effects must occur over nanoseconds (ns), so that 60-Hz fields (with period of **17 milliseconds**) are identical to earth's static field

The only interaction on Table C3 approaching the realm of physical plausibility is the twisting of magnetic particles (which would act like compass needles) or molecular magnetic moments by the 1,000 mG field. Although magnetite particles may function as geomagnetic field sensors (Adair 1994; Kirschvink *et al*. 1992, 2001), functional biogenic ferromagnetic material is found only in a limited number of organisms (for example, magnetotactic bacteria) (Blakemore, 1982). Such sensory guidance function is not likely to be related to disease initiation. Moreover, the response of ferromagnetic particles to 60-Hz magnetic fields is limited by the reversal the power-line magnetic field direction 120 times every second. That is, any rotation over the first $1/120^{th}$ of a second will be reversed by the next $1/120^{th}$ of a second, so that the average of the full cycle ($1/60^{th}$ second) will be zero. Because of the viscosity of biological materials, only a tiny amount of twist can take place even during the $1/120^{th}$ of a second that the magnetic field points in a given direction.

Consistent and reproducible laboratory effects from low-level power-line EMF exposure have not been established. This is likely due to the fact that typical power-line EMF do not affect biology in a manner detectable above the many sources of disturbance ("noise") in biological systems. This inability of power-line EMF to cause effects in bioassay systems leads to the conclusion that EMF is not playing a causal role in the epidemiologic associations.

Appendix D

List of Recent Key Studies: Epidemiology, Animal, and Mechanistic

EPIDEMIOLOGICAL STUDIES

E1) Draper G , Vincent T et al: Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. BMJ:1290-1293, 2005

E2) Greenland S. Multiple-bias modelling for analysis of observational data
Journal Of The Royal Statistical Society Series A-Statistics In Society 168: 267-291 Part 2, 2005

E3) Kheifets L, Shimkhada R. Childhood leukemia and EMF: Review of the epidemiologic evidence. Bioelectromagnetics. 2005 Jul 29;26(S7):S51-S59 [Epub ahead of print]

E4) Klaeboe L , Blaasaas KG et al: Residential and occupational exposure to 50-Hz magnetic fields and brain tumours in Norway: a population-based study. Int J Cancer 115:137-141, 2005.

E5) Kleinerman RA , Linet MS et al: Self-reported electrical appliance use and risk of adult brain tumors. Am J Epidem 161:136-146, 2005.

E6) Baldwin, RT, Preston-Martin, S Epidemiology of brain tumors in childhood - a review Toxicology And Applied Pharmacology 199 (2): 118-131, 2004.

E7) Mizoue T, Onoe Y, Moritake H, Okamura J, Sokejima S, Nitta H. Residential proximity to high-voltage power lines and risk of childhood hematological malignancies. J Epidemiol. 2004 Jul;14(4):118-23.

E8) Schlehofer B, Hettinger I et al: Occupational risk factors for low grade and high grade glioma: Results from an international case control study of adult brain tumours. Int J Cancer 113:116-125, 2004.

E9) Brain JD , Kavet R et al: Childhood leukemia: electric and magnetic fields as possible risk factors. Environ Health Perspect 111:962-970, 2003.

E10) Infante-Rivard, C.; Deadman, J. E. Maternal occupational exposure to extremely low frequency Magnetic fields during pregnancy and childhood leukemia. Epidemiology 14(4):437-441 2003

E11) Linet MS,Wacholder S et al: Interpreting epidemiologic research: lessons from studies of childhood cancer. Pediatrics 112:218-232, 2003.

E12) Tynes T, Haldorsen T. Residential and occupational exposure to 50 Hz magnetic fields and hematological cancers in Norway. Cancer Causes Control. Oct;14(8):715-20 2003.

E13) Willett, EV; McKinney, PA; Fear, NT; Cartwright, RA; Roman, E
Occupational exposure to electromagnetic fields and acute leukaemia: analysis of a case-control study Occup Environ Med 60: 577-583 2003.

E14) Lagiou, P.; Tamimi, R.; Lagiou, A.; Mucci, L.; Trichopoulos, D.
Is epidemiology implicating extremely low frequency electric and magnetic fields in childhood leukemia? Environ Health Prev Med 7(2):33-39 2002

E15) Navas-Acién A , Pollán M et al: Interactive effect of chemical substances and occupational electromagnetic field exposure on the risk of gliomas and meningiomas in Swedish men. Cancer Epidem Biomark Prev 11:1678-1683, 2002.

E16) Oppenheimer M and Preston-Martin S Adult onset acute myelogenous leukemia and electromagnetic fields in Los Angeles County: Bed-heating and occupational exposures. Bioelectromag 23:411-415, 2002.

E17) Skinner, J; Mee, TJ; *et al*. Exposure to power frequency electric fields and the risk of childhood cancer in the UK British Journal Of Cancer 87: 1257-1266 2002

E18) Villeneuve PJ , Agnew DA et al: Brain cancer and occupational exposure to magnetic fields among men: Results from a Canadian population-based case-control study. Int J Epidem 31:210-217, 2002.

E19) Kheifets LI Electric and magnetic field exposure and brain cancer: A review. Bioelectromag Suppl 5:S120-S131, 2001.

E20) Schüz J, Grigat JP et al: Residential magnetic fields as a risk factor for childhood acute leukaemia: Results from a German population-based case-control study. Int J Cancer 91:728-735, 2001.

E21) UK Childhood Cancer Study Investigators: Childhood cancer and residential proximity to power lines. Brit J Cancer 83:1573-1580, 2000.

ANIMAL STUDIES

A1) Sommer AM and Lerchl A The risk of lymphoma in AKR/J mice does not rise with chronic exposure to 50 Hz magnetic fields (1 mT and 100 mT). Rad Res 162:194-200, 2004.

A2) Abramsson-Zetterberg L and Grawé J Extended exposure of adult and fetal mice to 50 Hz magnetic field does not increase the incidence of micronuclei in erythrocytes. Bioelectromag 22:351-357, 2001.

A3) Anderson LE , Morris JE et al: Large granular lymphocytic (LGL) leukemia in rats exposed to intermittent 60 Hz magnetic fields. Bioelectromag 22:185-193, 2001.

A4) Heikkinen P , Kosma VM *et al*. Effects of 50-Hz magnetic fields on cancer induced by ionizing radiation in mice. Int J Radiat Biol 77:483-495, 2001.

A5) Vallejo D , Sanz Pet al: A hematological study in mice for evaluation of leukemogenesis by extremely low frequency magnetic fields. Electro Magnetobio 20:281-298, 2001.

A6) Babbitt JT , Kharazi AI *et al.* Hematopoietic neoplasia in C57BL/6 mice exposed to split-dose ionizing radiation and circularly polarized 60 Hz magnetic fields. Carcinogenesis 21:1379-1389, 2000.

A7) Boorman GA , McCormick DL *et al.* Magnetic fields and mammary cancer in rodents: A critical review and evaluation of published literature. Radiat Res 153:617-626, 2000.

A8) Boorman GA , Rafferty CN *et al.* Leukemia and lymphoma incidence in rodents exposure to low-frequency magnetic fields. Radiat Res 627-636, 2000.

A9) Devevey L , Patinot C. et al: Absence of the effects of 50Hz magnetic fields on the progression of acute myeloid leukaemia in rats. Int J Radiat Biol 76:853-862, 2000.

A10) Mandeville R , Franco E *et al*. Evaluation of the potential promoting effect of 60 Hz magnetic fields on N-ethyl-N-nitrosourea induced neurogenic tumors in female F344 rats. Bioelectromag 21:84-93, 2000.

A11) McCann J, Kavet R, Rafferty CN. Assessing the potential carcinogenic activity of magnetic fields using animal models. Environ Health Perspect. 2000 Mar;108 Suppl 1:79-100.

A12) Boorman GA , McCormick DL et al: Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats. Toxicol Pathol 27:267-278, 1999.

A13) McCormick DL , Boorman GA et al: Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice. Toxicol Pathol 27:279-285, 1999.

MECHANISTIC AND *IN VITRO* STUDIES:

M1) Ivancsits, S., *et al.* Cell type-specific genotoxic effects of intermittent extremely low-frequency electromagnetic fields. Mutat Res 583(2):184-188 2005.

M2) Swanson, J and L. Kheifets Bio-physical mechanisms: a component in the weight of evidence for EMFs. in press.

M3) Vijayalaxmi and Obe G Controversial cytogenetic observations in mammalian somatic cells exposed to extremely low frequency electromagnetic radiation: A review and future research recommendations. Bioelectromag 26:412-430, 2005.

M4) Wolf, FI.; *et al.* 50-hz extremely low frequency electromagnetic fields enhance cell proliferation and dna damage: possible involvement of a redox mechanism. Biochim Biophys Acta 1743(1-2):120-129 2005

M5) Risk evaluation of potential environmental hazards from low-frequency electromagnetic field exposures using sensitive in vitro methods (REFLEX Report). European Union, 2004.
On-line at: http://www.itis.ethz.ch/downloads/REFLEX_Final%20Report_171104.pdf

M6) Stronati L , Testa A et al: Absence of genotoxicity in human blood cells exposed to 50 Hz magnetic fields as assessed by comet assay, chromosome aberration, micronucleus, and sister chromatic exchange analyses. Bioelectromag 25:41-48, 2004.

M7) Testa A , Cordelli E et al: Evaluation of genotoxic effect of low level 50 Hz magnetic fields on human blood cells using different cytogenetic assays. Bioelectromag 25:613-619, 2004.

M8) Cho YH and Chung HW The effect of extremely low frequency electromagnetic Fields (ELF-EMF) on the frequency of micronuclei and sister chromatid exchange in human lymphocytes induced by benzo(a)pyrene. Toxicol Let 143:37-44, 2003.

M9) Ikeda, K.; Shinmura, Y.; *et al*. No effects of extremely low frequency magnetic fields found on cytotoxic activities and cytokine production of human peripheral blood mononuclear cells in vitro. Bioelectromagnetics 24(1):21-31 2003

M9) Ikeda, K.; Shinmura, Y.; *et al*. No effects of extremely low frequency magnetic fields found on cytotoxic activities and cytokine production of human peripheral blood mononuclear cells in vitro. Bioelectromagnetics 24(1):21-31 2003

M10) Ivancsits S, Diem E *et al*. Intermittent extremely low frequency electromagnetic fields cause DNA damage in a dose-dependent way. Int Arch Occup Environ Health 76:431-436, 2003.

M11) Ivancsits S, Diem E *et al*. Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts. Mut Res 519:1-13, 2002.

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Appendix E

Summary Conclusions from Recent Key Literature Articles
Part 1: Epidemiology: E1 through E21
Part 2: Laboratory Animal Research: A1 through A13
Part 3: Mechanistic and In Vitro Research: M1 through M16

Summary of Current Epidemiological Studies of EMF and health effects

Citation E1:	Draper G. *et al*. BMJ 2005, 330: 1290-1293
Article Title	Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study
Study Name (if any)	
Study Type	Case-control
Study Population	Records of 29,081 children with cancer, including 9700 with leukemia; children ages 0-14 born in England and Wales (1962-1995); Controls matched for sex, approximate date of birth, birth registration district
Health Effects Studied	Childhood cancer (Leukemia, CNS/brain tumors, Other)
Effects Data Source	Cancer registry
Type of power frequency field	Low frequency magnetic fields from 275, 400 and 132 kV power lines
Exposure Data Source	National Grid records; distance from home address at birth to the nearest high voltage overhead power line
Exposure Levels/ Length	Distance to line (meters) was divided up into increments of 0-49, 50-99, 100-199….500-599, >600 (reference)
What They Did	Used conditional logistic regression on matched case-control pairs to calculated relative risks of childhood leukemia associated with distance to power lines
Results	• Children who lived within 200 meters of a high voltage power line at birth had a RR of leukemia of 1.69 (95% CI: 1.13-2.53) • Children who lived between 200 and 600 m had a RR of 1.23 (1.02-1.49). • Adjustment for socioeconomic status changed the estimates very slightly (1.68, 1.22) • There was a significant trend in risk in relation to the reciprocal of distance to the line. • No excess risk with proximity to lines for any other childhood cancer.
Conclusions	'There is an association between childhood leukemia and proximity of home address at birth to high voltage power lines, and the apparent risk extends to a greater distance than would have been expected from other studies. About 4% of children in England and Wales live with 600 m of high voltage power lines at birth." This could account for about 1% of childhood leukemia if the association is real.
Study Limitations	• Selection bias associated with selection of controls, but no participation bias • No actual estimates or measures of magnetic field levels from power lines or other sources
Comments[a]	• Results are not consistent with the large UK Child Cancer Study (2000-see below). • The reference group (>600m) has no biological significance as beyond 200 m exposures are considered to be background levels. • A strengths of the study is the large number of cases.

Citation E2:	Greenland S. Journal Of The Royal Statistical Society Series A-Statistics In Society 168: 267-291 Part 2, 2005
Article Title	Multiple-bias modeling for analysis of observational data
Study Name (if any)	
Study Type	Review; Statistical analysis
Study Population	Various Childhood leukemia studies
Health Effects Studied	Childhood leukemia
Effects Data Source	14 Epidemiological Studies
Type of power frequency field	Low frequency magnetic fields
Exposure Data Source	Direct measurements or calculated fields
Exposure Levels/ Length	
What they did	Multiple-bias modeling was done on a pooled analysis of 12 pre-1999 case–control studies of residential magnetic fields and childhood leukemia and two additional studies unpublished at the time of the analysis. This analysis allows systematic integration of major sources of uncertainty.
Results	• The odds ratios were consistent across studies (homogeneity P =0.24), and the pooled odds ratio was 1.69 (1.28- 2.23) for an estimated average exposure above 3 mG. • The association is not explained or modified by any known study characteristic or features of the data, such as using finer categories or continuous field measurements • There was no evidence of publication bias • The conventional analysis, however, ignore every source of uncertainty other than random error, including: ▶ Possible uncontrolled shared causes (confounders) of field exposure and leukemia ▶ Possible uncontrolled associations of exposure and disease with selection and participation (sampling and response biases) ▶ Magnetic field measurement errors. • The multiple-bias analysis showed that selection bias was present but unlikely to account for the associations. • Also, confounding was probably less important than selection bias and that misclassification tended to increase the risk estimates but also increase the confidence intervals.
Conclusions	The authors concluded that study limitations accounted for most of the uncertainty in the risk estimates and that little added information would come from more studies using similar designs.
Study Limitations	NA
Comments[a]	NA

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E3:	Kheifets L, Shimkhada R. Bioelectromagnetics. 2005 Jul 29;26(S7):S51-S59
Article Title	Childhood leukemia and EMF: Review of the epidemiologic evidence.
Study Name (if any)	
Study Type	Review
Study Population	Children
Health Effects Studied	Leukemia
Effects Data Source	Review of Published Epidemiological Studies
Type of power frequency field	Low frequency and radio frequency magnetic fields
Exposure Data Source	Various
Exposure Levels/ Length	Various
What They Did	The authors report on the possible explanations for the consistent but small relative risk found in epidemiological studies of EMF exposure and childhood leukemia including random error or chance, selection bias, exposure misclassification, and confounding. Summaries of two pooled analyses (Ahlbom and Greenland) are also presented.
Results (Summary)	• Errors due to random error or chance are unlikely since the pooled analyses (large sample size) demonstrate consistency in the size of the effect and confidence intervals. • Some evidence of selection bias from recent studies in which exclusion of participants increased the risk estimates for leukemia. • Exposure misclassification is typically non-differential in that it affects controls and cases equally, tending to bias results towards the null. • The etiology of leukemia is poorly understood, thus identifying potential confounders has been difficult. • Multiple-bias analysis has shown that study design and limitations account for uncertainty in most epidemiological studies. More studies of similar design would not improve estimate uncertainty (See Greenland 2005, E2)
Conclusions	All possible theories (contact currents, melatonin and children's susceptibility) are speculative and no solid evidence has been provided in the literature to support them. "It is worth mentioning that epidemiologic data appears to be not only consistent, but also specific. For cancer, the observed association seems to be limited to leukemia, and even more specifically to childhood leukemia." This consistent and specific association was the basis for IARC's classification of ELF as a "possible carcinogen"
Study Limitations	NA
Comments[a]	NA

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E4:	Klaeboe L , Blaasaas KG et al: Int J Cancer 115:137-141, 2005.
Article Title	Residential and occupational exposure to 50-Hz magnetic fields and brain tumors in Norway: a population-based study.
Study Name (if any)	
Study Type	Nested case-control
Study Population	Norwegian subjects 16 yrs or older residing in "a broad corridor" around a high voltage power line 454 cases/908 controls
Health Effects Studied	Brain tumors
Effects Data Source	Cancer Registry of Norway
Type of power frequency field	Low frequency magnetic fields
Exposure Data Source	• Magnetic fields were calculated taking into account height of the tower, distance between phases, ordering of phases, distance between power line and house, and average load on the power line. • Magnetic fields exposure at work was assessed using an expert panel and job titles.
Exposure Levels/ Length	A time-weighted average residential exposure was categorized as < 0.05 μT, 0.05-0.19 μT and ≥ 0.2 μT
What They Did	Odds ratios (OR) with 95% confidence intervals (CI) were calculated using conditional logistic models, adjusting for education level and type of residence to determine whether residential or occupational exposures to magnetic fields increased the risk of brain tumors in adults.
Results	• For residential exposures the risk for all brain tumors was OR= 1.3 (CI: 0.7-2.3), for a calculated exposure ≥ 0. 2 μT, with 21 cases. • Risks for meningioma were significant for the intermediate exposure category (0.05-0.19 μT) with an OR=3.0 (CI: 1.0-9.2), 8 cases • The risk for all brain tumors was increased and significant when considering exposures in the last 5 years before diagnosis (OR=1.6 (CI: 1.0-2.5), 35 cases. • Occupational exposure showed an inverse association to exposure for all brain tumor, OR= 0.6 (CI 0.3-0.9) and all of the specific brain tumors in the highest exposure category (≥31 years). • Combined high residential and occupation exposures gave an OR= 1.0 (CI: 0.4-27) • Adjustments for education and type of residence had very little effect on the estimates
Conclusions	The authors found a moderately elevated risk of brain tumors from residential exposures, but state that "our data provide no clear evidence of an association between brain tumors and electromagnetic fields when evaluating time-weighted average residential magnetic fields". No clear exposure-response pattern was found and the findings for occupational exposure groups showed an inverse association.
Study Limitations	No actual measurements of EMF in residential or occupational settings, lead to exposure misclassification. Occupational exposures were based on very crude exposure classifications
Comments [a]	The study was population based and had access to a large and complete data from the Norwegian Cancer Registry

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E5:	Kleinerman RA , Linet MS *et al.* Am J Epidem 161:136-146,
Article Title	Self-reported electrical appliance use and risk of adult brain tumors.
Study Name (if any)	
Study Type	Case-control
Study Population	Adults; 410 glioma, 178 meningioma, and 90 acoustic neuroma cases and 686 controls
Health Effects Studied	Intracranial glioma or neuroepitheliomatous tumor, meningioma, or acoustic neuroma
Effects Data Source	Regional referral centers for diagnosis and treatment of brain tumors (Boston, MA; Phoenix, AZ; and Pittsburgh, PA)
Type of power frequency field	Low frequency magnetic fields
Exposure Data Source	Questionnaire on 10 common household appliances used near the head and 4 not used near the head
Exposure Levels/ Length	Appliance use: ever use; age first and last use; frequency of use
What They Did	Unconditional logistic regression was used to generate odds ratios and 95% confidence intervals associated with the risk of brain tumors from exposures to magnetic fields from use of household appliances.
Results	• There was little evidence of any associations between brain tumors and use of curling irons, heating pads, vibrating massagers, electric blankets, heated water beds, sound systems, computers, televisions, humidifiers, microwave ovens, and electric stoves. • Ever use of a hair dryer was associated with a significantly increased risk of glioma in males and females, with an odds ratio (OR) of 1.7 (CI 1.1-2.5), and was significant for males only OR=1.7 (1.1-2.7), but not females alone OR 2.2 (0.7-6.5). There was no clear pattern of increase risk with increased use of hair dryers • The risk for meningioma was significantly associated with ever use by males of an electric shaver, OR = 10.9 (CI 1.7-50). • The risk for use of either rechargeable or plug-in shavers was ORs of 10.6 (CI 1.7-68) and 16.5 (CI 2.8-95), respectively. • For meningioma the odds ratio increased with increased years of use of electric shavers.
Conclusions	• Twelve of the 14 appliances studied showed no association between risk of brain tumors and exposures. • This is the first study to evaluate associations between hair dryer and shaver use and risk of brain tumors. • The inconsistent associations found for hair dryers are difficult to interpret. • The high association found for shavers and risk of meningioma is "noteworthy but should be interpreted cautiously pending replication in other study populations" according to the authors. Furthermore, they note that the findings lack biologic and epidemiologic plausibility. • The potential for recall bias as well as the lack of internal consistency in the results argue against a causal role of EMF from appliances and the occurrence of brain tumors in adults.

Citation E5:	Kleinerman RA , Linet MS *et al.* Am J Epidem 161:136-146,
Study Limitations	• Recall bias can lead to differential exposure misclassification from a possible tendency by cases to over-report appliance use, and similarly under-reporting by controls. • Other appliances used near the head were not included in the study • Cumulative exposures from several appliances were not considered. • There were several reasons including internal inconsistencies that make the finding of high ORs from shavers suspect ▶ Results were based on only 2 non-exposed case subjects. ▶ Men had longer cumulative exposures to hair dryers than electric shavers, yet there was no significant meningioma association with this appliance. ▶ Rechargeable (battery operated) shavers produce much lower ELF EMF exposures than shavers operating from household current (although they do generate higher frequency transients), yet ORs for the two types of shavers are similar. ▶ Since electric shaver exposure to the head is unique to men, there should be a differential effect on meningioma incidence, but meningioma is 2-3 times more common in women than men. • A chance association could also explain observed associations with shavers and hair dryers
Comments [a]	Largest weakness was the lack of real exposure data and dependence on the questionnaire data that is prone to recall bias (as recognized by the authors). The large number of comparisons done make a chance association possible.

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E6:	Baldwin, RT, Preston-Martin, S Toxicology And Applied Pharmacology 199 (2): 118-131, 2004.
Article Title	Epidemiology of brain tumors in childhood - a review
Study Name (if any)	
Study Type	Review
Study Population	Children
Health Effects Studied	Brain Tumors
Effects Data Source	
Type of power frequency field	Ionizing radiation, N-nitroso compounds (NOC), pesticides, tobacco smoke, electromagnetic frequencies (EMF), infectious agents, medications, and parental occupational exposures.
Exposure Data Source	
Exposure Levels/ Length	
What They Did	This is a general review of medical literature up to 2003 covering the epidemiology of childhood brain tumors
Results	• Brain tumors are the second most common pediatric cancer but etiology remains unknown. • Known risk factors include some genetic syndromes and ionizing radiation. • Exposure to electromagnetic fields is a potential risk factor for brain tumors and has been evaluated in multiple epidemiologic studies. First studied in 1979 in Denver ▸ reported that children who resided close to high current power lines had an increased risk of leukemia and brain cancer. • Subsequent studies have been inconsistent and have methodological weaknesses, although several have found a positive association. • Exposure to high levels of electromagnetic frequencies (EMF) at close proximity suggests an increased but small risk. Variations in EMF exposure including proximity to power lines of various strengths, exposure to electrical appliances, and parental occupational exposure, can have a substantial impact on risk assessment. • The largest childhood cancer study, the United Kingdom (UK) Childhood Cancer Study found no association between EMF and childhood cancer, or for brain tumors specifically, after performing an extensive exposure assessment including several different types of EMF measurement (OR = 0.97, 95% CI = 0.46–2.05).
Conclusions	"The fact that few associations have been consistently replicated in studies by different investigators suggests that there may be multiple distinct etiologies. An alternative explanation for the limited associations is the belief of some cancer investigators that most pediatric tumors reflect the inherent risk associated with the complex process of normal development rather than a response to an external toxic insult."
Study Limitations	NA
Comments[a]	NA

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E7:	Mizoue T, Onoe Y, Moritake H, Okamura J, Sokejima S, Nitta H. J Epidemiol. 2004 Jul;14(4):118-23.
Article Title	Residential proximity to high-voltage power lines and risk of childhood hematological malignancies.
Study Name (if any)	
Study Type	Descriptive study
Study Population	Japanese children under the age of 15 yrs; 14 cases diagnosed with a hematological malignancy (out of 50000 children in the city)
Health Effects Studied	Hematological malignancies (mostly acute lymphocytic leukemia (11), acute myeloid leukemia (2), and one non-hodgkin's lymphoma)
Effects Data Source	Health records
Type of power frequency field	EMF *via* residential proximity to high-voltage power lines (HVPL)
Exposure Data Source	Districts in which more than half the homes fell within 300 m of HVPL were considered to be "exposed districts"
Exposure Levels/ Length	A few "spot" measurements taken outside the homes of three cases living 100 m from HPVL (measurement of 0.03 uT at all the homes) and outside two of the schools 50 m from HPVL (measures of ~0.3 uT).
What They Did	The authors computed an age-adjusted incidence rate ratio (IRR) and 95% confidence intervals (CI) comparing districts in which no area fell within 300 m of an HVPL and districts in which at least half of the districts fell within 300 m of HVPL.
Results	Districts in which at least half of the area fell within 300 m of an HVPL showed an increased childhood hematologic cancer risk, IRR = 2.2 (CI: 0.5-9.0). This association was strengthened and approached statistical significance for homes in which cases had lived the longest, IRR = 3.4 (95% CI 0.9-13.2).
Conclusions	Applying small area analysis, an increased risk of hematological cancers, although non-significant, is found for children living in small districts near HVPLs
Study Limitations	Larger area districts tend to have more than half their residential areas further from HVPLs. There are also exposure variations that depend on power line characteristics, such as height overhead and current capacity, which are not considered in the model. No adjustments were made for potential confounders such as socioeconomic status, air pollutants, or demographics. Other EMF exposures were not considered.
Comments[a]	The study suffered from several weaknesses including the very small sample size (14 cases), no controls used in the study, only a few "spot" measurements were taken, and no other exposure data was available. The rate ratio was consistent with other epidemiological studies.

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E8:	**Schlehofer B, Hettinger I et al: Int J Cancer 113:116-125, 2004.**
Article Title	Occupational risk factors for low grade and high grade glioma: Results from an international case control study of adult brain tumours.
Study Name (if any)	
Study Type	Case-control; Review of occupational risk factors for brain tumors;
Study Population	Adults (20-80 yrs old) ; 1178 cases and 1987 controls matched by 5-yr age group, gender and center
Health Effects Studied	High-grade gliomas (HGG), low-grade gliomas (LGG)
Effects Data Source	Data obtained from 8 study centers and 6 countries: Australia, Canada, France, Germany, Sweden and USA (Los Angeles, women only).
Type of power frequency field	6 categories of jobs identified *a priori*: agricultural, chemical, construction, metal, electric/electronic and transport
Exposure Data Source	Interviews (standardized questionnaire) of occupational history and information on exposures
Exposure Levels/ Length	NA
What They Did	Cases were determined from data collected on gliomas and meningiomas from 8 and 6 research centers, respectively and controls were matched by age, gender and center. Conditional logistic regression was used to determine odds ratios and 95% confidence intervals for estimating the occupational risks associated with brain tumors.
Results	• Non-significant results for electric/electronic job categories • For men increased risk OR: 1.59 (1.00-2.52) for LGG and for 'metal' category, • For women food production showed and increased OR 1.95 (1.04-3.68)
Conclusions	The results do not provide evidence of a strong association between occupational exposures and glioma development.
Study Limitations	No exposure data was available for any of the job categories
Comments[a]	This study was not specific to EMF and in particular no increased risks for the "electric/electronic" job category.

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E9:	Brain JD , Kavet R *et al*. Environ Health Perspect 111:962-970, 2003.
Article Title	Childhood leukemia: electric and magnetic fields as possible risk factors.
Study Name (if any)	Review based on a workshop sponsored by the Electric Power Research Institute and the Harvard School of Public Health entitled "Childhood Leukemia: Added Risk from the Use of Electricity," held on 8 November 2001 in Lexington, MA
Study Type	Review
Study Population	Children
Health Effects Studied	Leukemia
Effects Data Source	Review of Epidemiological Studies
Type of power frequency field	Low frequency magnetic fields
Exposure Data Source	
Exposure Levels/ Length	
What They Did	Review of the current status of knowledge about electromagnetic fields (EMFs) as possible risk factors for childhood leukemia. The following topics were covered: (1) a summary of epidemiologic studies (2) the biology of childhood leukemia, (3) the epidemiology of childhood leukemia, (4) the pathogenesis of acute leukemia, (5) animal carcinogenicity studies (6) EMF interaction with matter, and (7) contact currents as a possible explanatory exposure
Results (Summary)	• Pooled analyses of epidemiologic studies have shown increased risks for childhood leukemia with exposure to the upper end of magnetic field strengths, to which only a small proportion of US residents are exposed. • A relative risk of 1.7 (1.2-2.3) was estimated for residential exposures above 0.3 μT, with a population-attributable fraction of 3% (2% to >8%). • Results of animal experiments examining EMF exposure as a risk factor for leukemia have been overwhelmingly negative. The negative results from animal studies may reflect the fact that typical power-frequency EMFs do not give a "dose" detectable above the many sources of "noise" in biological systems. • Residential fields away from appliances rarely exceed 1 μT (10 mG). Model simulations have shown that even at 5 μT, a 60-Hz field cannot induce an electric field of 1 mV/m, the minimum level thought to be capable of causing biological effects. • Contact currents (or contact voltages) have been proposed as a possible alternative explanatory factor for the observed epidemiologic association between EMF exposure and childhood leukemia. These exposures meet the plausibility conditions of association with EMF, i.e. biologically plausible doses encountered in homes, as well as opportunities for those exposures.
Conclusions	Failure to detect EMFs in bioassay systems may reflect the fact that EMFs are not the causal exposure in the epidemiologic studies. There is a need for further experimental studies addressing the effects of contact currents as this may be an alternate explanation for the observed epidemiological effects.
Study Limitations	NA
Comments[a]	NA

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E10:	Infante-Rivard, C.; Deadman, J. E. Epidemiology 14(4):437-441 2003
Article Title	Maternal occupational exposure to extremely low frequency magnetic fields during pregnancy and childhood leukemia.
Study Name (if any)	
Study Type	Case-control (491 cases/491 controls matched on age, sex, region of residence)
Study Population	Canadian Children
Health Effects Studied	Acute lymphoblastic leukemia (ALL)
Effects Data Source	Tertiary care centers in greater Montreal that treat and hospitalize children with cancer. Participation rates were 96% for cases and 84% for controls
Type of power frequency field	ELF Low frequency magnetic fields
Exposure Data Source	Job exposure matrix- exposure levels assigned to specific jobs based on sources of ELF (primarily electrical equipment) , work environment, and duration of exposure
Exposure Levels/ Length	• Exposure metrics included cumulative exposure, average exposures, and maximum exposures; cumulative and average exposures were dichotomized using 0.4 μT as the cutpoint (based on previous work) • 54% of the jobs held by mothers of cases and controls (waitressing and agricultural) did not involve significant exposure to ELF, • More control mothers were exposed to ELF at work than cases, but cumulative exposures were slightly higher in controls than in cases (24.7 μT *vs*. 21.3 μT) • More case mothers had maximum levels of exposure at a given occupation (9% *vs*. 4%).
What They Did	Applied conditional logistic regression to compute odds ratios and 95% confidence intervals to evaluate the possible effects on childhood leukemia from maternal occupational exposures.
Results	• The risk for ALL was 1.7 (CI: 1.1-2.6) for cumulative exposures (controlling for age and sex of the child). • Results did not change when controlling for potential confounding factors or age of the mother and when limiting the analysis to women who worked outside the home. • Women with the highest exposures were sewing machine operators (weekly TWA =0.68 μT) and electronics workers (0.43 μT). When these women were removed from the analysis, the ALL risk was still elevated, but not significant for cumulative or average exposure metrics.
Conclusions	The results are consistent with an increased risk of childhood ALL among children whose mothers were exposed to high levels of ELF magnetic fields during pregnancy; The ALL risk increase could not be attributed solely to their jobs, however.
Study Limitations	Exposure misclassification is probably the largest limitation of this study. Exposure estimations have not been used before and need to be validated by others. No measurements of MF at home, but authors did not think this would contribute very much to overall exposures.
Comments[a]	No discussion on potential confounding exposures (study only controlled for PAH exposures). Small number of highly exposed women.

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E11:	Linet MS, Wacholder S *et al*. Pediatrics 112:218-232, 2003.
Article Title	Interpreting epidemiologic research: lessons from studies of childhood cancer.
Study Name (if any)	
Study Type	Review
Study Population	Children
Health Effects Studied	Cancer, leukemia, lymphoma, CNS/brain
Effects Data Source	
Type of frequency field	ElectroLow frequency magnetic fields
Exposure Levels/ Length	NA
Exposure Data Source	NA
What They Did	This is a general review of the strengths and limitation of epidemiology
Results	• The EMF-leukemia association is discussed as an example of a relationship that fails to meet criteria for causality. This conclusion is based primarily on three deficiencies: ▶ (1) lack of a consistent dose-response pattern in data from the larger US, Canadian, and UK studies completed in the 1990s ▶ (2) no results in experimental studies with laboratory animals to support the biological plausibility of tumor induction, and a lack of evidence from in vitro studies of carcinogenic changes to DNA or other components of cells; and ▶ (3) a modest increase in risk among children in US studies that could be attributed to selection bias (i.e. because of a higher participation rate for case families residing in homes with high magnetic field or wire code levels than for control families).
Conclusions	"whether evaluating the results of a single study, a body of work, or a pooled analysis, pediatricians must evaluate the weight of the evidence when deciding whether small statistical associations are likely to be causal."
Study Limitations	NA
Comments[a]	NA

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E12:	Tynes T, Haldorsen T. Cancer Causes Control. Oct;14 (8):715-20 2003.
Article Title	Residential and occupational exposure to 50 Hz magnetic fields and hematological cancers in Norway.
Study Name (if any)	
Study Type	Nested case-control
Study Population	Norwegian residents, 16 yr or older, living in a home within a broad corridor around a high-voltage power line;1,068 cases of hematologic cancer (57.2% male) were identified and included in the analyses
Health Effects Studied	hematological cancer
Effects Data Source	Norwegian Cancer Registry
Type of power frequency field	Residential low frequency magnetic fields (MFs) exposure was defined as MFs generated by power lines close to the homes
Exposure Data Source	• MFs were calculated based on the height of the towers, distance between phases, ordering of phases, distance between the power line and the residence, and average load on the power line for each year a case or control lived in the home. • Changes in the configuration of the power lines were also taken into account. • Occupational MF exposures were calculated based on experts using a scoring system that rated jobs according to the number of hours that exposures above a background level (0.1 μT) occurred
Exposure Levels/ Length	MF were grouped into categories for low exposure <0.05 μT, intermediate exposure (0.05-0.19 μT) and high exposure (≥ 0.2 μT)
What They Did	The odds ratio (OR) was used as the measure of association between MF exposure and disease and was computed by conditional logistic regression models for matched sets. Combined residential and occupational exposure was analyzed by introducing an interaction term into the regression model
Results	• The upper residential TWA MF exposure category (≥0.2 μT) showed nonsignificantly elevated ORs for all leukemia combined: ORs 1.5 (CI 0.8-3.0). • Chronic lymphocytic leukemia (CLL), acute lymphocytic leukemia (ALL), and acute myeloid leukemia (AML) all showed nonsignificantly increased ORs: 1.7, 2.8 and 1.6. • Analysis of linear trend showed a borderline result for CLL only (p =0.06; p=0.03 using the last 10 yr before diagnosis). • Analysis of all leukemia combined using 0.4 μT as the upper residential cut-off produced an OR of 1.6 (CI 0.6-3.8), based on 9 cases. • Analysis by gender yielded somewhat higher (but still not significant) leukemia ORs for women: 1.8 (CI 0.9-3.6) vs. 1.1 (CI 0.6-2.1) for men. • For lymphoma, the ORs were lower than unity, except for women in the intermediate exposure category (0.05-0.19 μT), OR 2.3 (CI 0.8-6.9). • For residential MF exposures during the last 10 yr before diagnosis, CLL showed a borderline significant result in the intermediate exposure category, OR 4.2 (CI 1.0-17.9).

Citation E12:	Tynes T, Haldorsen T. Cancer Causes Control. Oct;14 (8):715-20 2003.
	• All leukemia combined and multiple myeloma yielded results of borderline significance in the highest residential category, with ORs of 1.6 (CI 1.0-2.6) and 4.0 (CI 1.0-16.0), respectively. • Occupational MF exposure was not associated with an excess risk for any type of hematological malignancy. • Joint analysis of combined residential and occupational MF exposure indicated no combined effect.
Conclusions	The authors concluded that the results of the study do not allow conclusions about exposure to MFs and hematological cancers to be drawn because of the small numbers of subjects and marginal significance of the elevated ORs that were observed
Study Limitations	
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E13:	Willett, EV; McKinney, PA; Fear, NT; Cartwright, RA; Roman, E Occup Environ Med 60: 577-583 2003.
Article Title	Occupational exposure to electromagnetic fields and acute leukaemia: analysis of a case-control study
Study Name (if any)	
Study Type	Population-based case-control /sex- and age-matched with 1,510 controls from the same geographic areas in the UK (South West, Wessex, Yorkshire and the counties of Cumbria and Lancashire)
Study Population	764 adult white patients, age 20 yr or older
Health Effects Studied	Acute lymphoblastic leukemia (ALL)
Effects Data Source	
Type of power frequency field	Low frequency magnetic fields (EMF)
Exposure Data Source	Job exposure matrix (JEM) based on job title; Information for constructing the JEM was obtained from complete detailed job histories provided by the subjects through a questionnaire and face-to-face interview
Exposure Levels/ Length	NA
What They Did	Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated using conditional logistic regression techniques
Results	• No associations with acute leukemia overall were observed for probable EMF exposure, before, or at 2 yr prior to diagnosis; • ALL appeared to be associated with probable EMF exposure, OR 1.70 (CI 0.86-3.35), because of an excess observed among women with both current and past probable EMF exposures, OR 3.48 (CI 1.18-10.2, based on 14 cases and 13 controls). • The ALL risk was increased among women in all categories of exposure duration, <10 yr, 10-19 yr, and 20+ yr: ▸ ORs of 2.50 (CI 0.70-8.80), 9.44 (CI 0.64-1.38), and 5.73 (CI 0.37-88.6), respectively.
Conclusions	The authors interpreted their results as providing little evidence to support an association between occupational exposure to EMFs and acute leukemia. Although a significant excess of ALL was found among women occupationally exposed to EMF, the authors considered it unlikely that occupational EMF exposure was a causal factor since the increased risks remained during periods when exposure above background levels was improbable, and there was no corresponding risk in males probably exposed to higher EMF levels
Study Limitations	• Adjustments to see if the positive result could be explained away as a consequence of recall bias, confounding by socioeconomic group, or a result of inaccurate proxy reporting did not greatly change the OR. • The authors not that there is little available data to compare with the observed ALL risk increase in women occupationally exposed to EMF, because women are seldom studied. • The authors point out a need for additional studies of women using personal dosimetry to better characterize the strength, frequency and other EMF metrics of their occupational EMF exposures within specific work tasks.
Comments[a]	

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E14:	Lagiou, P.; Tamimi, R.; Lagiou, A.; Mucci, L.; Trichopoulos, D. Environ Health Prev Med 7(2):33-39 2002
Article Title	Is epidemiology implicating extremely low frequency electric and magnetic fields in childhood leukemia?
Study Name (if any)	
Study Type	Review
Study Population	Children
Health Effects Studied	Leukemia
Effects Data Source	Data from 24 studies were reviewed
Type of frequency field	Extremely low frequency electromagnetic fields (ELF-EMF)
Exposure Data Source	Only studies that investigated residential exposures from power lines
Exposure Levels/ Length	
What They Did	A critical review of epidemiologic studies investigating associations between residential exposure to ELF EMFs and childhood leukemia
Results	• 18 studies were deemed "basic studies" as they suffered from small sample size, poor description of the study base, questionable selection of controls, no safeguards against bias, and/or poor selection of exposure; • 6 studies were considered methodologically superior, 4 from Scandinavian countries which have population registries that allow valid sampling, and the large NCI studies done in the US and UK. • Five of the 6 methodologically advanced studies reported negative results. • Ten of the 18 basic studies reported positive results. Most of these, however, focused on wire codes rather than actual measurements to assess EMF exposures. • A meta-analysis of the 4 Scandinavian studies with similar methodology gave individual relative risks (RRs) of the Swedish, Danish, Finnish, and Norwegian studies: ▸ 2.7 (1.0-6.3), 1.5 (CI 0.3-6.7), 1.6 (CI 0.3-4.5), and 0.8 (CI 0.3-2.4), respectively. • The combined OR of the studies was 1.6 (CI 0.9-2.8).
Conclusions	The evidence from the Scandinavian studies provides little or no support for an association of EMF exposure with childhood leukemia, as the pooled OR was not statistically significant, and this summary risk estimate was elevated primarily because of the Swedish study (the only study reporting a positive result), which had some internal and external inconsistencies. The NCI studies also provided no evidence to support an association between residential EMF exposure and childhood leukemia.
Study Limitations	NA
Comments[a]	NA

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E15:	Navas-Acién A , Pollán M et al: Cancer Epidem Biomark Prev 11:1678-1683, 2002.
Article Title	Interactive effect of chemical substances and occupational electromagnetic field exposure on the risk of gliomas and meningiomas in Swedish men.
Study Name (if any)	
Study Type	Cohort
Study Population	Adult employed males 24 yrs or older and with a job title from the job exposure matrix (JEM) used for ELF magnetic fields; 1,516,552 males, 25-64 yr old, were followed for 19 yr (26,654,664 person-yr)
Health Effects Studied	gliomas and meningiomas
Effects Data Source	The Swedish Cancer Environment Register
Type of power frequency field	ELF magnetic field exposures using job exposure matrix + "co-exposures" to chromium/nickel; lead;mercury; metallic compounds; pesticides/herbicides; petroleum products; solvents; and arsenic
Exposure Data Source	Job exposure matrix
Exposure Levels/ Length	
What They Did	The expected number of glioma and meningioma cases in any specific occupation was computed using age- and period-specific rates in the overall cohort in 1970 as the reference. On the assumption that the observed number of cases in each stratum would show a Poisson distribution, log linear models were fit to the data, replacing occupation by the magnetic field exposure group for each tumor type, and adjusting for geographical risk area and town size
Results	• A total of 2,859 gliomas and 993 meningiomas occurred in the cohort during the study period. • A weak increased risk of glioma was seen for occupational magnetic field exposure alone in the second (0.13-0.20 μT) and third exposure categories (0.20-0.30 μT) ▶ RRs = 1.12 (95% CI: 1.02-1.22) and 1.12 (CI 1.01-1.25). • Trend was not maintained in the highest exposure category (>0.30 μT): RR 1.07 (CI 0.94-1.21). • No association between magnetic field exposure and meningioma risk was seen. • For workers in the lowest magnetic field exposure category, a significant increased risk of glioma was seen only for exposure to petroleum products. • In the medium magnetic field exposure category, significant increased glioma risks were seen for peak exposure to arsenic and pesticides/herbicides. • In the highest magnetic field exposure group, significantly increased glioma risk was associated with exposure to lead or solvents. • The analysis for combined magnetic field and chemical exposure for meningioma risk was limited by the small number of cases, and the only combined exposure that produced a significant risk increase in meningioma risk was with lead (based on 5 cases) in the medium ELF magnetic field exposure category.
Conclusions	• The main finding of this study was the lack of any effect of ELF

	magnetic field exposure on glioma risk in the absence of simultaneous exposure to chemical agents. • The observed interactive effect of petroleum products was independent of magnetic field exposure. • The observed effects of solvents, lead, and pesticide/herbicides were associated with glioma only in workers also exposed simultaneously to moderate or high magnetic field levels. • ELF magnetic field exposure was not associated with meningioma risk.
Study Limitations	
Comments[a]	

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation E16:	Oppenheimer M and Preston-Martin S Bioelectromag 23:411-415, 2002.
Article Title	Adult onset acute myelogenous leukemia and electromagnetic fields in Los Angeles County: Bed-heating and occupational exposures.
Study Name (if any)	Part of a larger population-based case-control study being conducted in Los Angeles County (LAC), California
Study Type	Case-control
Study Population	30-69 yr old residents (last 15 yrs); 412 cases (57%) participated, matched individually to 412 controls selected from the cases' neighborhood according to birth yr (+/- 5 yr), race, and gender
Health Effects Studied	Acute myelogenous leukemia (AML)
Effects Data Source	LAC Cancer Surveillance Program
Type of power frequency field	Low frequency magnetic fields (MF)
Exposure Data Source	Interview including questions on use of electric blankets and electrically heated waterbeds, and employment in occupations where substantial MF exposure was likely
Exposure Levels/ Length	NA
What They Did	Matched-pair design, conditional logistic regression was used to calculate odds ratios (ORs) and 95% confidence limits of the risks of AML associated with occupational exposures and residential (from electric blankets and heated waterbeds) MF exposures. Stratified analysis as well as dose response analyses were done.
Results	• Electric waterbed use (1-5 years) was associated with an elevated OR=1.8 (CI: 0.9-3.4) but this was the only positive association found, the inverse association OR=0.6 (CI: 0.3-1.2) was seen for 6-23 years of use. • No evidence was seen of any association between electric blanket use and AML (OR~1.0). • Employment in service of electrical appliances, near high voltage equipment, near large electrical motors, as electrician, and as welder had non-significant but elevated ORs: 1.4, 1.5, 1.4, 1.2, 2.2. All positive results were using only data from direct personal interviews (excluding proxy interviews). This accounted for only ~50% of the data.
Conclusions	There was no evident association between incident adult AML cases and MFs associated with electrical bed heating and occupational exposure.
Study Limitations	MF exposure assessments were qualitative and prone to misclassification, exposure misclassification resulting from proxy interviews could have resulted in a negative bias. The paucity of known risk factors for AML limited the ability to account for possible confounding. Selection bias was likely due to the poor participation rates for cases and controls
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E17:	Skinner, J; Mee, TJ; *et al*. UK British Journal Of Cancer 87: 1257-1266 2002
Article Title	Exposure to power frequency electric fields and the risk of childhood cancer
Study Name (if any)	UK Child Cancer Study
Study Type	Case-control
Study Population	Children 0-14 years (473 cases with leukemia or CNS cancer, 453 controls matched on age,sex and geographic location)
Health Effects Studied	Leukemia and CNS cancers
Effects Data Source	Used UKCCS cohort
Type of power frequency field	Power frequency electric fields
Exposure Data Source	Measurements of E-fields; "spot" measurements
Exposure Levels/ Length	2 exposure metrics: the mean of the 2 pairs of spot measurements obtained on the bed (pillow and bed center) and the mean of the 4 pairs of household spot measurements (family room, bedside, pillow, and bed center). The mean of the bed measurements was divided into 3 categories: < 10 V/m, 10 to 20 V/m, and 10 V/m or greater.
What They Did	• Valid E-field measurements were obtained for 549 subjects (273 cases and 276 controls; 59.3% of the initial measured population); 75 subjects unmatched. • Data analysis consisted of determining the risk of leukemia, CNS malignancies, and all cancers combined using odds ratios (ORs) for 10 V/m exposure increments and calculated using the mean of the bed spot measurements and the mean of the household spot measurements.
Results	• ORs for ALL, all leukemias, CNS malignances, and all cancers combined computed for subjects in this group with the highest E-field exposures (>20 V/m) : ▸ 1.31 (0.68-2.54), 1.32 (0.73-2.39), 2.12 (CI 0.78-5.78), and 1.26 (CI 0.77-2.07)
Conclusions	Results provide little support for the hypothesis that residential exposure to power-frequency E-fields is associated with childhood cancer
Study Limitations	The authors indicated that this should be regarded as a pilot study since it was added on halfway through the main UKCCS and included only a small portion of the cases
Comments[a]	The main UKCCS study measured magnetic field exposures (see E21).

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E18:	Villeneuve PJ , Agnew DA et al: Int J Epidem 31:210-217, 2002.
Article Title	Brain cancer and occupational exposure to magnetic fields among men: Results from a Canadian population-based case-control study.
Study Name (if any)	
Study Type	Case-control study
Study Population	Adult men (543 cases from 8 Canadian provinces / 543 controls)
Health Effects Studied	Brain cancer (astrocytoma, glioblastoma multiforme, other)
Effects Data Source	Canadian Cancer Registries Epidemiology Research Group
Type of power frequency field	Occupational exposures to low frequency magnetic fields (MF)
Exposure Data Source	• Each subject's occupation was assigned an exposure value based on a time-weighted average (TWA) flux density for full-time workers. • The exposures were assigned to the various jobs by expert review of the published literature • 86% of jobs held by cases were determined to have and average MF exposure of <0.3 μT, whereas for controls it was 88%.
Exposure Levels/ Length	The categories of exposure were below 0.3 μT (3 mG), 0.3-0.6 μT, and 0.6 μT or greater.
What They Did	Odds ratios (ORs) and 95% confidence intervals were estimated using conditional logistic regression techniques to evaluate the risks of brain tumors from occupational MF exposures.
Results	• A nonsignificant increased risk of brain cancer was seen among subjects who ever held a job characterized by a TWA exposure of 0.6 μT or greater OR: 1.33 (CI: 0.75-2.36). • With a restricted analysis that included only cases with glioblastoma multiforme (GM) the OR was higher and significant OR= 5.36 (CI: 1.16-24.78), 18 cases • Cases of GM also had an increased risk (nonsignificant) for those whose longest held job had a TWA exposure above 0.6 μT OR = 3.70 (CI 0.96-1.20) • Cases of GM also had an increased risk for the first and last jobs in the highest exposure categories OR= 4.81 (CI: 0.94-24.71), 10 cases and OR=12.59 (CI: 1.50-150), 8 cases
Conclusions	Results support the hypothesis that magnetic field exposure plays a role in the etiology of brain cancer, most specifically for glioblastoma multiforme (GM). The authors suggest that MF may act as at a promotional stage in the development of brain tumors, as GM tumors often evolve from less malignant forms
Study Limitations	No direct measures of magnetic field strengths Participation bias from non-response from cases and controls Small number of cases in each histological category
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E19:	Kheifets LI Bioelectromag Suppl 5:S120-S131, 2001.
Article Title	Electric and magnetic field exposure and brain cancer: A review.
Study Name (if any)	
Study Type	Review
Study Population	Children and adults
Health Effects Studied	Brain Cancer
Effects Data Source	
Type of power frequency field	Low frequency magnetic fields (MFs)
Exposure Data Source	
Exposure Levels/ Length	
What They Did	Review of evidence that residential or occupational exposure to electric and magnetic fields (MFs) can cause brain cancer in adults and children. The review considered major retrospective studies in children and adults, examining associations between EMF exposure and childhood and adult brain cancers
Results	• The largest childhood cancer study conducted to date (Day, *et al*. 1999), which incorporated field measurements found no association OR = 0.46 (CI: 0.11-1.86) for exposures above 2 mG. • A meta-analysis (Wartenberg et al. 1998), ORs varied from 1.1 to 1.4 and were NS. • Studies that examined brain tumor incidence and use of electric appliances by children or by their mothers during pregnancy produced inconsistent results • Few studies have examined potential associations between brain cancer and residential EMF exposures in adults, and none have investigated appliance use. The few existing studies have found little or no evidence of an association. • Many studies have examined possible associations between occupational exposure and brain cancer risk in adults. Some studies have found a higher risk for workers in a broadly defined category of "electrical occupations." Risks are small and there is considerable heterogeneity in the results.
Conclusions	The author concluded that most of the available evidence provides little support for an association between residential MF exposure and adult and childhood brain cancer. Some occupational studies do indicate a higher risk for workers in electrical occupations. There is substantial heterogeneity in the data and large exposure misclassification, which reduces the likelihood that occupational MF exposures are responsible for the observed excess risks.
Study Limitations	NA
Comments[a]	NA

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E20:	Schüz J, Grigat JP et al: Int J Cancer 91:728-735, 2001.
Article Title	Residential magnetic fields as a risk factor for childhood acute leukaemia: Results from a German population-based case-control study.
Study Name (if any)	
Study Type	Retrospective case-control
Study Population	Children (847 cases and 2127 controls)
Health Effects Studied	
Effects Data Source	German Childhood Cancer Registry
Type of power frequency field	50- Hz residential Low frequency magnetic fields
Exposure Data Source	24 hour measurements
Exposure Levels/ Length	Measurements were taken in the homes at 2 locations- under the mattress of the child's bed and in the living room, median of the 24-hr measurements ion the child's bedroom used with a cutoff point of 0.2 μT; dose-exposure assessed using 4 exposure categories, highest at >0.4 μT
What They Did	Used logistic regression models
Results	• Childhood leukemia was weakly associated with overall 24-hr median magnetic field exposures, OR=1.55 (CI 0.65-3.67). • When the data were stratified to nighttime and daytime levels, at night OR=3.21 (CI 1.33-7.80) based on 12 cases and 12 controls; Daytime exposure, OR= 0.77 (CI 0.29-2.03). • Dose-response trend with increasing cutpoints for nighttime exposure: 1.42 (0.90-2.23) for 0.1 to <0.2 μT (34 cases, 70 controls), 2.53 (0.86-7.46) for 0.2 to < 0.4 μT (7 cases, 8 controls), and 5.53 (1.15-26.6) for > 0.4 μT (5 cases, 4 controls). • The prevalence of residential magnetic field exposures exceeding 0.2 μT was very low, only 27 subjects (1.5%) were exposed to median 24-hr magnetic fields above 0.2 μT, and only 24 subjects (1.3%) were exposed to this intensity during the night. • Only 8 of the 27 median 24-hr magnetic field exposures above 0.2 μT were due to high-voltage transmission lines.
Conclusions	The authors concluded that they have found evidence for an association between residential magnetic field exposures and childhood leukemia, with the association primarily attributed to exposure to magnetic fields above 0.2 uT during the night.
Study Limitations	Despite the large size of this study, the results are based on small numbers of exposed children
Comments[a]	Results were consistent with results of the previous Michaelis et al. study (1998) that found an association with nighttime exposures. Small sample size in the highly exposed group. Non-participation bias is likely.

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation E21:	UK Childhood Cancer Study Investigators; Brit J Cancer 83:1573-1580, 2000.
Article Title	Childhood cancer and residential proximity to power lines.
Study Name (if any)	UK Childhood Cancer Study
Study Type	Case-control
Study Population	Children 3380 cases and 3390 controls
Health Effects Studied	Leukemias, CNS cancers, all cancers
Effects Data Source	Pathologically confirmed malignancy registered with the Family Health Services Authority (England and Wales) or a Health Board (Scotland)
Type of power frequency field	Low frequency magnetic fields
Exposure Data Source	Residential proximity to electricity supply equipment, distances to high-voltage lines, underground cables, substations and distribution circuits; Magnetic field exposure from this equipment was calculated using distance, load and other circuit information
Exposure Levels/ Length	Calculated fields were categorized into <0.1, 0.1-<0.2, ≥0.2, 0.2-<0.4, and ≥0.4 μT
What They Did	Follow-up study to the previous analysis (1999) expanding the number of cases and controls.
Results	• For residence within 50 m of an overhead line odds ratios (95% CI) were ▶ 0.73 (95% CI = 0.42-1.26) for acute lymphoblastic leukemia ▶ 0.75 (95% CI = 0.45-1.25) for all leukemias, ▶ 1.08 (95% CI = 0.56-2.09) for central nervous system cancers ▶ 0.92 (95% CI = 0.64-1.34) for all malignancies • For individuals with a calculated magnetic field exposure > 0.2 μT odds ratios were ▶ 0.51 (95% CI = 0.11-2.33) for acute lymphoblastic leukemia ▶ 0.41 (95% CI = 0. 09-1.87) for total leukemia ▶ 0.48 (95% CI =0.06-3.76) for central nervous system cancers ▶ 0.62 (95% CI = 0.24-1.61) for all malignancies
Conclusions	There was no evidence that either proximity to electrical installations or the magnetic field levels they produce in the UK is associated with increased risk of childhood leukemia or any other cancer
Study Limitations	The results were based on a very small number of cases in the higher exposure groups (>0.2 μT only 10 cases and 30 controls with Leukemia, 2 cases of CNS cancers)
Comments	The previous more limited study (1999), also found no association between measured MF and risk for any childhood malignancy.

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

ANIMAL STUDIES

Citation A1:	Sommer AM and Lerchl A Rad Res 162:194-200, 2004.
Article Title	The risk of lymphoma in AKR/J mice does not rise with chronic exposure to 50 Hz magnetic fields (1 mT and 100 mT).
Study Name (if any)	
Study Type	Animal Study
Study Population	480, 4- to 5-wk old female mice, genetically predisposed to lymphoma
Health Effects Studied	lymphoma
Effects Data Source	
Type of power frequency field	50-Hz low frequency magnetic fields (sinusoidal)
Exposure Data Source	The MFs were generated by 2 exposure systems consisting of rectangular Merritt-type coils driven by a sine wave generator and amplifier
Exposure Levels/ Length	3 groups of 160 animals each to receive: (1) sham exposure; (2) exposure to a 1-µT, 50-Hz MF 24 hr/day, 7 days/wk for 38 wk; and (3) similar exposure to a 100-µT, 50-Hz MF. Investigators were blinded as to experimental status of the coils
What They Did	Survival of the mice and development and increased incidence of lymphoma were assessed after exposures to MF. Data were tested statistically.
Results	• Exposure to either 1- or 100-µT MF had no effect on body weight. • Similar survival rates and median survival times were seen in the 3 groups of mice, indicating no effect on MF exposure on survival. • Nearly all observed deaths were due to the development of lymphoblastic lymphomas. • The incidence of lymphoma did not differ significantly between groups, being 85.6% in the sham exposure group, 91.9% in the 1-µT MF group, and 83.8% in the 100-µT MF group.
Conclusions	The authors concluded that these results do not support the view that chronic exposure to 50-Hz MFs is a significant risk factor for developing hematopoietic malignancies or that MF have a promoting effect.
Study Limitations	
Comments	blinded design, animals distributed randomly to MF exposures or sham exposures

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A2:	Abramsson-Zetterberg L and Grawé JBioelectromag 22:351-357, 2001.
Article Title	Extended exposure of adult and fetal mice to 50 Hz magnetic field does not increase the incidence of micronuclei in erythrocytes.
Study Name (if any)	
Study Type	Animal study
Study Population	Adult male and female mice (20 exposed and 20 sham; half of ea. sex) + 20 pregnant mice
Health Effects Studied	micronuclei in erythrocytes
Effects Data Source	The erythrocytes were analyzed for micronucleated polychromatic (PCEs) and normochromatic erythrocytes (NCEs) by a flow cytometric procedure.
Type of power frequency field	50-Hz Low frequency magnetic fields
Exposure Data Source	Mice were placed in different racks equipped with coils fed by 50-Hz AC. The coils were configured to give a homogeneous field.
Exposure Levels/ Length	50-Hz, 14-µT (140-mG) magnetic field for 18 days
What They Did	2 experiments to test the direct and the delayed effects of extended exposure of young adult and fetal mice to a 50-Hz magnetic field on induction of micronucleated erythrocytes using a highly sensitive flow cytometer-based assay
Results	In neither experiment did exposure to the magnetic field cause a significant increase in micronucleated PCEs or NCEs compared to sham exposure. There was also no significant difference in the frequency of PCEs between exposed and sham exposed groups.
Conclusions	The authors concluded that exposure of mice to a 50-Hz EMF under their experimental conditions does not induce direct or indirect effects on chromosomes in erythroid cells, when expressed as increases in the frequency of micronucleated erythrocytes. No examples of any delayed genetic effects were found.
Study Limitations	Difficult to draw conclusions on negative results as other alternative experimental designs are possible that may yield positive results (eg sampling time, target cells, different strains or species)
Comments [a]	No information on blinding as to exposure status. Positive controls were not used for delayed exposures. Physical parameters used were the same as two other previous studies done in 1998 in which researchers also found no changes in PCEs and NCEs

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A3:	Anderson LE , Morris JE et al: Bioelectromag 22:185-193, 2001.
Article Title	Large granular lymphocytic (LGL) leukemia in rats exposed to intermittent 60 Hz magnetic fields.
Study Name (if any)	
Study Type	Animal Study
Study Population	Large granular lymphocytic leukemia (LGLL) was initiated in 72 7-wk-old male rats by injecting them with fresh spleen cells obtained from donor rats with LGLL.
Health Effects Studied	Large granular lymphocytic leukemia (LGLL)
Effects Data Source	
Type of power frequency field	60-Hz low frequency magnetic fields (MF)
Exposure Data Source	Small animal magnetic field exposure system described by Rommerein et al. (1996).
Exposure Levels/ Length	The 7-wk-old rats were divided randomly into 4 groups (18 animals/group) and were exposed to: (1) a linearly polarized 1.0-mT (10-G), 60-Hz magnetic field (2) an intermittent 1.0-mT, 60-Hz magnetic field (off/on at 3-min intervals) (3) ambient controls with no exposure (4) positive controls, whole-body irradiated with 5-Gy cobalt 60 radiation. Magnetic field-exposed rats were exposed for 20 hr daily 7 days/wk for the duration of the study (22 wk). Ambient controls received magnetic field exposures of less than 0.1 uT (1 mG).
What They Did	The authors examined the effects of 60-Hz magnetic fields on the progression of large granular lymphocytic leukemia (LGLL) in a rat model. Repeated measures analysis was done
Results	• No significant differences were seen between the two MF exposed groups and the ambient controls. • Significant differences were generally observed between the positive and ambient controls. • A comparison of the survival curves of the 4 groups showed no significant effect of either the continuous or intermittent MF exposure.
Conclusions	The authors concluded that exposure to continuous or intermittent 1-mT, 60-Hz magnetic fields does not affect the progression of LGLL in leukemic rats.
Study Limitations	
Comments	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A4:	Heikkinen P , Kosma VM *et al*. Int J Radiat Biol 77:483-495, 2001.
Article Title	Effects of 50-Hz magnetic fields on cancer induced by ionizing radiation in mice.
Study Name (if any)	
Study Type	Animal Study
Study Population	150 female mice, 3- to 5-wk old
Health Effects Studied	Effects of EMF on cancer induced by ionizing radiation
Effects Data Source	
Type of power frequency field	50-Hz low frequency magnetic fields (MF) with ionizing radiation
Exposure Data Source	Linear accelerators (ionizing radiation); 5 rectangular 0.4- x 1.2-m coils energized by a Wavetek Signal generator and power amplifier (MF)
Exposure Levels/ Length	3 groups of 50 animals each: Two groups were exposed to 4 gray (Gy) of ionizing radiation fractionated into 3 doses One of these groups was also exposed for 24 hr/day for 1.5 yr to vertical 50-Hz magnetic fields at intensities 1.3, 13, and 130 μT that were varied randomly at 20-min intervals.
What They Did	Examined the effects of 50-Hz magnetic field exposure on ionizing radiation-induced carcinogenesis in a mouse model.
Results	• Survival to the end of the experiment was 96% in the cage control group, 54% in the irradiated/sham exposed group, and 66% in the irradiated/magnetic field exposed group. • The decrease in survival in the irradiation/sham exposed group was statistically significant compared to the cage controls. • The only significant difference in hematology between magnetic field- and sham-exposed animals was a decrease in the median proportion of lymphocytes and an increase in the median proportion of neutrophils in the magnetic field-exposed group. • Magnetic field exposure did not increase the incidence of any of the primary malignancies. • The incidence of non-neoplastic basophilic liver foci (considered a potential preneoplastic change in the liver) was increased from 18 to 50% of examined animals, p=0.002. • The incidence of benign hepatocellular adenomas, however, was unchanged at 24 and 28%. • The incidence of hepatocellular carcinomas was elevated (from 14 to 28%), but not statistically significant.
Conclusions	The authors concluded that results do not provide evidence supporting a role for 50-Hz magnetic fields as a tumor promoter, although the increased incidence of liver changes may warrant further study.
Study Limitations	
Comments	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A5:	Vallejo D. , *et al.* Electro Magneto Bio 20:281-298, 2001.
Article Title	A hematological study in mice for evaluation of leukemogenesis by extremely low frequency magnetic fields.
Study Name (if any)	
Study Type	Animal study
Study Population	Six-wk-old male and female mice (94 total, distributed into 4 groups)
Health Effects Studied	Hematological changes
Effects Data Source	Blood profiles
Type of power frequency field	50-Hz Low frequency magnetic fields
Exposure Data Source	Field was produced by a Helmholtz coil-based system
Exposure Levels/ Length	Continuously to a 15-µT (150-mG) 50-Hz magnetic field starting 14 wk before mating; Exposure of pregnant female mice to the 15-µT, 50-Hz field continued during gestation, birth, and lactation to weaning. After weaning, 30 female offspring were exposed to the field until they were 14-15 wk old (young adults) and an additional 20 were exposed until they were 50-52 wk old (mature adults)
What They Did	The authors examined hematological changes resulting from chronic exposure to extremely low frequency (ELF) magnetic fields to identify changes in blood profiles that may be related to leukemogenesis.
Results	• The individual hematological diagnoses showed that 60% of young adults exposed to the magnetic field for 15 wk had some type of leukoproliferative disorder vs. only 20% of controls (Relative risk (RR) of 3.00 (95% CI 1.38-6.50). • In surviving mature adults exposed for 52 wk, 64% of the mice developed a leukoproliferative disorder vs. 25% of the control groups (RR= 2.57 (CI 1.10-6.04). • The lymphoproliferative disorders represented the most frequent alteration, and the difference was significant in the younger animals (RR at 15 wk was 6.50 (CI 1.60-26.37) but not at 52 wk (RR of 3.57 (CI 0.80-15.87).
Conclusions	The authors concluded that, under their experimental conditions, exposure to a 15-µT 50-Hz magnetic field produces alterations in hematologic parameters and a leukemic tendency in the first generation of mice. Differences in these responses as a function of length of exposure were also detected.
Study Limitations	
Comments	No information as to whether authors used a blinded design, no positive controls used

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A6:	Babbitt JT , Kharazi AI et al: Carcinogenesis 21:1379-1389, 2000.
Article Title	Hematopoietic neoplasia in C57BL/6 mice exposed to split-dose ionizing radiation and circularly polarized 60 Hz magnetic fields.
Study Name (if any)	
Study Type	Animal Study
Study Population	2,280 female mice, 27-32 days old; 1,520 animals exposed; 1,290 animals sham exposed ; mouse strain is susceptible to spontaneous lymphomas
Health Effects Studied	Hematopoietic neoplasias
Effects Data Source	
Type of power frequency field	Circularly polarized 60-Hz low frequency magnetic fields
Exposure Data Source	Magnetic field was produced by a system constructed for the US EMF RAPID Program.
Exposure Levels/ Length	1.42-mT (14.2-G) for 18 hr/day over their lifetime
What They Did	Examined the effects of chronic exposure to circularly polarized 60-Hz magnetic fields and split dose ionizing radiation on induction of hematopoietic malignancies in mice. The Cox proportional hazard model was used to compare the incidence of lymphoma subtypes in exposed and control mice.
Results	• Total lymphoma incidence in magnetic field-exposed mice did not differ significantly from those of unexposed mice. • Mortality rates were not significantly affected by magnetic field exposure. • A trend toward reduced mortality was seen in magnetic field-exposed mice irradiated with 4.0-Gy gamma rays.
Conclusions	• The authors concluded that although the design of this study does not enable an assessment of the effect of chronic magnetic field exposure on initiation of neoplastic lesions, the results suggest that neoplastic growth may be accelerated (termed tumor "progression") in mice that received only magnetic field exposure or only gamma irradiation. • This conclusion is based mainly on the observation that histiocytic sarcomas and lymphomas were found approximately 50 days earlier in unirradiated mice exposed to the magnetic field, although the increase was not statistically significant and the final incidence of hematopoietic neoplasia in these mice was not different from that of mice in the unexposed control group. • The data also suggest an interaction between gamma radiation and magnetic field exposure in the development of radiation-induced thymic LB lymphomas. The mechanisms of this interactive effect remain to be elucidated.
Study Limitations	
Comments	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A7:	Boorman GA , McCormick DL et al: . Radiat Res 153:617-626, 2000.
Article Title	Magnetic fields and mammary cancer in rodents: A critical review and evaluation of published literature
Study Name (if any)	
Study Type	Review
Study Population	Animal Models
Health Effects Studied	Mammary Cancer
Effects Data Source	
Type of power frequency field	50/60-Hz Low frequency magnetic fields
Exposure Data Source	
Exposure Levels/ Length	
What They Did	• Reviewed studies examining possible associations between power-frequency magnetic field exposure and mammary cancer in rodent models. • The evaluation includes 3 large-scale bioassays of carcinogenesis in rats and mice that were exposed to 50/60-Hz magnetic fields of up to 5,000 µT (50 G) for 2 yr and 12 studies of mammary carcinogenesis in which rats were treated with 7,12-dimethylbenz(a)anthracene (DMBA) with or without exposure to 50/60-Hz magnetic fields. • The DMBA initiation/promotion studies involved over 5,000 animals and ranged in length from 13 to 27 wk. • All studies are reviewed for adequacy of exposure and experimental details and for the extent of histopathological evaluation of tissues. • The 3 large-scale 2-yr bioassays appeared to have been carefully conducted, with extensively documented magnetic field exposures and complete histopathological evaluation of tissues
Results	• None of the 3 studies indicated significant increases in the incidence of mammary tumors. • None of the 12 DMBA initiation/promotion studies revealed any consistent pattern of magnetic field effects on induction of mammary cancer. • None of the studies that included a histological examination of tissues showed significant increases in the incidence of all malignant mammary tumors in the exposed groups compared to the controls. • Significant increases in tumor incidence in groups exposed to magnetic fields at 10 wk of age (used as a measure of early tumor appearance) were found in only 2 of 13 exposure groups that used this endpoint. • When any positive effects were found, the results came from just one laboratory. The results could not be replicated by 2 other laboratories, which conducted 1 study and the 3 large NTP studies.
Conclusions	The authors conclude that when the experimental data are viewed all together they do not support the hypothesis that power-frequency magnetic fields enhance mammary carcinogenesis

Citation **A7:**	Boorman GA , McCormick DL et al: . Radiat Res 153:617-626, 2000.
	in rodents, nor do they provide experimental support for possible epidemiological associations between magnetic field exposure and increased breast cancer risk.
Study Limitations	The authors note that the discrepant results from the DMBA initiation/promotion studies cannot be explained. Many minor differences in study design are identified including: genetic differences in rat strains used, minor differences in rodent diet formulations, differences in magnetic field exposure protocols, and differences in procedures used to analyze the endpoints.
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A8:	Boorman GA , Rafferty CN et al: Radiat Res 153: 627-636, 2000.
Article Title	Leukemia And Lymphoma Incidence In Rodents Exposed To Low-Frequency Magnetic Fields.
Study Name (if any)	
Study Type	Review
Study Population	Animal Models
Health Effects Studied	Leukemia And Lymphoma
Effects Data Source	
Type of power frequency field	50- or 60-Hz extremely low-frequency (ELF) magnetic fields
Exposure Data Source	
Exposure Levels/ Length	
What They Did	• Review of 15 experimental studies investigating the possibility that 50- or 60-Hz extremely low-frequency (ELF) magnetic fields can affect the incidence of leukemia or lymphoma in rodent models. • Also summarizes the pathogenesis of and risk factors for leukemia and lymphoma in humans, and the rationale for using rodent models for studying human carcinogens. • The studies, which evaluated the potential carcinogenicity of magnetic fields on leukemia and lymphoma in mice (10 studies) and rats (5 studies), include standard long-term animal bioassays, initiation/promotion studies, studies using transgenic mouse models, and leukemia progression studies using transplanted tumor cells. • Collectively, the studies include more than 5,000 animals and approximately 12 different exposure conditions.
Results	• Exposures of more than 2,600 mice to 60-Hz 1,400-μT (14-G) circularly polarize MF for 28 months did not affect the incidence of lymphoma. • Exposure of 1,000 mice to 60-Hz MF of up to 1,000 μT for 2 yr produced no increase in leukemia/lymphoma. • Exposure of approximately 500 transgenic mice, highly susceptible to leukemia, to 50-Hz magnetic fields for up to 18 months produced no increase in the incidence of leukemia . • In another study, exposure of groups of 30 male and female transgenic mice to 60-Hz MF of up to 1,000 μT for 23 wks following a single dose of ethylnitrosourea produced no increase in lymphoma incidence. In the male mice, the incidence of lymphoma was significantly decreased by exposure to an intermittent (1 hr on/1 hr off) 1,000-μT field.
Conclusions	The authors conclude that the studies, taken as a whole, provide an adequate and sufficient evaluation of 50/60-Hz magnetic field exposures in rodents and are virtually consistent in showing no effect of 50/60-Hz magnetic fields on leukemia or lymphoma initiation, promotion, or progression in rats and mice. These results tend to weaken the suggested epidemiological association between magnetic-field exposures and leukemia in humans.
Study Limitations	
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A9:	Devevey L , Patinot C. et al: Int J Radiat Biol 76:853-862, 2000.
Article Title	Absence of the effects of 50Hz magnetic fields on the progression of acute myeloid leukaemia in rats.
Study Name (if any)	
Study Type	Animal Study
Study Population	340 5-wk-old male rats with AML ; 73 for positive control
Health Effects Studied	Acute myeloid leukemia (AML)
Effects Data Source	
Type of power frequency field	50-Hz Low frequency magnetic fields
Exposure Data Source	Constructed by Electricite de France (EDF), consisted of a system of rectangular Helmholtz coils into which the animal cages were placed. The fields within the cages were homogeneous; Sham exposed rats received average 50-Hz magnetic field exposures of 5 nT (0.05 mG) at night and 35 nT during the day
Exposure Levels/ Length	Sinusoidal 50-Hz magnetic field, at a flux density of 100 μT (1 G) for 18 hr/day 7 days/wk throughout the period of leukemia progression
Controls	As a positive control, some rats were whole-body irradiated 4 days after leukemic cell injection with 5-Gy radiation from a cobalt-60 source. Rats not injected with leukemic cells served as a negative control group.
What They Did	• The authors examined the effects of magnetic fields on the progression of experimental acute myeloid leukemia (AML) in a rat model. • Four separate experiments were conducted: Leukemic MF-exposed and sham exposed rats and non-leukemic MF-exposed and sham exposed rats. • The data were tested statistically by one-way analysis of variance (ANOVA).
Results	• All rats injected with leukemic splenocytes developed leukemia. • There was no significant difference between the MF-exposed and unexposed rats in the parameters related to the progression of leukemia including survival time, body weight, number of leukemic blast cells in the blood and bone marrow and spleen and liver infiltration. • No deaths occurred in non-leukemic rats exposed or sham exposed to the magnetic field. • In the positive controls, survival times were significantly shortened in leukemic rats irradiated with 5 Gy compared with non-irradiated leukemic rats
Conclusions	The authors conclude that exposure to the magnetic field under these experimental conditions did not alter the progression of leukemia in this rat model of AML. These results, therefore, do not support the hypothesis that 50-Hz magnetic fields influence leukemia progression in humans.
Study Limitations	
Comments[a]	The negative results are in agreement with previous studies in mice and rats and various *in vitro* studies. Not clear if the staff was blinded as to the exposure status of the animals.

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A10:	Mandeville R , Franco E *et al*. Bioelectromag 21:84-93, 2000.
Article Title	Evaluation of the potential promoting effect of 60 Hz magnetic fields on N-ethyl-N-nitrosourea induced neurogenic tumors in female F344 rats.
Study Name (if any)	
Study Type	Animal Study
Study Population	260 pregnant rats; 8 groups of 32 animals each
Health Effects Studied	Promotion of neurogenic tumors
Effects Data Source	All animals were observed daily for signs of deteriorating health, abnormal health, abnormal behavior, unusual appearance, and/or tumor development. Body weight gains and survival were monitored. The necropsies focused on detecting nervous system tumors
Type of power frequency field	60-Hz Low frequency magnetic fields
Exposure Data Source	The magnetic fields were produced by the computer-operated system described by Tremblay et al. (1996) and also used by Mandeville et al. (1997)
Exposure Levels/ Length	Five N-ethyl-N-nitrosourea (ENU) injected groups were sham exposed or exposed to a 2-, 20-, 200-, or 2,000-μT (20 mG to 20 G) 60-Hz magnetic field for 8 hours starting 48 hr after ENU injection. Exposure continued through gestation and until weaning. Female offspring (1 or 2 animals per litter) were exposed for up to 65 wks. Sham exposed group were exposed to the ambient 60-Hz field (less than 0.02 μT or 0.2 mG)
Controls	Negative controls included one group injected with saline only and received no further treatment (saline controls); One ENU-treated groups received no further treatment (ENU controls); As a positive control, one group of ENU-injected dams was injected 12-O-tetradecanoylphorbol-13-acetate (TPA, a chemical tumor promoter) on gestational days 19, 20, and 21 and female offspring from the same group were injected with TPA every 15 days starting on postnatal day 14 and continuing to the end of the study.
What They Did	The promotional activity of 60-Hz magnetic fields on neurogenic tumors induced in a rat model by N-ethyl-N-nitrosourea (ENU) was studied. The data were tested statistically for significance
Results	• No significant differences in body weight gain were seen between the 8 groups. • No statistically significant differences in survival to the end of the study were seen. • Logistic regression analysis showed that the sham exposed controls had the highest overall incidence of neurogenic tumors (60%) when compared to magnetic field-exposed animals ▸ 52, 56, 48, and 46% in animals exposed to the 2-, 20-, 200-, and 2,000-μT fields. • None of these differences between the various groups were statistically significant
Conclusions	The authors conclude that, under their experimental conditions, exposure to 60-Hz magnetic fields had no effect on survival of these female rats or on the number of animals bearing neurogenic tumors following injection with ENU. These results suggest that magnetic fields have no promoting effects on neurogenic tumors in this animal model.
Study Limitations	
Comments	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A11:	McCann J, Kavet R, Rafferty CN. Environ Health Perspect. 2000 Mar;108 Suppl 1:79-100.
Article Title	Assessing the potential carcinogenic activity of magnetic fields using animal models.
Study Name (if any)	
Study Type	Review
Study Population	Animal models
Health Effects Studied	Carcinogenicity
Effects Data Source	
Type of power frequency field	50- or 60-Hz Low frequency magnetic fields
Exposure Data Source	
Exposure Levels/ Length	More than 90% of the exposure conditions used flux densities ranging from 1 μT (10 mG) to 2 mT (20 G)
What They Did	• Follow-up review from 1997 review in EHP, including 23 new studies (earlier review included ~36 studies). • More than 60 completed studies were available for review, most examining the potential tumorigenicity of 50- or 60-Hz sinusoidal magnetic fields delivered either continuously or intermittently • 34 studies met good lab practice (GLP) and other quality criteria and of these 12 had positive results • More than 90% of the exposure conditions used flux densities ranging from 1 uT (10 mG) to 2 mT (20 G), considered to be the range of or slightly exceed environmental human exposures. • Evidence of independent replication was available only for negative results in 2 model systems (lifetime or multi-generation exposure studies in rats and mice, and promotion/copromotion studies using the mouse skin model). • None of the 12 positive studies have been independently replicated. One of the positive studies was a comprehensive 2-yr chronic bioassay conducted by the Natl. Toxicology Program (NTP) in rats and mice which found increased incidences of thyroid gland C-cell tumors in male rats, this finding was judged by the authors to represent a statistical artifact resulting from random variability in tumor distribution. • Another large study by Fam and Mikhail (1996) reported a highly significant increase in leukemia, but the validity of this study was questioned because of its failure to meet quality control criteria. • Six positive studies utilized the rat mammary carcinoma model in which the promotional effects of magnetic fields on mammary tumors initiated with 7,12-dimethylbenz(a)anthracene (DMBA) or N-methyl-N-nitrosourea (NMU) were evaluated, the only independent replication attempt produced a negative result. High variability of tumor rates among unexposed control animals and the sensitivity of the DMBA/mammary system to a variety of endogenous and dietary

Citation A11:	McCann J, Kavet R, Rafferty CN. Environ Health Perspect. 2000 Mar;108 Suppl 1:79-100.
	factors makes evaluation of these results difficult. • Three positive studies were conducted in a mouse skin mode. • 2 positive studies utilized rat or mouse models of human leukemia and lymphoma. ► One of the 2 positive studies occurred in the rat large granular lymphocyte (LGL) transplant assay and the other in a mouse lymphoma assay utilizing DMBA as an initiator. ► Interpretation of the results was not straightforward as a comparison of the 2 studies indicated some inter-experimental variability.
Results	Thirty-four studies included in this review and in the McCann et al. (1997) review were judged to meet good lab practice (GLP) and additional quality criteria. Of these, 12 studies reported positive results and 23 uniformly negative results.
Conclusions	The authors conclude that long-term exposure to continuous 50- or 60-Hz magnetic fields with flux densities in the 0.002- to 5-mT range is not likely to be carcinogenic to rats or mice. Although the results of most promotion/progression assays are negative, the possibility that 50- or 60-Hz magnetic fields may cause a weak promoting effect under certain experimental conditions cannot be ruled out.
Study Limitations	
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation A12:	Boorman GA , McCormick DL et al: Toxicol Pathol 27:267-278, 1999.
Article Title	Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats.
Study Name (if any)	National Toxicology Program Study
Study Type	Animal Study
Study Population	Rats (100 male and 100 female in each of the continuous and intermittent exposure experiments)
Health Effects Studied	Carcinogenicity
Effects Data Source	
Type of power frequency field	60-Hz Low frequency magnetic fields
Exposure Data Source	Animal exposure rooms containing coils that generated transient-free 6-Hz MFs of 20 mG-10 G; The characteristics of this exposure facility were validated by the Natl. Inst. of Standards and Technology prior to and during the course of the study
Exposure Levels/ Length	Animals were continuously exposed to 20-mG, 2-G or 10-G (2-uT, 0.2- or 1-mT) MFs or intermittently (1 hr on/1 hr off) exposed to a 10-G MF for 18.5 hr/day over the course of 2 yr
What They Did	The authors report on a 2-yr carcinogenesis study conducted in rats exposed in vivo to MFs.
Results	• No significant differences in exposure groups in terms of overall survival. • No significant difference in body weights by MF exposure and no indication of an effect of on clinical observations or gross pathological changes on necropsy. • Neoplastic lesions were not significantly different after MF exposure and were consistent with historical data for this rat strain. • Chronic exposure to 60-Hz MFs was not a significant risk factor for neoplastic development based on the total incidence and number of malignant or benign neoplasms. • Specific cancers that have been suggested to be associated with EMF exposure was evaluated in detail: ▸ Leukemia was not significantly increased in any group of rats exposed to the MF, with the only significant finding being a decrease in leukemia incidence for rats exposed intermittently to 10-G MFs compared to sham-exposed (50% vs 36%, respectively). ▸ 4 brain tumors were seen in controls (2 males and 2 females) compared with 1 in a male rat with intermittent MF exposure and none in MF-exposed females. ▸ Mammary cancer was seen in 1 male rat exposed to 20 mG. Benign mammary tumors rates were 6% in male controls and ranged from 6 to 11% in MF-exposed males. In females, there were 2 mammary carcinomas in controls and an incidence of 2-7% in MF-exposed rats, similar to historical control levels. The incidence of benign mammary tumors was 56% in female controls and ranged from 52 to 64% in MF-exposed females. ▸ A significant increase in the incidence of thyroid C-cell

Citation A12:	Boorman GA , McCormick DL et al: Toxicol Pathol 27:267-278, 1999.
	adenomas in males exposed to field strengths of 20 mG or 2 G, but not in those exposed continuously or intermittently to the highest field strength of 10 G. ▶ An increased incidence of thyroid C-cell carcinomas in male rats exposed to 20-mG fields and an increased incidence of preputial gland carcinomas in male rats exposed to 2-G fields ▶ The incidence of trichoepitheliomas, but not the overall incidence of epithelial skin cancer, was increased in male rats in the continuous 10-G exposure group and the incidence of adrenal cortical adenomas was significantly decreased in females exposed intermittently to 10-G fields. The authors considered these statistically significant increases and decreases in specific tumor incidence a chance occurrence.
Conclusions	Overall, they concluded that these findings do not provide support for the hypothesis that exposure to power frequency MF increases cancer risk.
Study Limitations	
Comments[a]	Very large animal study, carefully designed and conducted

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation A13:	McCormick DL , Boorman GA *et al*. Toxicol Pathol 27:279-285, 1999.
Article Title	Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice.
Study Name (if any)	National Toxicology Program Study
Study Type	Animal Study
Study Population	Mice (100 male and 100 female)
Health Effects Studied	Carcinogenicity; emphasis of evidence of leukemia, brain tumors, and mammary tumors
Effects Data Source	
Type of power frequency field	60-Hz Low frequency magnetic fields (MFs)
Exposure Data Source	Animal exposure rooms containing coils that generated transient-free 60-Hz MFs of 20 mG-10 G
Exposure Levels/ Length	Randomized to no MF exposure (sham controls) or exposure for 18.5 hr/day, 7 days/wk to MFs at field strengths of 20 mG, 2 G, or 10 G (2 uT, 0.2 mT, or 1 mT). An additional group of animals was exposed intermittently (1 hr on/ 1 hr off) to 10-G MFs.
What They Did	The authors reported results of a 2-yr toxicology/oncogenicity study of mice exposed to pure, linearly polarized 60-Hz magnetic fields
Results	• There was no evidence of an effect of MF exposure on group mean body weights, body weight gains, or mortality throughout the study; however, male mice continuously exposed to 10 G had a significant reduction in survival compared with controls. • There was no increase in the incidence of neoplasia in lymph, brain and mammary sites in MF-exposed mice compared with controls. • Female mice intermittently exposed to the MF exhibited a significant decrease in the incidence of malignant lymphoma. • No mice developed primary glial tumors and no male mice developed

Citation A13:	McCormick DL , Boorman GA *et al*. Toxicol Pathol 27:279-285, 1999.
	mammary gland tumors. • Four mammary gland adenomas were found in mice exposed continuously to 2 G MFs (n=1), continuously to 10 G MFs (n=2) and intermittently to 10 G MFs (n=1). One control mouse and 1 mouse intermittently exposed to 10 G MFs developed mammary gland carcinomas. • The incidence of alveolar/bronchiolar adenomas was significantly lower in male mice continuously exposed to field strengths of 20 mG or 2 G and in female mice continuously exposed to 2 G MFs compared with controls and the incidence of combined alveolar/bronchiolar adenomas and carcinomas was significantly decreased in male and female mice exposed to 2 G MFs. • Other tumors that occurred with at least 5% incidence in 1 or more exposure or control groups included tumors of the adrenal cortex, Harderian gland, and liver
Conclusions	The findings of this study, along with the parallel study in rats and other long-term animal model EMF exposure studies do not provide evidence supporting the hypothesis that exposure to MFs is a significant risk factor for human cancer.
Study Limitations	
Comments [a]	Very large animal study, carefully designed and conducted

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Cellular/In vitro Studies

Citation M1:	Ivancsits, S., *et al.* Mutat. Res. 583(2):184-188 2005
Article Title	Cell type-specific genotoxic effects of intermittent extremely low-frequency electromagnetic fields.
Study Name (if any)	
Study Type	*In vitro*
Study Population	Human fibroblasts, human melanocytes, rat granulosa cells, human lymphocytes, human monocytes, and human skeletal muscle cells
Health Effects Studied	DNA strand breaks
Effects Data Source	Alkaline and neutral comet assay
Type of power frequency field	50 Hz sinusoidal extremely low frequency magnetic fields (MF)
Exposure Data Source	Built and provided by the Foundation for Information Technologies in Society, Zurich, Switzerland; two four-coil systems inside a mu-metal box placed in an icubator
Exposure Levels/ Length	1 mT for 1-24 hrs at intermittent exposures (5 min on/10 min off)
What They Did	The authors tested whether the potential genotoxic effects of MF were different for diverse cell types. Cultured cells from different tissues were exposure to MF and DNA strand breaks were assessed using the comet assay
Results	• Differences in DNA damage were seen for the different cell types. • The highest level of DNA damage was seen in the rat granulose cells and the human fibroblasts. • Human melanocytes also showed a positive response in the assay although to a lesser degree. • The human lymphocytes, monocytes and skeletal muscle cells did not show an y response (i.e. DNA damage) in the assays.
Conclusions	The authors "identified three responder (human fibroblasts, human melanocytes, rat granulosa cells) and three non-responder cell types (human lymphocytes, human monocytes, human skeletal muscle cells), which points to the significance of the cell system used when investigating genotoxic effects of ELF-EMF".
Study Limitations	
Comments[a]	

Citation M2:	Swanson, J and L. Kheifets; in press
Article Title	Bio-physical mechanisms: a component in the weight of evidence for EMFs.
Study Name (if any)	
Study Type	Review
Study Population	
Health Effects Studied	
Effects Data Source	
Type of power frequency field	
Exposure Data Source	
Exposure Levels/ Length	
What They Did	The authors discuss the use of bio-physical arguments in the weight of evidence risk assessment and present how to assess plausibility for a given bio-physical mechanism.
Results	• Environmental field levels are generally less than 1 μT and 100 V/m but can be (rarely) up to 10^4 V/m near a high-voltage power line and 1 mT near some appliances. Epidemiological studies suggest biological effects at levels well below 1 μT (e.g. <0.4 μT) • Most bio-physical mechanisms that have been proposed could not be the cause of disease at these environmental levels • Induced fields produce effects in cells at the mT level, the level used for most standards. • Given potential uncertainties in the effect level 100 μT would not be unreasonable and this could be even lower when applied to neural cells (say 50 μT). • Free-radical mechanisms are not expected below this level of 50 μT. • Even effects on ferromagnetic materials are not expected at levels below 5 μT.
Conclusions	The authors conclude that health effects associated with MF exposures below 5 μT are implausible. At 50 μT, there are possible effects but no specific mechanism has been identified. At levels above 500 μT, there are established biological mechanism or likely effects. Risk assessments should consider the lack of a plausible bio-physical mechanism, but this should not be used as proof that there are no health effects from low level exposures to MFs.
Study Limitations	
Comments[a]	

Citation M3:	Wolf, FI, *et al.* Biochim Biophys Acta 1743(1-2):120-129 2005
Article Title	50-hz extremely low frequency electromagnetic fields enhance cell proliferation and DNA damage: possible involvement of a redox mechanism
Study Name (if any)	
Study Type	*In vitro*
Study Population	Embryonic lung fibroblasts (normal cell line), human leukemia cells (neoplastic cell line), and rat fibroblasts (immortalized cell line)
Health Effects Studied	cell proliferation, DNA damage
Effects Data Source	Cell proliferative activity was assessed using an automatic Coulter counter. DNA damage was determined by the presence of 8-hydroxydeoguanosine (8-OHdG) adducts using the immunohistochemical technique; DNA single-strand breaks (SSBs) were determined by single-cell microgel electrophoresis, antioxidant treatment used to test for a redox mechanism
Type of power frequency field	Extremely low frequency magnetic fields (MFs)
Exposure Data Source	Solenoid system within an incubator described by Grassi et al. (2004)
Exposure Levels/ Length	Flux densities of 0.5, 0.75, or 1.0-mT; exposure times from 3 to 72 hr
What They Did	The authors examined the potential for MFs to induce cell proliferation and DNA damage in several types of mammalian cells. All experimental data were tested statistically.
Results	• At 1-mT, proliferation of the 3 cell types was increased in a time-dependent manner and became statistically significant after 48-hr of exposure. Proliferation rate had increased by 20-30% in all cells by 72 hrs. Smaller increases were induced by exposure at 0.5 & 0.75 mT. • MF exposure caused a dose-dependent increase in single-stranded breaks (SSBs), with 2 peaks occurring after 24 and 72 hr of exposure. After a 24-hr recovery period after 1-mT MF exposure, 92% of the SSBs induced in rat fibroblasts cells had been repaired and 44% in human leukemia cells. • Exposure to the 1-mT MF significantly increased levels of 8-OHdG adducts, with the peak response occurring after 24 and 72 hr. • Pretreatment with 10-uM vitamin E inhibited formation of 8-OHdG adducts by about 50% throughout the period of MF exposure. • In an experiment to examine possible changes in expression of proteins involved in redox-mediated signaling, rat fibroblasts cells were exposed to the 1-mT MF for 3-36 hr changes in expression of several proteins were evaluated. The results suggest that redox-mediated signals are involved in the cell proliferative responses to MF exposures.
Conclusions	The authors concluded that ELF MFs affect cellular proliferation and DNA damage in normal and transformed (or tumor) cells through the actions of free radical species. Because normal and transformed/tumor cells have very different proliferation rates, these results emphasize the importance of continued research aimed at characterizing the role of ELF EMFs in carcinogenesis and tumor progression.
Study Limitations	
Comments[a]	

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M4:	Vijayalaxmi and Obe G. Bioelectromag 26:412-430, 2005.
Article Title	Controversial cytogenetic observations in mammalian somatic cells exposed to extremely low frequency electromagnetic radiation: A review and future research recommendations.
Study Name (if any)	
Study Type	Review
Study Population	
Health Effects Studied	
Effects Data Source	
Type of power frequency field	extremely low frequency electromagnetic fields (EMF)
Exposure Data Source	
Exposure Levels/ Length	
What They Did	Reviewed 63 peer-reviewed scientific reports of investigations using animals, cultured rodent and human cells as well as freshly collected human blood lymphocytes to determine the genotoxic potential of exposure to extremely low frequency electromagnetic fields (EMF)
Results	• The conclusions from 29 studies (46%) did not indicate increased damage to the genetic material, as assessed from DNA strand breaks, incidence of chromosomal aberrations (CA), micronuclei (MN), and sister chromatid exchanges (SCE), in EMF exposed cells as compared with sham exposed and/or unexposed cells • 14 investigations (22%) suggested an increase in such DNA damage in EMF exposed cells. • Results from 20 other studies (32%) were inconclusive. • Twenty-three studies investigated effects of combined exposure to ELF MF, with a known genotoxic mutagen and 10 of these studies did not identify any cytogenetic effect, 1 yielded evidence of a genotoxic effect, and the remaining 12 produced inconclusive results. • Most of the studies that indicated no genotoxic effects described the exposure conditions and experimental protocols in sufficient detail so that the results could be verified by independent researchers. Most of the studies reporting positive effects could not be replicated. • The authors suggested a number of possible causes for the discrepant findings. ► Historically, there has been a 10% incidence of sporadic and non-reproducible positive results in micronuclei assays in vivo studies in rodents. ► With in vitro studies, changes in the osmolarity or pH of the medium during treatment/exposure have been shown to alter the incidence of chromosomal aberrations, micronuclei, and SCEs. ► Unless appropriate statistical procedures to consider the multiple observations tested are used, analysis of results obtained from multiple genotoxic endpoints could have misidentified and reported as a "significant effect" positive

Citation M4:	Vijayalaxmi and Obe G. Bioelectromag 26:412-430, 2005.
	results that were, in fact, due to random chance.
Conclusions	• The authors concluded that the preponderance of data thus far available in the literature shows that ELF EMF exposure itself is not genotoxic to mammalian cells. • Research is recommended to resolve the positive findings reported in some of the studies. • Data obtained from a well-coordinated multicenter collaborative study with adequate statistical power will be needed to identify factors contributing to the controversial findings. • Multiple cytogenetic endpoints (e.g., chromosome aberrations, micronuclei, SCEs) and multiple cell types of human origin (e.g., blood lymphocytes, fibroblasts, tumor cells) should be examined. • It may also be desirable to examine cells with different genetic backgrounds.
Study Limitations	The authors noted that the majority of reviewed studies used a wide range of EMF exposure variables and experimental protocols, thereby making it almost impossible to directly compare results obtained by different investigators and independent researchers.
Comments	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation M5:	REFLEX Report; European Union, 2004. On-line at: http://www.itis.ethz.ch/downloads/REFLEX_Final%20Report_171104.pdf
Article Title	Risk evaluation of potential environmental hazards from low-frequency electromagnetic field exposures using sensitive in vitro methods
Study Name (if any)	REFLEX Study
Study Type	Review of in vitro studies of health effects ELF magnetic fields
Study Population	
Health Effects Studied	
Effects Data Source	
Type of power frequency field	
Exposure Data Source	
Exposure Levels/ Length	
What They Did	The report identified five priority areas of research: (1) Direct and indirect genotoxic effects of EMFs. (2) Effects of EMFs on differentiation and function of embryonic stem cells. (3) Effects of EMFs on gene expression and protein targeting. (4) Effects of EMFs on the immune system. (5) Effects of EMFs on cell transformation and apoptosis. Eleven research groups from European countries were asked to contribute to the project. The exposure conditions and dosimetric measurements were controlled across laboratories to ensure quality control of the data
Results	• Exposure at flux densities >100 µT increased the number of DNA strand breaks in cultured human diploid fibroblasts, but not in human lymphocytes and induced damage reverted within 24 hr to baseline

Citation M5:	REFLEX Report; European Union, 2004. On-line at: http://www.itis.ethz.ch/downloads/REFLEX_Final%20Report_171104.pdf
	values. • Incubation in the absence of EMF, but at an elevated temperature (38 degC) resulted in a similar increase in the number of DNA strand breaks. • Reactive oxygen species may not be generated by ELF MF, since the 8-OHdG levels in cellular DNA remained unchanged after exposure. • The growth of human neuroblastoma cells increased significantly at a flux density of 100 µT. • In contrast, DNA synthesis, cell cycle and membrane activation markers of human peripheral blood mononuclear cells were not altered after exposure to 50 Hz MF 50 µT.
Conclusions	Despite limitations, the results reported in the literature and obtained so far in the research laboratories suggest EMF affects living cells at the DNA level.
Study Limitations	Initial research period was very short and the data have not been confirmed by control experiments or by reproduction in other laboratories
Comments	Most of the data presented in this report have not been published in peer-reviewed journals.

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M6:	Stronati L , Testa A *et al*. . Bioelectromag 25:41-48, 2004.
Article Title	Absence of genotoxicity in human blood cells exposed to 50 Hz magnetic fields as assessed by comet assay, chromosome aberration, micronucleus, and sister chromatic exchange analyses
Study Name (if any)	
Study Type	In vitro
Study Population	Human blood cells
Health Effects Studied	comet assay (DNA damage), chromosome aberration (CA), micronucleus (MN), and sister chromatic exchange analyses (SCE)
Effects Data Source	Blood samples were collected from five nonsmoking healthy male volunteers, 30-40 yr old.
Type of power frequency field	50 Hz Low frequency magnetic fields
Exposure Data Source	Helmholtz coil system with heating controlled by circulating water
Exposure Levels/ Length	Treatments included: (1) sham control; (2) positive controls, exposure to 1-Gy X-radiation; (3) exposure to a 50-Hz, 1-mT uniform horizontal magnetic field for 2 hr; and (4) combined treatment, exposure to the 50-Hz, 1-mT magnetic field + 1-Gy X-irradiation.
What They Did	1-mT
Results	• No significant differences in any of the genotoxicity endpoints were seen between magnetic field-exposed and sham-exposed blood cell cultures. • X-irradiation caused significant increases ($p<0.05$ or $p<0.01$) in comet tail lengths and CA and MN frequencies, but had no effect on SCE frequency. • Combined magnetic field exposure and X-irradiation did not cause any greater alteration of the endpoints beyond that induced by X-irradiation alone. • Magnetic field exposure alone caused a slight, but statistically significant ($p<0.05$) decrease in cell proliferation, reflected in a decrease in the proliferation rate indices.
Conclusions	Since other investigators have reported both higher and lower rates of proliferation in human lymphocytes exposed to magnetic fields, the authors found this result hard to interpret. They concluded that, under their experimental conditions, 2-hr exposure to a 50-Hz 1-mT magnetic field does not appear to be genotoxic to human blood cells.
Study Limitations	
Comments	See Testa above- this study is also one of the negative studies for each of the assays described

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation M7:	Testa A , Cordelli E *et al*. Bioelectromag 25:613-619, 2004.
Article Title	Evaluation of genotoxic effect of low level 50 Hz magnetic fields on human blood cells using different cytogenetic assays.
Study Name (if any)	
Study Type	In vitro
Study Population	Human Blood Cells
Health Effects Studied	Induction of DNA damage using the alkaline comet assay, induction of sister chromatid exchanges (SCEs), micronuclei (MN), and chromosome aberrations (CAs)
Effects Data Source	Blood samples were collected from 4 healthy nonsmoking male volunteers, 30-40 yr old
Type of power frequency field	50 Hz Magnetic Field
Exposure Data Source	Commercial Helmholtz coil system with temperature control (circulating water)
Exposure Levels/ Length	
What They Did	Each sample was divided into 4 aliquots to receive one of the following treatments: (1) untreated control, (2) irradiation with 1-Gy X-rays (positive controls), (3) exposure for 48 hr to 1-mT MF, and (4) combined 1-mT MF and X-ray exposure.
Results	• Cell cultures exposed to the 50-Hz, 1-mT MF showed no significant evidence of genotoxicity, as evaluated by the comet, CA, MN, or SCE assays, when compared to control cultures. • Combined MF exposure and X-irradiation did not produce any additional increases in MN and SCE frequency and DNA damage above those produced by X-irradiation alone, suggesting a lack of a synergistic interaction between ionizing radiation and nonionizing radiation. There was also no evidence of any antagonistic effect.
Conclusions	The authors concluded that exposure of human lymphocytes to a 50-Hz, 1-mT MF for 48 hr does not cause any direct genotoxic effect nor does it affect cell proliferation.
Study Limitations	These results contradict those reported by others using different cell types (Simko et al., 1998) or very high flux densities (Yaguchi et al. 2000). The authors suggested that contradictory results may arise because of variation in exposure conditions, experimental protocols, and biological systems.
Comments	• One of 12 studies of the ability of magnetic fields to cause SCEs. There has been only one positive study (Khalil and Qassem, 1991) of pulsed 1050 µT fields in humans lymphocytes; but the study has never been replicated. • One of 9 negative studies (11 total) of EMF and DNA strand breaks. ▶ One study reported that exposure to a MF caused DNA strand breaks if the exposure was intermittent, but not if it was continuous. ▶ Another study reported that 24 or 72 hours of exposure to at 750 or 1000 µT caused DNA damage, but 48 hr exposures or exposures at 500 µT did not. • One of 11 negative studies of EMF and MN formation (18 total). ▶ Simkó *et al*. (98,99,01) reported that exposures to 800-1000 µT fields enhanced MN formation in tumor cells, but there were no effects for lower field intensities, shorter exposure times or in

Citation M7:	Testa A , Cordelli E *et al*. Bioelectromag 25:613-619, 2004.
	normal human cells. ▶ Pasquini *et al*. (2003) reported that exposures at 5000 µT for 24 hrs caused chromosome damage, but a 1-hr exposure did not.

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M8:	Cho YH and Chung HW Toxicol Let 143:37-44, 2003.
Article Title	The effect of extremely low frequency electromagnetic Fields (ELF-EMF) on the frequency of micronuclei and sister chromatid exchange in human lymphocytes induced by benzo(a)pyrene.
Study Name (if any)	
Study Type	*in vitro*
Study Population	human lymphocytes induced by benzo(a)pyrene.
Health Effects Studied	micronuclei and sister chromatid exchange
Effects Data Source	
Type of power frequency field	60-Hz Low frequency magnetic fields
Exposure Data Source	2 identical electrically coupled 0.15-m diameter, 0.30-m long solenoid coils
Exposure Levels/ Length	The cultures were exposed or sham exposed for 24 hr to a 60-Hz, 0.8-mT (8-G) magnetic field in the presence or absence of 1, 5, 10, or 15-ug/ml BaP, followed by an additional 48-hr of exposure to BaP (at the same concentration) alone
What They Did	
Results	• No significant inter-group differences in the MN, SCE, or RI values were seen between the 3 independent experiments. • Induction of MN and SCEs by BaP increased in dose-dependent manner in both sham- and field-exposed groups ($p<0.001$). • Co-exposure of lymphocytes to the magnetic field along with BaP resulted in significantly greater increases in MN and SCE than exposure to BaP alone. • All MN frequencies were significantly greater than sham controls at the corresponding BaP level ($p<0.05$). • There were no significant differences in MN and SCE frequencies or RI between magnetic-field exposed and sham-exposed lymphocyte cultures that were not treated with BaP. • Similarly, SCE frequencies increased with increasing BaP dosage and were higher in BaP + EMF cultures than corresponding sham-exposed cultures in each experiment. • Overall BaP vs. EMF + BaP SCE frequencies were significantly different ($p<0.001$) at all 4 BaP levels.
Conclusions	The authors concluded that EMF exposure has no mutagenic effect in itself, but co-exposure of lymphocytes to BaP and an 0.8-mT, 60-Hz EMF for 24 hr, followed by 48-hr exposure to BaP alone significantly enhanced induction of MN and SCE compared to BaP treatment alone. This suggests that the EMF exposure interacts with cellular systems by some indirect mechanism, probably as an enhancer of BaP-induced carcinogenesis or as a co-carcinogen, leading to increased formation of MN and SCEs in vitro.
Study Limitations	
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation M9:	Ikeda, K.; *et al*. Bioelectromagnetics 24(1):21-31 2003
Article Title	No effects of extremely low frequency magnetic fields found on cytotoxic activities and cytokine production of human peripheral blood mononuclear cells in vitro.
Study Name (if any)	
Study Type	*In vitro*
Study Population	human peripheral blood mononuclear cells
Health Effects Studied	natural killer (NK) cell cytotoxic activity and lymphokine activated killer
Effects Data Source	healthy male donors, 24 to 47 yr old
Type of power frequency field	50- or 60-Hz linearly polarized (vertical) or circularly or elliptically polarized Low frequency magnetic fields
Exposure Data Source	Sets of square Merritt-like coils (Shoden Co., Japan) were configured so as to have 2 pairs of 3 coils mutually crossing in the horizontal and vertical direction. A 30 x 30 x 30-cm incubator
Exposure Levels/ Length	Vertical fields were set at 2, 20, 100, or 500 uT rms, and the flux densities of the rotating fields were set at 500 uT rms
What They Did	Twenty-four-hr exposures were used followed by a 4-hr chromium-51 release assay using K-562 (myeloid leukemia) and Daudi (Burkitt Lymphoma) cells as the target cells for the NK and LAK assays. Cytokine production was assessed by measuring production of interferon-gamma (INFg), tumor necrosis factor-alpha (TNFa), interleukin-2 (IL2), and interleukin-10 (IL10) by the cells using enzyme-linked immunosorbent assays
Results	• None of the magnetic field exposure conditions significantly altered NK and LAK activity or production of INFg, TNFa, IL2 or IL10 relative to sham exposure. • In a few experiments, a third run was added because results of the statistical analysis between the first and second runs were different. ▶ For example, in experiments in which production of IL2 following exposure to a vertical 100-μT MF was measured, the exposed/sham ratio was 1.07 +/- 0.05 (p=0.04) in run #1, 0.99 +/- 0.05 (p=0.78) in run #2 and 1.03 +/- 0.03 (p=0.04) in the 3rd run. ▶ Similarly, in three runs with a vertical 2-μT 60-Hz field, exposed/sham ratios were 1.05 +/- 0.04, 0.98 +/- 0.03, and 1.03 +/- 0.03 (p=0.01). • There were no significant exposed/sham differences in production of the other cytokines in these experiments using the same culture samples.
Conclusions	The authors concluded that the few positive results were inconsistent with the rest of the data. Under their experimental conditions exposure of human PBMCs to 50- and 60-Hz linearly, elliptically, and circularly polarized magnetic fields did not appear to affect NK and LAK activity of and production of INFg, TNFa, IL2, and IL10 by the cells.
Study Limitations	
Comments[a]	All experiments were blinded to exposure conditions.

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M10:	Ivancsits S, Diem E *et al.* . Int Arch Occup Environ Health 76:431-436, 2003.
Article Title	Intermittent extremely low frequency electromagnetic fields cause DNA damage in a dose-dependent way
Study Name (if any)	
Study Type	*In vitro*
Study Population	human fibroblasts
Health Effects Studied	DNA damage using the comet assay
Effects Data Source	Human diploid fibroblasts harvested from 3 healthy donors: a 6-yr-old boy, a 28-yr-old female, and a 43-yr-old male
Type of power frequency field	50-Hz Low frequency magnetic fields intermittent sinusoidal
Exposure Data Source	Custom-built by the Foundation for Information Technologies in Society and placed in a commercial incubator
Exposure Levels/ Length	
What They Did	flux densities ranging from 20 to 1000 uT (200 mG to 10 G) for periods of 1 to 24 hr.
Results	• Cells exposed to a 1-mT magnetic field for 1-24 hr yielded increased comet tail factors with increasing exposure time to a maximum at 15-19 hr of exposure and decreasing at later times, but did not return to control values. • The 3 different cell donors exhibited different baseline comet tail factors, different maxima, and different end comet tail factors. • When exposure was terminated after 15 hr, the comet factors returned to baseline levels after a repair time of 7 to 9 hr. This incorporated a fast repair rate of DNA SSBs (<1 hr) and a slow repair rate of DNA DSBs (>7 hr). • A pronounced peak in comet tail factors between 12 and 17 hr and the following period of repair kinetics could also be detected when magnetic field exposure was terminated after 12 hr. It disappeared when the comet assay was performed at pH 12.1 instead of pH >13, which eliminated the cleavage of alkali labile sites in the DNA. • When magnetic flux densities were varied between 20 uT and 1 mT, dose-dependent increases in comet tail factors were observed under both alkaline and neutral conditions. These increases became statistically significant at a flux density of 35 uT ($p<0.01$).
Conclusions	• The authors concluded that these results imply that intermittent exposure to ELF EMFs is potentially genotoxic. • Induction of DNA damage was both time- and dose-dependent. • The detection of significant DNA damage at a flux density as low as 35 μT raises concerns about the validity of environmental and occupational exposure standards. For example, the observed 35-μT threshold for DNA damage is well below the guidelines of the International Commission of Nonionizing Radiation Protection, which proposes a limit of 500 μT/work day for occupational exposure, and 100 μT/24 hr for the general public.

Citation M10:	Ivancsits S, Diem E *et al*. . Int Arch Occup Environ Health 76:431-436, 2003.
Study Limitations	
Comments [a]	The experiments were blinded

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M11:	Ivancsits S, Diem E *et al*. Mut Res 519:1-13, 2002.
Article Title	Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts.
Study Name (if any)	
Study Type	*In vitro*
Study Population	normal human diploid fibroblasts
Health Effects Studied	DNA strand breaks
Effects Data Source	2 healthy donors, a 28-yr old female and a 6-yr old male
Type of power frequency field	Extremely low frequency (ELF) magnetic fields (50-Hz)
Exposure Data Source	Fields were produced by two 4-coil systems (2 coils made up of 56 windings; 2 coils made up of 50 windings) located inside mu-metal boxes
Exposure Levels/ Length	Exposed continuously or intermittently to vertical sinusoidal 50-Hz magnetic fields for 24 hr; 1-mT
What They Did	The authors examined the DNA-damaging effects of extremely low frequency (ELF) magnetic fields in normal human diploid fibroblasts.
Results	• No significant differences in the incidence of DNA SSB or DSB were seen between exposed cells and sham-exposed cells for continuous exposures. • Cells exposed to intermittently, the highest level of DNA strand breakage measured in both assays was induced by the field with the 5/10 intermittency. Significant increases in DNA damage were seen at all other on times in the alkaline comet assay and at on times of 3 to 15 min in the neutral comet assay. • Flux densities of 70 μT or greater induced significant increases in DNA damage, as determined in both assays. • There was evidence of a plateau in the response between 100 and 500 μT and between 1,000 and 2,000 μT.
Conclusions	• The authors concluded that intermittent exposure to a 50-Hz magnetic field can induce reproducible increases in DNA strand breakage in cultured human diploid fibroblasts. • This finding strongly indicates a genotoxic potential resulting from exposure to intermittent EMFs and indicates a need for further in vivo studies and reconsideration of thresholds for environmental exposure to ELF EMFs
Study Limitations	
Comments [a]	

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M12:	McNamee JP , Bellier PV *et al*. Mutat Res 513:121-133, 2002.
Article Title	DNA damage and apoptosis in the immature mouse cerebellum after acute exposure to a 1 mT, 60 Hz magnetic field.
Study Name (if any)	
Study Type	*In vitro*
Study Population	Ten-day-old mice
Health Effects Studied	DNA damage by the alkaline comet assay
Effects Data Source	
Type of power frequency field	Extremely low frequency (ELF) magnetic fields (60-Hz)
Exposure Data Source	Merritt coil system contained in a Quad/4x in vivo magnetic field exposure chamber
Exposure Levels/ Length	1-mT (10-G), 60-Hz magnetic field for 2 hr
Controls	As positive controls, additional 10-day old mice were irradiated with 0 to 3-Gy X-rays from a Dinex 150R X-ray unit
What They Did	The authors examined the ability of an extremely low frequency (ELF) magnetic field to induce DNA damage and apoptosis in the brains of immature mice.
Results	• X-ray irradiation caused a significant (p<0.05) dose-related increase in DNA damage, as reflected in all 4 comet assay parameters, and apoptosis. • Only in cerebellar samples was the comet tail ratio significantly (p<0.05) increased compared with the control value, indicating possible DNA damage. However The values of the other 3 comet parameters did not differ significantly from control values. • Values of all 4 comet parameters in exposed samples determined at the other post-exposure times did not differ from control values. • No increase in apoptosis was observed in the EGCL of exposed mice compared with sham-exposed mice.
Conclusions	The authors therefore concluded that the single positive result was a chance (false positive) effect and the results, when taken together, do not support the notion that acute exposure to ELF magnetic fields causes DNA damage in the cerebellum of immature mice.
Study Limitations	
Comments [a]	All experimental procedures were blinded

[a](*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)

Citation M13:	Yoshizawa H , Tsuchiya T *et al.* Bioelectromag 23:355-368, 2002.
Article Title	No effect of extremely low-frequency magnetic field observed on cell growth or initial response of cell proliferation in human cancer cell lines.
Study Name (if any)	
Study Type	*In vitro*
Study Population	5 human cancer cell lines derived from promyelocytic leukemia, chronic myelogenous leukemia, breast cancer, malignant melanoma, and glioma
Health Effects Studied	cell growth and morphological changes
Effects Data Source	trypan blue dye test and counting viable cells in a hemocytometer;cells were also examined for morphological changes by light microscopy after fixing with methanol and Giemsa staining
Type of power frequency field	extremely low frequency (ELF) magnetic fields (60-Hz)
Exposure Data Source	The magnetic fields were produced by the rotating field-generating system designed by Yamazaki et al. (2000); 2 pairs of 3 Merritt-type square coils that were arranged to be mutually crossing in the horizontal and vertical directions; temperature controlled incubators
Exposure Levels/ Length	Exposed or sham exposed to vertically polarized, elliptically polarized, or circularly polarized 500-μT rms, vertically polarized 100-μT rms, vertically polarized 20-μT rms, or 2-μT rms vertically polarized 50 or 60-Hz magnetic fields for 3 days
Controls	In replicate cultures for each experiment, 10% FBS was added to the medium as a positive control condition, and cells were cultured in a sham-exposure incubator.
What They Did	The effects of field exposure on the initial stages of cellular proliferation were assessed in 2 cell lines (H4 and MCF-7) by synchronizing the cells in the G1 phase by serum starvation. They were then exposed to the magnetic fields for 18 hr (H4 cells) or 24 hr (MCF-7 cells) and increases in DNA synthesis were determined from measurements of the uptake of tritium-labeled thymidine (3H-TdR) added to the cell cultures 2 hr before the end of magnetic field or sham exposure. Each magnetic field experiment was repeated twice
Results	• Positive controls for all experiments showed significant increases in cell number ($p<0.001$). • None of the magnetic field exposures significantly affected cell growth (exposed/control ratios of 0.88-1.12) or the initial stage of cell proliferation. • Some individual experiments yielded significant changes, but these were not replicated in subsequent experiments.
Conclusions	• The authors concluded that, under their experimental conditions, ELF magnetic fields of the type used in electrical power systems did not significantly affect growth and early proliferative activity in the tested human cancer cell lines. • These results provide no support for cancer promoting or progressing effects of power-frequency magnetic fields. • They also do not indicate any mechanism that could explain the reported associations between magnetic field exposure and carcinogenesis.
Study Limitations	
Comments [a]	Experiments were blinded

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation M14:	Simko M , Richard D *et al*. Mutat Res 495:43-50, 2001.
Article Title	Micronucleus induction in Syrian hamster embryo cells following exposure to 50 Hz magnetic fields, benzo(a)pyrene, and TPA in vitro.
Study Name (if any)	
Study Type	*In vitro*
Study Population	Syrian hamster embryo (SHE) cell cultures; 13-day-old embryos
Health Effects Studied	The cancer promoting or co-carcinogenic potential
Effects Data Source	Induction of MN was assessed by staining the cells (after drying) with the fluorescent DNA dye bisbenzimide and examining the cells by fluorescence microscopy.
Type of power frequency field	50-Hz Low frequency magnetic fields
Exposure Data Source	Helmholtz coil exposure system
Exposure Levels/ Length	Cells were exposed while in their exponential growth phase to a horizontally polarized 1-mT (10-G) 50-Hz magnetic field for 24, 48, or 72 hr
Controls	Control SHE cells were placed in a separate incubator or sham exposed in parallel.
What They Did	• The authors assessed the ability of magnetic fields to induce micronuclei (MN) in hamster embryo cell cultures. • Cell cultures were treated with benzo(a)pyrene (BaP) or 12-O-tetradecanoylphorbol-13-acetate (TPA) for the first 24 hr and fixed for the MN assay at 24, 48 or 72 hr. • Additional cell cultures were treated with TPA or BaP and exposed to the magnetic field in a double treatment protocol, or were exposed to the magnetic field and treated with both TPA and BaP in a triple treatment protocol. • One 3-day double treatment protocol involved treating cells with BaP for 24 hr, changing the medium and adding TPA for another 24 hr, then changing the medium and incubating the cells for an additional 24 hr (72 hr total). • In experiments designed to test the magnetic field as an initiator or co-carcinogen ("promoter-like" action), cells were continuously exposed to the magnetic field and treated with BaP or TPA for 24 hr starting on day 2, or cells were treated with BaP or TPA for 24 hr starting on day 1, followed by magnetic field exposure on day 2 until the end of the experiment (72 hr). • The triple treatment protocol involved treating cells with BaP or exposing them to the magnetic field during the first 24 hr, followed by a second treatment with TPA or magnetic field as a "promoter-like" treatment, followed by a third treatment, TPA with or without magnetic field exposure as a co-carcinogen.
Results	• Exposure to the magnetic field or TPA alone had no significant effects on MN frequency. • The concentration of BaP used was too low to induce a significant increase in MN formation at 24 hr or 48 hr, but the increase at 72 hr was significant.

	• In the double treatment protocol, only continuous exposure to the magnetic field (72 hr) and treatment with BaP for 24 hr on day 2 led to an additive genotoxic response compared to treatment with BaP alone, the number of MN per 1000 cells increasing from 19.3 +/- 11.2 (BaP alone) to 35.9 +/- 22.3 with the combined treatment ($p<0.05$). • Treatment with BaP followed by magnetic field exposure beginning on day 2, used to detect any initiator/"promoter-like" effects did not lead to a significant difference compared to the control (72-hr BaP treatment). • In the triple treatment protocol, with magnetic field exposure for 24 hr, followed by treatment with BaP and then TPA, a small but nonsignificant increase in MN formation was observed. • Changing the treatment protocol, BaP followed by magnetic field exposure and TPA or BaP followed by TPA and magnetic field exposure caused a slight decrease in MN frequency.
Conclusions	The authors concluded that their results suggest that magnetic field exposure enhances the initiation capability of BaP, since initiation with MF exposure caused a significant increase in MN formation. This co-carcinogenic effect may reflect an indirect cell activation process. The resulting genomic instability (MN formation) may be due to free radicals and/or the unscheduled "switching on" of signal transduction pathways.
Study Limitations	
Comments [a]	

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Citation M15:	Adair, R. K. Rep Prog Phys 63(3):415-454 2000
Article Title	Static and low-frequency magnetic field effects: health risks and therapies.
Study Name (if any)	
Study Type	Review
Study Population	
Health Effects Studied	
Effects Data Source	
Type of power frequency field	
Exposure Data Source	
Exposure Levels/ Length	
What They Did	The author discusses the plausibility of health effects from exposure to low-frequency MFs, with an emphasis on mechanisms of physical interaction. The author argues that physical considerations preclude possible bioeffects at intensity levels characteristic of environmental exposures, largely because these field intensities are too low to be distinguishable from endogenous fields and thermal noise. This situation is contrasted with higher intensity low-frequency MFs that are employed for therapeutic applications: these fields generate signals that must be large enough to produce bioeffects, generally requiring intensities greater than 0.1 mT (1 G).
Results	• In the low-frequency range, electric and magnetic components of electromagnetic fields are essentially independent so MFs can be considered separately. • The electric field induced by environmental intensity MFs, which do penetrate to the interior of cells, is well below noise levels. • Pulse waveforms can have a stronger effect since the capacitive admittance of the cell membrane will admit some higher frequency components (especially in the frequency range beyond 100 kHz), but calculations show MF pulses also generate fields in the cell interior that are much less than noise agitation and therefore cannot be expected to have biological consequences. • The author calculates thermal noise effects and dismisses other possible modes of interaction, taking into account Johnson-Nyquist noise levels in cell membranes, possible resonances, relaxation oscillations, direct MF interactions with biological magnetite, and MF actions on radical-pair half-life. • While evidence clearly supports biological effects from electric fields of 1-10 mV/m (or MFs that induce such electric fields), the author concludes there is no persuasive experimental evidence for biological effects produced by 50-60 Hz MFs smaller than 50 μT (0.5 G). • Experiments, which include those on the effects of low-intensity MFs on calcium homeostasis, melatonin, cardiac irregularities, and temporal coherence requirements for altering ornithine decarboxylase enzyme levels in a rat fibroblast cell line, are offered as examples of unreplicated and unreliable reported bioeffects. • Examples of high intensity MFs producing clear effects include magnetophosphenes (with a threshold of 10 mT at 20 Hz), and

Citation M15:	Adair, R. K. Rep Prog Phys 63(3):415-454 2000
	experiments on bone and soft tissue repair (requiring induced currents of 1 mA/m or more, which requires MF changes on the order of 0.2 mT over 200 usec). • For bone healing, in particular, there is a substantial body of clinical evidence supported by in vitro data providing biologically plausible hypotheses for a mechanism. • Epidemiological studies are characterized as beset with experimental uncertainties and confounders, suggesting at most a statistically weak association, which the author finds not compelling.
Conclusions	There has been large interest in the field of possible health effects of 50/60 Hz magnetic fields in the range of 0.1-0.5 μT as evidenced by the large amount of money, effort, funding and public sensitivity. There are no credible biophysical models that suggest any effects at such low exposure levels to MF. There are many studies in vivo and in vitro that claim to find effects from weak fields, but the inconsistency of the results and replication failure weakens these findings. The epidemiological data are mostly negative except for a weak association with childhood leukemia. The author discounts this association bases on the high level of biophysical improbability. The author recommends 'prudent avoidance' and cautions against unwarranted fears that can lead to excessive costs (in the US an estimated $23 billion) and potential industrial accidents.
Study Limitations	
Comments[a]	

Citation M16:	Boorman GA , Owen RD *et al*. Radiat Res 153:648-657, 2000.
Article Title	Evaluation of *in vitro* effects of 50 and 60 Hz magnetic fields in regional EMF exposure facilities.
Study Name (if any)	
Study Type	Review of *in vitro* studies of the effects of magnetic fields
Study Population	Various cell lines
Health Effects Studied	gene expression, intracellular calcium levels, cell growth
Effects Data Source	
Type of power frequency field	50 and 60 Hz low frequency magnetic fields
Exposure Data Source	Regional exposure facilities at the FDA and NIOSH
Exposure Levels/ Length	
What They Did	4 major in vitro effects reported in the scientific literature were reviewed: (1) induction of MYC gene expression in HL-60 cells (2) increases in the intracellular calcium ion concentration (Ca^{2+}) in Jurkat cells (3) increased growth on soft agar (anchorage-independent growth) of JB6 cells (4) increases in ornithine decarboxylase (ODC) activity in L929 cells. The laboratories that first reported the examined bioeffects provided experimental protocols, cell lines, and other relevant experimental details
Results	None of the studies investigating the 4 bioeffects were able to replicate the original reported effects.
Conclusions	These experiments provide insights into the problems associated with trying to replicate subtle effects in complex biological systems. Experimental techniques can explain, at least in part, some of the differences in results between the regional facility and the original investigator. The authors stress the need for a multidisciplinary approach to produce well-controlled cell culture and exposure conditions with minimal experimental bias, and note their inclusion of both positive and negative controls to validate the experimental model.
Study Limitations	
Comments [a]	These studies used a blinded design and sham/sham controls to establish whether constant differences existed between exposure chambers and what degree of variability could be expected from the systems in the absence of EMF exposure

[a]**(*i.e.*, notable strengths/weaknesses, consistency with other studies, *etc.*)**

Appendix F

List of EMF Articles Identified, year 2000 to the Present

Authors	Category	Title	Journal	Year	Vol	Page start	Page end
Abramsson-Zetterberg L; Grawé J	Animal Studies	Extended exposure of adult and fetal mice to 50 Hz magnetic field does not increase the incidence of micronuclei in erythrocytes.	BIOELECTROMAGNETICS	2001	22	351	357
Adair, RK	Review/General	Static and low-frequency magnetic field effects: health risks and therapies	REPORTS ON PROGRESS IN PHYSICS	2000	63	415	454
Adams, J; Bitler, JS; Riley, K	Review/Commentary	Importance of addressing National Electrical Code (R) violations that result in unusual exposure to 60 Hz magnetic fields	BIOELECTROMAGNETICS	2004	25	102	106
Ahlbom, A; Cardis, E; Green, A; Linet, M; Savitz, D; Swerdlow, A	Review/Epi	Review of the epidemiologic literature on EMF and health	ENVIRONMENTAL HEALTH PERSPECTIVES	2001	109	911	933
Ahlbom, A; Day, N; Feychting, M; Roman, E; Skinner, J; Dockerty, J; Linet, M; McBride, M; Michaelis, J; Olsen, JH; Tynes, T; Verkasalo, PK	Epi	A pooled analysis of magnetic fields and childhood leukaemia	BRITISH JOURNAL OF CANCER	2000	83	692	698
Ahlbom, A; Feychting, M	Review/General	Electromagnetic radiation	BRITISH MEDICAL BULLETIN	2003	68	157	165
Ahlbom, A; Feychting, M	Review/General	Current thinking about risks from currents	LANCET	2001	357	1143	1144
Aksyonov, SI; Bulychev, AA; Grunina, TY; Goryachev, SN; Turovetsky, VB	Plant study	Effects of ELF-EMF treatment on wheat seeds at different stages of germination and possible mechanisms of their origin	ELECTRO- AND MAGNETOBIOLOGY	2001	20	231	253
Aldinucci, C; Palmi, M; Sgaragli, G; Benocci, A; Meini, A; Pessina, F; Pessina, GP	Mechanism/in vitro	The effect of pulsed electromagnetic fields on the physiologic behaviour of a human astrocytoma cell line	BIOCHIMICA ET BIOPHYSICA ACTA-MOLECULAR CELL RESEARCH	2000	1499	101	108
Amemiya, Y	Review/Commentary	On the logic of a Swedish (Karolinska Institute) paper and an analysis of the pooled data of three Nordic epidemiologic studies related to cancer and the magnetic fields of power lines	ELECTRICAL ENGINEERING IN JAPAN	2001	134	53	59
Anderson LE, Morris JE, Miller DL, Rafferty CN, Ebi KL, Sasser LB.	Animal Studies	Large granular lymphocytic (LGL) leukemia in rats exposed to intermittent 60 Hz magnetic fields.	BIOELECTROMAGNETICS	2001	22	185	193
Ansari, RM; Hei, TK	Mechanism/in vitro	Effects of 60 Hz extremely low frequency magnetic fields (EMF) on radiation- and chemical-induced mutagenesis in mammalian cells	CARCINOGENESIS	2000	21	1221	1226
Armstrong, BG; Deadman, J; McBride, ML	Exposure	The determinants of Canadian children's personal exposures to magnetic fields	BIOELECTROMAGNETICS	2001	22	161	169
Auvinen, A; Linet, MS; Hatch, EE; Kleinerman, RA; Robison, LL; Kaune, WT; Misakian, M;	Review/Epi	Extremely low-frequency magnetic fields and childhood acute lymphoblastic leukemia: An exploratory analysis of alternative exposure metrics	AMERICAN JOURNAL OF EPIDEMIOLOGY	2000	152	20	31

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Niwa, S; Wacholder, S; Tarone, RE							
Babbitt, JT; Kharazi, AI; Taylor, JMG; Bonds, CB; Mirell, SG; Frumkin, E; Zhuang, DL; Hahn, TJ	Animal Studies	Hematopoietic neoplasia in C57BL/6 mice exposed to split-dose ionizing radiation and circularly polarized 60 Hz magnetic fields	CARCINOGENESIS	2000	21	1379	1389
Bailey, WH	Review/Standards	Health effects relevant to the setting of emf exposure limits	HEALTH PHYSICS	2002	83	376	386
Baldwin, RT; Preston-Martin, S	Review/Epi	Epidemiology of brain tumors in childhood - a review	TOXICOLOGY AND APPLIED PHARMACOLOGY	2004	199	118	131
Banks, RS; Thomas, W; Mandel, JS; Kaune, WT; Wacholder, S; Throne, RE; Linet, MS	Exposure	Temporal trends and misclassification in residential 60 Hz magnetic field measurements	BIOELECTROMAGNETICS	2002	23	196	205
Baumgardt-Elms, C; Schumann, M; Ahrens, W; Bromen, K; Stang, A; Jahn, I; Stegmaier, C; Jockel, KH	Epi	Residential exposure to overhead high-voltage lines and the risk of testicular cancer: results of a population-based case-control study in Hamburg (Germany)	INTERNATIONAL ARCHIVES OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH	2005	78	20	26
Behrens, T; Terschuren, C; Kaune, WT; Hoffmann, W	Exposure	Quantification of lifetime accumulated ELF-EMF exposure from household appliances in the context of a retrospective epidemiological case-control study	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL EPIDEMIOLOGY	2004	14	144	153
Belyaev, IY; Alipov, ED	Mechanism/in vitro	Frequency-dependent effects of ELF magnetic field on chromatin conformation in Escherichia coli cells and human lymphocytes	BIOCHIMICA ET BIOPHYSICA ACTA-GENERAL SUBJECTS	2001	1526	269	276
Beraldi, R; Sciamanna, I; Mangiacasale, R; Lorenzini, R; Spadafora, C	Animal Studies	Mouse early embryos obtained by natural breeding or in vitro fertilization display a differential sensitivity to extremely low-frequency electromagnetic fields	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2003	538	163	170
Beruto, DT; Botter, R; Perfumo, F; Scaglione, S	NA	Interfacial effect of extremely low frequency electromagnetic fields (EM-ELF) on the vaporization step of carbon dioxide from aqueous solutions of body simulated fluid (SBF)	BIOELECTROMAGNETICS	2003	24	251	261
Bianchi, N; Crosignani, P; Rovelli, A; Tittarelli, A; Carnelli, CA; Rossitto, F; Vanelli, U; Porro, E; Berrino, F	Epi	Overhead electricity power lines and childhood leukemia: A registry-based, case-control study	TUMORI	2000	86	195	198
Blaasaas KG, Tynes T, Irgens A, Lie RT.	Epi	Risk of birth defects by parental occupational exposure to 50 Hz electromagnetic fields: a population based study.	OCCUPATIONAL AND ENVIRONMENTAL MEDICINE	2002	59	92	97

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Blaasaas KG, Tynes T, Lie RT.	Epi	Residence near power lines and the risk of birth defects.	EPIDEMIOLOGY	2003	14	95	98
Blaasaas KG, Tynes T, Lie RT.	Epi	Risk of selected birth defects by maternal residence close to power lines during pregnancy.	OCCUPATIONAL AND ENVIRONMENTAL MEDICINE	2004	61	174	176
Blaasaas, KG; Tynes, T	Exposure	Comparison of three different ways of measuring distances between residences and high voltage power lines	BIOELECTROMAGNETICS	2002	23	288	291
Boland, A; Delapierre, D; Mossay, D; Dresse, A; Seutin, V	Mechanism/in vitro	Effect of intermittent and continuous exposure to electromagnetic fields on cultured hippocampal cells	BIOELECTROMAGNETICS	2002	23	97	105
Boorman GA, McCormick DL, Findlay JC, Hailey JR, Gauger JR, Johnson TR, Kovatch RM, Sills RC, Haseman JK.	Animal Studies	Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in F344/N rats.	TOXICOLOGIC PATHOLOGY	1999	27	267	278
Boorman GA, McCormick DL, Ward JM, Haseman JK, Sills RC.	Animal Studies	Magnetic fields and mammary cancer in rodents: A critical review and evaluation of published literature.	RADIATION RESEARCH	2000	153	617	626
Boorman, GA; Owen, RD; Lotz, WG; Galvin, MJ	Mechanism/in vitro	Evaluation of in vitro effects of 50 and 60 Hz magnetic fields in regional EMF exposure facilities	RADIATION RESEARCH	2000	153	648	657
Boorman, GA; Rafferty, CN; Ward, JM; Sills, RC	Animal Studies	Leukemia and lymphoma incidence in rodents exposed to low-frequency magnetic fields	RADIATION RESEARCH	2000	153	627	636
Borugian MJ, Spinelli JJ, Mezei G, Wilkins R, Abanto Z, McBride ML.	Epi	Childhood leukemia and socioeconomic status in Canada	EPIDEMIOLOGY	2005	16	526	531
Boulton, A; Boyd, P; Cheng, KK; Cook, J; Gilman, EA; Lunt, D; Mahler, H; Walker, C; Wardroper, M; Darbyshire, PJ; Hill, FGH; Mann, JR; Morland, B; Raafat, F; Stevens, MCG; Ahmed, A; Amos, P; Bone, V; Bonney, S; Bray, M; Cambouropoulos, P; Cook, S; Day, N;	Review	The United Kingdom Childhood Cancer Study: objectives, materials and methods	BRITISH JOURNAL OF CANCER	2000	82	1073	1102
Bowman, JD; Methner, MM	Exposure	Hazard surveillance for industrial magnetic fields: II. Field characteristics from waveform measurements	ANNALS OF OCCUPATIONAL HYGIENE	2000	44	615	633
Bowman, JD; Thomas, DC	Commentary	Re: "Are children living near high-voltage power lines at increased risk of acute lymphoblastic leukemia?"	AMERICAN JOURNAL OF EPIDEMIOLOGY	2001	153	615	616
Brain, JD; Kavet, R; McCormick, DL; Poole, C; Silverman, LB; Smith, TJ; Valberg, PA; Van Etten, RA; Weaver, JC	Review/Epi	Childhood leukemia: Electric and magnetic fields as possible risk factors	ENVIRONMENTAL HEALTH PERSPECTIVES	2003	111	962	970

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Brazzale, AR; Salvan, A; Roletti, S	Exposure	A hierarchical modelling approach for measuring reliability of and agreement between two types of magnetic field dosimeter	JOURNAL OF THE ROYAL STATISTICAL SOCIETY SERIES C-APPLIED STATISTICS	2004	53	261	278
Brazzale, AR; Salvan, A; Roletti, S; Pons, O	Exposure	Use of mixed effects models in assessing reliability and agreement of ELF-EMF dosimeters	EPIDEMIOLOGY	2002	13	S254	S255
Brix, J; Wettemann, H; Scheel, O; Feiner, F; Matthes, R	Exposure	Measurement of the individual exposure to 50 and 16 2/3 Hz magnetic fields within the Bavarian population	BIOELECTROMAGNETICS	2001	22	323	332
Buffler, PA; Kwan, ML; Reynolds, P; Urayama, KY	Review	Environmental and genetic risk factors for childhood leukemia: Appraising the evidence	CANCER INVESTIGATION	2005	23	60	75
Caplan, LS; Schoenfeld, ER; O'Leary, ES; Leske, MC	Review	Breast cancer and electromagnetic fields - A review	ANNALS OF EPIDEMIOLOGY	2000	10	31	44
Cecconi, S; Gualtieri, G; Di Bartolomeo, A; Troiani, G; Cifone, MG; Canipari, R	Mechanism/in vitro	Evaluation of the effects of extremely low frequency electromagnetic fields on mammalian follicle development	HUMAN REPRODUCTION	2000	15	2319	2325
Chang, K; Chang, WHS; Wu, ML; Shih, C	Mechanism/in vitro	Effects of different intensities of extremely low frequency pulsed electromagnetic fields on formation of osteoclast-like cells	BIOELECTROMAGNETICS	2003	24	431	439
Chen, G; Upham, BL; Sun, W; Chang, CC; Rothwell, EJ; Chen, KM; Yamasaki, H; Trosko, JE	Mechanism/in vitro	Effect of electromagnetic field exposure on chemically induced differentiation of Friend erythroleukemia cells	ENVIRONMENTAL HEALTH PERSPECTIVES	2000	108	967	972
Cheng, KK; Day, NE; Cartwright, R; Craft, A; Birch, JM; Eden, OB; McKinney, PA; Peto, J; Beral, V; Roman, E; Elwood, P; Alexander, FE; Chilvers, CED; Doll, R; Greaves, M; Goodhead, D; Fry, FA; Adams, G; Gilman, E; Skinner, J; Williams, D; Deacon, J; Mott, M; Muir, K; Law, G; Simpson, J	Review	Childhood cancer and residential proximity to power lines	BRITISH JOURNAL OF CANCER	2000	83	1573	1580
Chiang, H; Hu, GL; Xu, ZP	Mechanism/in vitro	Effects of extremely low frequency magnetic fields on gap junctional intercellular communication and its mechanism	PROGRESS IN NATURAL SCIENCE	2002	12	166	169
Chin, RS; Stuchly, MA	Mechanism/in vitro	Electric fields in bone marrow substructures at power-line frequencies	IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING	2005	52	1103	1109

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Cho, YH; Chung, HW	Mechanism/in vitro	The effect of extremely low frequency electromagnetic fields (ELF-EMF) on the frequency of micronuclei and sister chromatid exchange in human lymphocytes induced by benzo(a)pyrene	TOXICOLOGY LETTERS	2003	143	37	44
Chung, MK; Kim, JC; Myung, SH	Animal Studies	Lack of adverse effects in pregnant/lactating female rats and their offspring following pre- and postnatal exposure to ELF magnetic fields	BIOELECTROMAGNETICS	2004	25	236	244
Chung, MK; Kim, JC; Myung, SH; Lee, DI	Animal Studies	Developmental toxicity evaluation of ELF magnetic fields in Sprague-Dawley rats	BIOELECTROMAGNETICS	2003	24	231	240
Cocco, P; Cocco, ME; Paghi, L; Avataneo, G; Salis, A; Meloni, M; Atzeri, S; Broccia, G; Ennas, MG; Erren, TC; Reiter, RJ	Exposure/internal does	Urinary 6-sulfatoxymelatonin excretion in humans during domestic exposure to 50 hertz electromagnetic fields	NEUROENDOCRINOLOGY LETTERS	2005	26	136	142
Coghill, R; Galonja-Coghill, T	Mechanism/in vitro	Protective effect of a donor's endogenous electric fields on human peripheral blood lymphocyte viability	ELECTRO- AND MAGNETOBIOLOGY	2000	19	43	56
Cook, CM; Thomas, AW; Keenliside, L; Prato, FS	Clinical studies	Resting EEG effects during exposure to a pulsed ELF magnetic field	BIOELECTROMAGNETICS	2005	26	367	376
Cook, CM; Thomas, AW; Prato, FS	Clinical studies	Resting EEG is affected by exposure to a pulsed ELF magnetic field	BIOELECTROMAGNETICS	2004	25	196	203
Cook, CM; Thomas, AW; Prato, FS	Review	Human electrophysiological and cognitive effects of exposure to ELF magnetic and ELF modulated RF and microwave fields: A review of recent studies	BIOELECTROMAGNETICS	2002	23	144	157
Crasson, M	Review	50-60 Hz electric and magnetic field effects on cognitive function in humans: A review	RADIATION PROTECTION DOSIMETRY	2003	106	333	340
Crosignani, P; Tittarelli, A; Borgini, A; Codazzi, T; Rovelli, A; Porro, E; Contiero, P; Bianchi, N; Tagliabue, G; Fissi, R; Rossitto, F; Berrino, F	Confounding exposures/Epi	Childhood leukemia and road traffic: A population-based case-control study	INTERNATIONAL JOURNAL OF CANCER	2004	108	596	599
Crumpton, MJ	Review	The Bernal Lecture 2004 - Are low-frequency electromagnetic fields a health hazard?	PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES	2005	360	1223	1230
Crumpton, MJ; Collins, AR	Review	Are environmental electromagnetic fields genotoxic?	DNA REPAIR	2004	3	1385	1387
Cruz, P; Izquierdo, C; Burgos, M	Interventions	Optimum passive shields for mitigation of power lines magnetic field	IEEE TRANSACTIONS ON POWER DELIVERY	2003	18	1357	1362

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Czyz, J; Nikolova, T; Schuderer, H; Kuster, N; Wobus, AM	Mechanism/in vitro	Non-thermal effects of power-line magnetic fields (50 Hz) on gene expression levels of pluripotent embryonic stem cells - the role of tumour suppressor p53	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2004	557	63	74
da Silva, RL; Albano, F; dos Santos, LRL; Tavares, AD; Felzenszwalb, I	Mechanism/in vitro	The effect of electromagnetic field exposure on the formation of DNA lesions	REDOX REPORT	2000	5	299	301
d'Amore, G; Anglesio, L; Tasso, M; Benedetto, A; Roletti, S	Exposure	Outdoor background ELF magnetic fields in an urban environment	RADIATION PROTECTION DOSIMETRY	2001	94	375	380
Dasdag, S; Sert, C; Akdag, MZ; Oflazoglu, HD	Mechanism/in vitro	Effects of microwaves and elf magnetic field on the phagocytic activity of variously treated rat macrophages	ELECTRO- AND MAGNETOBIOLOGY	2001	20	177	184
Dasdag, S; Sert, C; Akdag, Z; Batun, S	Occupational/Biological markers	Effects of extremely low frequency electromagnetic fields on hematologic and immunologic parameters in welders	ARCHIVES OF MEDICAL RESEARCH	2002	33	29	32
Datta, D; Kundu, PK; Deshpande, A	Mechanism/in vitro	Magnetic field stimulation of hybridoma cells in vitro	ELECTRO- AND MAGNETOBIOLOGY	2001	20	263	280
Davis, S; Mirick, DK; Stevens, RG	Review	Residential magnetic fields and the risk of breast cancer	AMERICAN JOURNAL OF EPIDEMIOLOGY	2002	155	446	454
de Bruyn, L; de Jager, L; Kuyl, JM	Animal Studies	The influence of long-term exposure of mice to randomly varied power frequency magnetic fields on their nocturnal melatonin secretion patterns	ENVIRONMENTAL RESEARCH	2001	85	115	121
Deadman, JE; Infante-Rivard, C	Exposure	Individual estimation of exposures to extremely low frequency magnetic fields in jobs commonly held by women	AMERICAN JOURNAL OF EPIDEMIOLOGY	2002	155	368	378
Devevey, L; Patinot, C; Debray, M; Thierry, D; Brugere, H; Lambrozo, J; Guillosson, JJ; Nafziger, J	Animal Studies	Absence of the effects of 50 Hz magnetic fields on the progression of acute myeloid leukaemia in rats	INTERNATIONAL JOURNAL OF RADIATION BIOLOGY	2000	76	853	862
Di Carlo, A; White, N; Guo, F; Garrett, P; Litovitz, T	Mechanism/in vitro	Chronic electromagnetic field exposure decreases HSP70 levels and lowers cytoprotection	JOURNAL OF CELLULAR BIOCHEMISTRY	2002	84	447	454
Di Luzio, S; Felaco, SM; Barbacane, RC; Frydas, S; Grilli, A; Castellani, ML; Macri, MA; Di Gioacchino, M; Merlitti, D; De Lutiis, MA; Masci, S; Di Giulio, C; Cacchio, M; Reale, M	Mechanism/in vitro	Effects of 50 Hz sinusoidal electromagnetic fields on MCP-1 and RANTES generated from activated human macrophages	INTERNATIONAL JOURNAL OF IMMUNOPATHOLOGY AND PHARMACOLOGY	2001	14	169	172
Ding, GR; Nakahara, T; Miyakoshi, J	Mechanism/in vitro	Induction of kinetochore-positive and kinetochore-negative micronuclei in CHO cells by ELF magnetic fields and/or X-rays	MUTAGENESIS	2003	18	439	443

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Draper, G; Vincent, T; Kroll, ME; Swanson, J	Epi	Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study	BRITISH MEDICAL JOURNAL	2005	330	1290	1292A
Dubreuil, D; Jay, T; Edeline, JM	Animal Studies	Does head-only exposure to GSM-900 electromagnetic fields affect the performance of rats in spatial learning tasks?	BEHAVIOURAL BRAIN RESEARCH	2002	129	203	210
Ebi, KL; Kheifets, LI; Pearson, RL; Wachtel, H	Review/Commentary	Description of a new computer wire coding method and its application to evaluate potential control selection bias in the Savitz et al. childhood cancer study	BIOELECTROMAGNETICS	2000	21	346	353
Eccles, NK	Review	A critical review of randomized controlled trials of static magnets for pain relief	JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE	2005	11	495	509
Erren, TC	Epi	A meta-analysis of epidemiologic studies of electric and magnetic fields and breast cancer in women and men	BIOELECTROMAGNETICS	2001		S105	S119
Eskelinen, T; Keinanen, J; Salonen, H; Juutilainen, J	Exposure	Use of spot measurements for assessing residential ELF magnetic field exposure: A validity study	BIOELECTROMAGNETICS	2002	23	173	176
Eskelinen, T; Niiranen, J; Juutilainen, J	Exposure	Use of short-term measurements for assessing temporal variability of residential ELF magnetic field exposure	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL EPIDEMIOLOGY	2003	13	372	377
Fadel, MA; El-Gebaly, RH; Aly, AA; Ibrahim, FF	Animal Studies	Control of Ehrlich tumor growth by electromagnetic waves at resonance frequency (in vivo studies)	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2005	24	9	21
Feychting M.	Review	Non-cancer EMF effects related to children.	BIOELECTROMAGNETICS	2005			
Feychting, M; Ahlbom, A	Review/Commentary	With regard to the relative merits of contemporary measurements and historical calculated fields in the Swedish childhood cancer study	EPIDEMIOLOGY	2000	11	357	358
Feychting, M; Ahlborn, A; Kheifets, L	Review/General	EMF and health	ANNUAL REVIEW OF PUBLIC HEALTH	2005	26	165	189
Filippopoulos, G; Tsanakas, D	Exposure	Analytical calculation of the magnetic field produced by electric power lines	IEEE TRANSACTIONS ON POWER DELIVERY	2005	20	1474	1482
Fojt, L; Strasak, L; Vetterl, V; Smarda, J	Mechanism/in vitro	Comparison of the low-frequency magnetic field effects on bacteria Escherichia coli, Leclercia adecarboxylata and Staphylococcus aureus	BIOELECTROCHEMISTRY	2004	63	337	341
Foliart, DE; Iriye, RN; Silva, JM; Mezei, G; Tarr, KJ; Ebi, KL	Exposure	Correlation of year-to-year magnetic field exposure metrics among children in a leukemia survival study	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL	2002	12	441	447

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			EPIDEMIOLOGY				
Foliart, DE; Iriye, RN; Tarr, KJ; Silva, JM; Kavet, R; Ebi, KL	Exposure	Alternative magnetic field exposure metrics: Relationship to TWA, appliance use, and demographic characteristics of children in a leukemia survival study	BIOELECTROMAGNETICS	2001	22	574	580
Forssen, UM; Ahlbom, A; Feychting, M	Exposure	Relative contribution of residential and occupational magnetic field exposure over twenty-four hours among people living close to and far from a power line	BIOELECTROMAGNETICS	2002	23	239	244
Freedman, DM; Stewart, P; Kleinerman, RA; Wacholder, S; Hatch, EE; Tarone, RE; Robison, LL; Linet, MS	Confounding exposures/Epi	Household solvent exposures and childhood acute lymphoblastic leukemia	AMERICAN JOURNAL OF PUBLIC HEALTH	2001	91	564	567
Galloni, P; Marino, C	Animal Studies	Effects of 50 Hz magnetic field exposure on tumor experimental models	BIOELECTROMAGNETICS	2000	21	608	614
Garrido, C; Otero, AF; Cidras, J	Exposure	Low-frequency magnetic fields from electrical appliances and power lines	IEEE TRANSACTIONS ON POWER DELIVERY	2003	18	1310	1319
Gomez, MJR; De la Pena, L; Pastor, JM; Morillo, MM; Gil, L	Mechanism/in vitro	25 Hz electromagnetic field exposure has no effect on cell cycle distribution and apoptosis in U-937 and HCA-2/1(cch) cells	BIOELECTROCHEMISTRY	2001	53	137	140
Graham, C; Sastre, A; Cook, MR; Gerkovich, MM	Clinical studies	All-night exposure to EMF does not alter urinary melatonin, 6-OHMS or immune measures in older men and women	JOURNAL OF PINEAL RESEARCH	2001	31	109	113
Graham, C; Sastre, A; Cook, MR; Kavet, R; Gerkovich, MM; Riffle, DW	Clinical studies	Exposure to strong ELF magnetic fields does not alter cardiac autonomic control mechanisms	BIOELECTROMAGNETICS	2000	21	413	421
Graham, JH; Fletcher, D; Tigue, J; McDonald, M	Animal Studies	Growth and developmental stability of Drosophila melanogaster in low frequency magnetic fields	BIOELECTROMAGNETICS	2000	21	465	472
Grainger, P; Preece, AW	Exposure	The contribution of local distribution substations and associated area distribution system to personal exposure to power frequency magnetic fields	INTERNATIONAL JOURNAL OF ENVIRONMENTAL HEALTH RESEARCH	2000	10	285	290
Greenland S.	Review	The impact of prior distributions for uncontrolled confounding and response bias: A case study of the relation of wire codes and magnetic fields to childhood leukemia	JOURNAL OF THE AMERICAN STATISTICAL ASSOCIATION	2003	98	47	54
Greenland S.	Review	Multiple-bias modelling for analysis of observational data	JOURNAL OF THE ROYAL STATISTICAL SOCIETY SERIES A-STATISTICS IN SOCIETY	2005	168	267	291

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Greenland, S	Review	Estimation of population attributable fractions from fitted incidence ratios and exposure survey data, with an application to electromagnetic fields and childhood leukemia	BIOMETRICS	2001	57	182	188
Greenland, S; Sheppard, AR; Kaune, WT; Poole, C; Kelsh, MA	Commentary	Pooled analysis of magnetic fields, wire codes, and childhood leukemia - Reply	EPIDEMIOLOGY	2001	12	473	474
Greenland, S; Sheppard, AR; Kaune, WT; Poole, C; Kelsh, MA	Epi	A pooled analysis of magnetic fields, wire codes, and childhood leukemia	EPIDEMIOLOGY	2000	11	624	634
Gutzeit, HO	Review	Biological effects of ELF-EMF enhanced stress response: New insights and new questions	ELECTRO- AND MAGNETOBIOL OGY	2001	20	15	26
Hansen, NH; Sobel, E; Davanipour, Z; Gillette, LM; Niiranen, J; Wilson, BW	Exposure	EMF exposure assessment in the Finnish garment industry: Evaluation of proposed EMF exposure metrics	BIOELECTROMA GNETICS	2000	21	57	67
Harada, S; Yamada, S; Kuramata, O; Gunji, Y; Kawasaki, M; Miyakawa, T; Yonekura, H; Sakurai, S; Bessho, K; Hosono, R; Yamamoto, H	Mechanism/in vitro	Effects of high ELF magnetic fields on enzyme-catalyzed DNA and RNA synthesis in vitro and on a cell-free DNA mismatch repair	BIOELECTROMA GNETICS	2001	22	260	266
Hassan, N; Chatterjee, I; Publicover, NG; Craviso, GL	Mechanism/in vitro	Numerical study of induced current perturbations in the vicinity of excitable cells exposed to extremely low frequency magnetic fields	PHYSICS IN MEDICINE AND BIOLOGY	2003	48	3277	3293
Hatch, EE; Kleinerman, RA; Linet, MS; Tarone, RE; Kaune, WT; Auvinen, A; Baris, D; Robison, LL; Wacholder, S	Review	Do confounding or selection factors of residential wiring codes and magnetic fields distort findings of electromagnetic fields studies?	EPIDEMIOLOGY	2000	11	189	198
Havas, M	Exposure	Intensity of electric and magnetic fields from power lines within the business district of 60 Ontario communities	SCIENCE OF THE TOTAL ENVIRONMENT	2002	298	183	206
Hefeneider, SH; McCoy, SL; Hausman, FA; Christensen, HL; Takahashi, D; Perrin, N; Bracken, TD; Shin, KY; Hall, AS	Animal Studies	Long-term effects of 60-Hz electric vs. magnetic fields on IL-1 and IL-2 activity in sheep	BIOELECTROMA GNETICS	2001	22	170	177
Heikkinen, P; Kosma, VM; Huuskonen, H; Komulainen, H; Kumlin, T; Penttila, I; Vaananen, A; Juutilainen, J	Animal Studies	Effects of 50 Hz magnetic fields on cancer induced by ionizing radiation in mice	INTERNATIONA L JOURNAL OF RADIATION BIOLOGY	2001	77	483	495
Henderson, B; Tagwerker, A; Mayrl, C; Pfister, G; Boeck, G; Ulmer, H; Dietrich, H; Wick, G	Animal Studies	Progression of arteriovenous bypass restenosis in mice exposed to a 50 Hz magnetic field	CELL STRESS & CHAPERONES	2003	8	373	380

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Henderson, BR; Pfister, G; Boeck, G; Kind, M; Wick, G	Mechanism/in vitro	Expression levels of heat shock protein 60 in human endothelial cells in vitro are unaffected by exposure to 50 Hz magnetic fields	CELL STRESS & CHAPERONES	2003	8	172	182
Heredia-Rojas, JA; la Fuente, AORD; Velazco-Campos, MD; Leal-Garza, CH; Rodriguez-Flores, LE; de la Fuente-Cortez, B	Mechanism/in vitro	Cytological effects of 60 hz magnetic fields on human lymphocytes in vitro: Sister-chromatid exchanges, cell kinetics and mitotic rate	BIOELECTROMAGNETICS	2001	22	145	149
Hone, P; Edwards, A; Halls, J; Cox, R; Lloyd, D	Review/Mechanism	Possible associations between ELF electromagnetic fields, DNA damage response processes and childhood leukaemia	BRITISH JOURNAL OF CANCER	2003	88	1939	1941
Hong, SC; Kurokawa, Y; Kabuto, M; Ohtsuka, R	Clinical studies	Chronic exposure to ELF magnetic fields during night sleep with electric sheet: Effects on diurnal melatonin rhythms in men	BIOELECTROMAGNETICS	2001	22	138	143
Hu, GL; Chiang, H; Wu, RY; Lu, DJ	Mechanism/in vitro	Absence of ELF magnetic field effects on transcription of the connexin43 gene	ELECTRO- AND MAGNETOBIOLOGY	2000	19	345	350
Hu, GL; Chiang, H; Zeng, QL; Fu, YD	Mechanism/in vitro	ELF magnetic field inhibits gap junctional intercellular communication and induces hyperphosphorylation of connexin43 in NIH3T3 cells	BIOELECTROMAGNETICS	2001	22	568	573
Hu, GL; Fu, YD; Zeng, QL; Xu, ZP; Chiang, H	Mechanism/in vitro	Study on gap junctional intercellular communication inhibition by elf magnetic fields using FRAP method	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2002	21	155	160
Ikeda K, Shinmura Y, Mizoe H, Yoshizawa H, Yoshida A, Kanao S, Sumitani H, Hasebe S, Motomura T, Yamakawa T, Mizuno F, Otaka Y, Hirose H.	Mechanism/in vitro	No effects of extremely low frequency magnetic fields found on cytotoxic activities and cytokine production of human peripheral blood mononuclear cells in vitro. Bioelectromagnetics	BIOELECTROMAGNETICS	2003	24	21	31
Ikehara, T; Park, KH; Yamaguchi, H; Hosokawa, K; Houchi, H; Azuma, M; Minakuchi, K; Kashimoto, H; Kitamura, M; Kinouchi, Y; Yoshizaki, K; Miyamoto, H	Mechanism/in vitro	Effects of a time varying strong magnetic field on release of cytosolic free Ca2+ from intracellular stores in cultured bovine adrenal chromaffin cells	BIOELECTROMAGNETICS	2002	23	505	515
Ikehara, T; Yamaguchi, H; Hosokawa, K; Houchi, H; Park, KH; Minakuchi, K; Kashimoto, H; Kitamura, M; Kinouchi, Y; Yoshizaki, K; Miyamoto, H	Mechanism/in vitro	Effects of a time-varying strong magnetic field on transient increase in Ca2+ release induced by cytosolic Ca2+ in cultured pheochromocytoma cells	BIOCHIMICA ET BIOPHYSICA ACTA-GENERAL SUBJECTS	2005	1724	8	16
Ikehara, T; Yamaguchi, H; Hosokawa, K; Miyamoto, H; Aizawa, K	Mechanism/in vitro	Effects of ELF magnetic field on membrane protein structure of living HeLa cells studied by fourier transform infrared spectroscopy	BIOELECTROMAGNETICS	2003	24	457	464

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Infante-Rivard C, Deadman JE.	Epi	Maternal occupational exposure to extremely low frequency Magnetic fields during pregnancy and childhood leukemia.	EPIDEMIOLOGY	2003	14	437	441
Ishido, M; Nitta, H; Kabuto, M	Mechanism/in vitro	Magnetic fields (MF) of 50 Hz at 1.2 mu T as well as 100 mu T cause uncoupling of inhibitory pathways of adenylyl cyclase mediated by melatonin 1a receptor in MF-sensitive MCF-7 cells	CARCINOGENESIS	2001	22	1043	1048
Ivancsits, S; Diem, E; Jahn, O; Rudiger, HW	Mechanism/in vitro	Intermittent extremely low frequency electromagnetic fields cause DNA damage in a dose-dependent way	INTERNATIONAL ARCHIVES OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH	2003	76	431	436
Ivancsits, S; Diem, E; Jahn, O; Rudiger, HW	Mechanism/in vitro	Age-related effects on induction of DNA strand breaks by intermittent exposure to electromagnetic fields	MECHANISMS OF AGEING AND DEVELOPMENT	2003	124	847	850
Ivancsits, S; Diem, E; Pilger, A; Rudiger, HW; Jahn, O	Mechanism/in vitro	Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2002	519	1	13
Ivancsits, S; Pilger, A; Diem, E; Jahn, O; Rudiger, HW	Mechanism/in vitro	Cell type-specific genotoxic effects of intermittent extremely low-frequency electromagnetic fields	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2005	583	184	188
Jaffa, KC	Epi	Pooled analysis of magnetic fields, wire codes, and childhood leukemia	EPIDEMIOLOGY	2001	12	472	473
Jaffa, KC; Kim, H; Aldrich, TE	Exposure	The relative merits of contemporary measurements and historical calculated fields in the Swedish childhood cancer study	EPIDEMIOLOGY	2000	11	353	356
Jamieson, D; Wartenberg, D	Review	The precautionary principle and electric and magnetic fields	AMERICAN JOURNAL OF PUBLIC HEALTH	2001	91	1355	1358
Johansen, C	Review	Electromagnetic fields and health effects - epidemiologic studies of cancer, diseases of the central nervous system and arrhythmia-related heart disease	SCANDINAVIAN JOURNAL OF WORK ENVIRONMENT & HEALTH	2004	30	1	30
Junkersdorf, B; Bauer, H; Gutzeit, HO	Mechanism/in vitro	Electromagnetic fields enhance the stress response at elevated temperatures in the nematode Caenorhabditis elegans	BIOELECTROMAGNETICS	2000	21	100	106
Juutilainen, J; Lang, S; Rytomaa, T	Review/Mechanism	Possible cocarcinogenic effects of ELF electromagnetic fields may require repeated long-term interaction with known carcinogenic factors	BIOELECTROMAGNETICS	2000	21	122	128

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Juutilainen, J; Stevens, RG; Anderson, LE; Hansen, NH; Kilpelainen, M; Kumlin, T; Laitinen, JT; Sobel, E; Wilson, BW	Occupational/Biological markers	Nocturnal 6-hydroxymelatonin sulfate excretion in female workers exposed to magnetic fields	JOURNAL OF PINEAL RESEARCH	2000	28	97	104
Kalhor, HA; Zunoubi, MR	Mitigation	Mitigation of power frequency fields by proper choice of line configuration and shielding	ELECTROMAGNETICS	2005	25	231	243
Kaune, WT	Exposure	Estimating the magnitude of the sum of two magnetic fields with uncertain spatial orientations, polarizations, and/or relative phase	BIOELECTROMAGNETICS	2002	23	59	67
Kaune, WT; Banks, RS; Linet, MS; Hatch, EE; Kleinerman, RA; Wacholder, S; Tarone, RE; Haines, C	Review/Standards	Static magnetic field measurements in residences in relation to resonance hypotheses of interactions between power-frequency magnetic fields and humans	BIOELECTROMAGNETICS	2001	22	294	305
Kaune, WT; Bracken, TD; Senior, RS; Rankin, RF; Niple, JC; Kavet, R	Exposure	Rate of occurrence of transient magnetic field events in US residences	BIOELECTROMAGNETICS	2000	21	197	213
Kaune, WT; Davis, S; Stevens, RG; Mirick, DK; Kheifets, L	Exposure	Measuring temporal variability in residential magnetic field exposures	BIOELECTROMAGNETICS	2001	22	232	245
Kaune, WT; Dovan, T; Kavet, RI; Savitz, DA; Neutra, RR	Exposure	Study of high- and low-current-configuration homes from the 1988 Denver childhood cancer study	BIOELECTROMAGNETICS	2002	23	177	188
Kaune, WT; Miller, MC; Linet, MS; Hatch, EE; Kleinerman, RA; Wacholder, S; Mohr, AH; Tarone, RE; Haines, C	Exposure	Magnetic fields produced by hand held hair dryers, stereo headsets, home sewing machines, and electric clocks	BIOELECTROMAGNETICS	2002	23	14	25
Kavet R, Stuchly MA, Bailey WH, Bracken TD.	Review/Standards	Evaluation of biological effects, dosimetric models, and exposure assessment related to ELF electric- and magnetic-field guidelines.	APPLIED OCCUPATIONAL AND ENVIRONEMENTAL HYGIENE	2001	16	1118	1138
Kavet, R; Zaffanella, LE	Exposure	Contact voltage measured in residences: Implications to the association between magnetic fields and childhood leukemia	BIOELECTROMAGNETICS	2002	23	464	474
Kavet, R; Zaffanella, LE; Daigle, JP; Ebi, KL	Exposure	The possible role of contact current in cancer risk associated with residential magnetic fields	BIOELECTROMAGNETICS	2000	21	538	553
Kavet, R; Zaffanella, LE; Pearson, RL; Dallapiazza, J	Exposure	Association of residential magnetic fields with contact voltage	BIOELECTROMAGNETICS	2004	25	530	536
Kheifets L, Shimkhada R.	Review	Childhood leukemia and EMF: Review of the epidemiologic evidence.	BIOELECTROMAGNETICS	2005	26	S51	S59
Kheifets, L; Repacholi, M; Saunders, R; van Deventer, E	Review	The sensitivity of children to electromagnetic fields	PEDIATRICS	2005	116	E303	E313
Kheifets, LI	Review	Electric and magnetic field exposure and brain cancer: A review	BIOELECTROMAGNETICS	2001		S120	S131

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Kim, YS; Cho, YS	Exposure	Exposure of workers to extremely low frequency magnetic fields and electric appliances	JOURNAL OF OCCUPATIONAL HEALTH	2001	43	141	149
King, RWP	Exposure	A review of analytically determined electric fields and currents induced in the human body when exposed to 50-60-Hz electromagnetic fields	IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION	2004	52	1186	1192
Kinlen, LJ	Review	The United Kingdom Childhood Cancer Study	BRITISH JOURNAL OF CANCER	2000	82	999	999
Klaeboe L, Blaasaas KG, Haldorsen T, Tynes T.	Epi	Residential and occupational exposure to 50-Hz magnetic fields and brain tumours in Norway: a population-based study.	INTERNATIONAL JOURNAL CANCER	2005	115	137	141
Kleinerman, RA; Linet, MS; Hatch, EE; Tarone, RE; Black, PM; Selker, RG; Shapiro, WR; Fine, HA; Inskip, PD	Epi	Self-reported electrical appliance use and risk of adult brain tumors	AMERICAN JOURNAL OF EPIDEMIOLOGY	2005	161	136	146
Kliukiene J, Tynes T, Andersen A.	Epi	Residential and occupational exposures to 50-Hz magnetic fields and breast cancer in women: a population-based study.	AMERICAN JOURNAL OF EPIDEMIOLOGY	2004	159	852	861
Koana, T; Okada, MO; Takashima, Y; Ikehata, M; Miyakoshi, J	Mechanism/in vitro	Involvement of eddy currents in the mutagenicity of ELF magnetic fields	MUTATION RESEARCH-FUNDAMENTAL AND MOLECULAR MECHANISMS OF MUTAGENESIS	2001	476	55	62
Koyama, S; Nakahara, T; Hirose, H; Ding, GR; Takashima, Y; Isozumi, Y; Miyakoshi, J	Mechanism/in vitro	ELF electromagnetic fields increase hydrogen peroxide (H2O2)-induced mutations in pTN89 plasmids	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2004	560	27	32
Koyama, S; Nakahara, T; Sakurai, T; Komatsubara, Y; Isozumi, Y; Miyakoshi, J	Mechanism/in vitro	Combined exposure of ELF magnetic fields and X-rays increased mutant yields compared with X-rays alone in pTN89 plasmids	JOURNAL OF RADIATION RESEARCH	2005	46	257	264
Koyama, S; Nakahara, T; Wake, K; Taki, M; Isozumi, Y; Miyakoshi, J	Mechanism/in vitro	Effects of high frequency electromagnetic fields on micronucleus formation in CHO-K1 cells	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2003	541	81	89
Kula, B; Sobczak, A; Kuska, R	Mechanism/in vitro	Effects of static and ELF magnetic fields on free-radical processes in rat liver and kidney	ELECTRO- AND MAGNETOBIOLOGY	2000	19	99	105

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Kula, B; Sobczak, A; Kuska, R	Mechanism/in vitro	A study of the effects of static and extremely low frequency magnetic fields on lipid peroxidation products in subcellular fibroblast fractions	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2002	21	161	168
Kurokawa, Y; Nitta, H; Imai, H; Kabuto, M	Clinical studies	No influence of short-term exposure to 50-Hz magnetic fields on cognitive performance function in human	INTERNATIONAL ARCHIVES OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH	2003	76	437	442
Laden, F; Neas, LM; Tolbert, PE; Holmes, MD; Hankinson, SE; Spiegelman, D; Speizer, FE; Hunter, DJ	Epi	Electric blanket use and breast cancer in the Nurses' Health Study	AMERICAN JOURNAL OF EPIDEMIOLOGY	2000	152	41	49
Lagiou, P.; Tamimi, R.; Lagiou, A.; Mucci, L.; Trichopoulos, D.	Epi	Is epidemiology implicating extremely low frequency electric and magnetic fields in childhood leukemia?	ENVIRONMENTAL HEALTH PREVENTIVE MEDECINE	2002	7	33	39
Lahijani, MS; Moham, HR	Animal Studies	Teratogenic effects on morphology and skeletal structure of chick embryos after exposure to 50 Hz sinusoidal electromagnetic fields	IRANIAN JOURNAL OF SCIENCE AND TECHNOLOGY	2000	24	173	182
Laitl-Kobierska, A; Cieslar, G; Sieron, A; Grzybek, H	Animal Studies	Influence of alternating extremely low frequency ELF magnetic field on structure and function of pancreas in rats	BIOELECTROMAGNETICS	2002	23	49	58
Lalic, H; Lekic, A; Radosevic-Stasic, B	Mechanism/in vitro	Comparison of chromosome aberrations in peripheral blood lymphocytes from people occupationally exposed to ionizing and radiofrequency radiation	ACTA MEDICA OKAYAMA	2001	55	117	127
Lambrozo, J	Exposure	Electric and magnetic fields with a frequency of 50-60 Hz: Assessment of 20 years of research	INDOOR AND BUILT ENVIRONMENT	2001	10	299	305
Lange, S; Richard, D; Viergutz, T; Kriehuber, R; Weiss, DG; Simko, M	Mechanism/in vitro	Alterations in the cell cycle and in the protein level of cyclin D1, p21(CIP1), and p16(INK4a) after exposure to 50 Hz MF in human cells	RADIATION AND ENVIRONMENTAL BIOPHYSICS	2002	41	131	137
Lange, S; Viergutz, T; Simko, M	Mechanism/in vitro	Modifications in cell cycle kinetics and in expression of G(1) phase-regulating proteins in human amniotic cells after exposure to electromagnetic fields and ionizing radiation	CELL PROLIFERATION	2004	37	337	349
Langholz, B	Review/Commentary	Factors that explain the power line configuration wiring code-childhood leukemia association: What would they look like?	BIOELECTROMAGNETICS	2001		S19	S31
Langholz, B; Ebi, KL; Thomas, DC; Peters, JM; London, SJ	Confounding exposures/Epi	Traffic density and the risk of childhood leukemia in a Los Angeles case-control study	ANNALS OF EPIDEMIOLOGY	2002	12	482	487
Lee, GM; Neutra, RR; Hristova, L; Yost, M; Hiatt, RA	Epi	A nested case-control study of residential and personal magnetic field measures and miscarriages	EPIDEMIOLOGY	2002	13	21	31

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Lee, JH; Lee, HC; Kim, DH; Kim, JY; Kim, DW; Nam, YT; Kim, KJ	Exposure	How much are anesthesiologists exposed to electromagnetic fields in operating rooms?	YONSEI MEDICAL JOURNAL	2003	44	133	137
Lee, JH; McLeod, KJ	Mechanism/in vitro	Morphologic responses of osteoblast-like cells in monolayer culture to ELF electromagnetic fields	BIOELECTROMAGNETICS	2000	21	129	136
Lee, JS; Ahn, SS; Jung, KC; Kim, YW; Lee, SK	Animal Studies	Effects of 60 Hz electromagnetic field exposure on testicular germ cell apoptosis in mice	ASIAN JOURNAL OF ANDROLOGY	2004	6	29	34
Lee, SH; Lee, HS; Lee, MK; Lee, JH; Kim, JD; Park, YS; Lee, SY; Lee, HY	Mechanism/in vitro	Enhancement of tissue type plasminogen activator (tPA) production from recombinant CHO cells by low electromagnetic fields	JOURNAL OF MICROBIOLOGY AND BIOTECHNOLOGY	2002	12	457	462
Li, DK; Odouli, R; Wi, S; Janevic, T; Golditch, I; Bracken, TD; Senior, R; Rankin, R; Iriye, R	Epi	A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage	EPIDEMIOLOGY	2002	13	9	20
Liboff, AR; Jenrow, KA	Mechanism/in vitro	Cell sensitivity to magnetic fields	ELECTRO- AND MAGNETOBIOLOGY	2000	19	223	236
Lightfoot, TJ; Roman, E		Causes of childhood leukaemia and lymphoma	TOXICOLOGY AND APPLIED PHARMACOLOGY	2004	199	104	117
Lindenblatt, G; Silny, J	Mechanism/in vitro	A model of the electrical volume conductor in the region of the eye in the ELF range	PHYSICS IN MEDICINE AND BIOLOGY	2001	46	3051	3059
Lindgren, M; Gustavsson, M; Hamnerius, Y; Galt, S	Exposure	ELF magnetic fields in a city environment	BIOELECTROMAGNETICS	2001	22	87	90
Lindstrom, E; Still, M; Mattsson, MO; Mild, KH; Luben, RA	Mechanism/in vitro	ELF magnetic fields initiate protein tyrosine phosphorylation of the T cell receptor complex	BIOELECTROCHEMISTRY	2001	53	73	78
Linet, MS; Wacholder, S; Zahm, SH	Review/Commentary	Interpreting epidemiologic research: Lessons from studies of childhood cancer	PEDIATRICS	2003	112	218	232
Loberg, LI; Luther, MJ; Gauger, JR; McCormick, DL	Mechanism/in vitro	60 Hz magnetic fields do not enhance cell killing by genotoxic chemicals in ataxia telangiectasia and normal lymphoblastoid cells	RADIATION RESEARCH	2000	153	685	689
London, SJ; Pogoda, JM; Hwang, KL; Langholz, B; Monroe, KR; Kolonel, LN; Kaune, WT; Peters, JM; Henderson, BE	Epi	Residential magnetic field exposure and breast cancer risk: A nested case-control study from a multiethnic cohort in Los Angeles County, California	AMERICAN JOURNAL OF EPIDEMIOLOGY	2003	158	969	980
Loomis, D; Kromhout, H	Exposure	Exposure variability: Concepts and applications in occupational epidemiology	AMERICAN JOURNAL OF INDUSTRIAL MEDICINE	2004	45	113	122
Loscher, W	Review	Do cocarcinogenic effects of ELF electromagnetic fields require repeated long-term interaction with carcinogens? Characteristics of positive studies using the DMBA breast cancer model in rats	BIOELECTROMAGNETICS	2001	22	603	614

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Ma, XM; Buffler, PA; Layefsky, M; Does, MB; Reynolds, P	Review/Epi	Control selection strategies in case-control studies of childhood diseases	AMERICAN JOURNAL OF EPIDEMIOLOGY	2004	159	915	921
Macri, MA; Di Luzio, S; Di Luzio, S	Review/General	Biological effects of electromagnetic fields	INTERNATIONAL JOURNAL OF IMMUNOPATHOLOGY AND PHARMACOLOGY	2002	15	95	105
Madec, F; Billaudel, B; de Sauvage, RC; Sartor, P; Veyret, B	Mechanism/in vitro	Effects of ELF and static magnetic fields on calcium oscillations in islets of Langerhans	BIOELECTROCHEMISTRY	2003	60	73	80
Maes, A; Collier, M; Vandoninck, S; Scarpa, P; Verschaeve, L	Mechanism/in vitro	Cytogenetic effects of 50 Hz magnetic fields of different magnetic flux densities	BIOELECTROMAGNETICS	2000	21	589	596
Mandeville, R; Franco, E; Sidrac-Ghali, S; Paris-Nadon, L; Rocheleau, N; Mercier, G; Desy, M; Devaux, C; Gaboury, L	Animal Studies	Evaluation of the potential promoting effect of 60 Hz magnetic fields on N-ethyl-N-nitrosourea induced neurogenic tumors in female F344 fats	BIOELECTROMAGNETICS	2000	21	84	93
Marinelli, F; La Sala, D; Cicciotti, G; Cattini, L; Trimarchi, C; Putti, S; Zamparelli, A; Giuliani, L; Tomassetti, G; Cinti, C	Mechanism/in vitro	Exposure to 900 MHz electromagnetic field induces an unbalance between pro-apoptotic and pro-survival signals in T-lymphoblastoid leukemia CCRF-CEM cells	JOURNAL OF CELLULAR PHYSIOLOGY	2004	198	324	332
Marino, AA; Nilsen, E; Frilot, C	Animal Studies	Consistent magnetic-field induced dynamical changes in rabbit brain activity detected by recurrence quantification analysis	BRAIN RESEARCH	2002	951	301	310
Marino, AA; Wolcott, RM; Chervenak, R; Jourd'Heuil, F; Nilsen, E; Frilot, C	Mechanism/in vitro	Nonlinear response of the immune system to power-frequency magnetic fields	AMERICAN JOURNAL OF PHYSIOLOGY-REGULATORY INTEGRATIVE AND COMPARATIVE PHYSIOLOGY	2000	279	R761	R768
Maruvada, PS; Harvey, SM; Jutras, P; Goulet, D; Mandeville, R	Exposure	A magnetic field exposure facility for evaluation of animal carcinogenicity	BIOELECTROMAGNETICS	2000	21	432	438
McCann J, Kavet R, Rafferty CN.	Animal Studies	Assessing the potential carcinogenic activity of magnetic fields using animal models.	ENVIRONMENTAL HEALTH PERSPECITVES	2000	108	79	100
McCormick DL, Boorman GA, Findlay JC, Hailey JR, Johnson TR, Gauger JR, Pletcher	Animal Studies	Chronic toxicity/oncogenicity evaluation of 60 Hz (power frequency) magnetic fields in B6C3F1 mice.	TOXICOLOGIC PATHOLOGY	1999	27	279	285
McCreary, CR; Thomas, AW; Prato, FS	Mechanism/in vitro	Factors confounding cytosolic calcium measurements in Jurkat E6.1 cells during exposure to ELF magnetic fields	BIOELECTROMAGNETICS	2002	23	315	328
McCurdy AL, Wijnberg L, Loomis D, Savitz D, Nylander-French LA.	Exposure	Exposure to extremely low frequency magnetic fields among working women and homemakers	ANNALS OF OCCUPATIONAL HYGIENE	2001	45	643	650
McDevitt, JJ; Breysse, PN; Bowman, JD; Sassone, DM	Exposure	Comparison of extremely low frequency (ELF) magnetic field personal exposure monitors	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENT	2002	12	1	8

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			ENVIRONMENTAL EPIDEMIOLOGY				
McDonald, LJ; Loberg, LI; McCormick, DL; Gauger, JR; Savage, RE; Zhu, H; Lotz, WG; Mandeville, R; Owen, RD; Cress, LW; Desta, AB	Mechanism/in vitro	Ornithine decarboxylase activity in tissues from rats exposed to 60 Hz magnetic fields, including harmonic and transient field characteristics	TOXICOLOGY MECHANISMS AND METHODS	2003	13	31	38
McMahan, S; Lutz, R; Meyer, J	Review/Standards	Should the threshold limit value for power frequency (60 Hz) magnetic fields be changed? Perceptions among scientists and other risk experts	AIHA JOURNAL	2002	63	636	640
McNamee, JP; Bellier, PV; McLean, JRN; Marro, L; Gajda, GB; Thansandote, A	Mechanism/in vitro	DNA damage and apoptosis in the immature mouse cerebellum after acute exposure to a 1 mT, 60 Hz magnetic field	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2002	513	121	133
Methner, MM; Bowman, JD	Exposure	Hazard surveillance for industrial magnetic fields: I. Walkthrough survey of ambient fields and sources	ANNALS OF OCCUPATIONAL HYGIENE	2000	44	603	614
Mezei, G; Kheifets, L	Review/Commentary	Is there any evidence for differential misclassification or for bias away from the null in the Swedish childhood cancer study?	EPIDEMIOLOGY	2001	12	750	750
Mezei, G; Kheifets, LI; Nelson, LM; Mills, KM; Iriye, R; Kelsey, JL	Exposure	Household appliance use and residential exposure to 60-Hz magnetic fields	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL EPIDEMIOLOGY	2001	11	41	49
Milham, S; Ossiander, EM	Epi	Historical evidence that residential electrification caused the emergence of the childhood leukemia peak	MEDICAL HYPOTHESES	2001	56	290	295
Miller, RD; Anderson, L; Beers, J; Bergeron, J; Blanchard, J; Erdreich, L; Feero, WE; Foster, KR; Male, J; Reilly, JP; Reiter, R; Polk, C; Sutton, C; Walleczek, J; Adair, E; Adair, R; Bassen, H; Chou, CK; Hansson-Mild, K; Moulder, J; Osepchuk, J; Repacholi, M; Swicord, M	Review/General	Possible health hazards from exposure to power-frequency electric and magnetic fields - A COMAR technical information statement	IEEE ENGINEERING IN MEDICINE AND BIOLOGY MAGAZINE	2000	19	131	137
Mills, KM; Kheifets, LI; Nelson, LM; Bloch, DA; Takemoto-Hambleton, R; Kelsey, JL	Review/Commentary	Reliability of proxy-reported and self-reported household appliance use	EPIDEMIOLOGY	2000	11	581	588

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Minder, CE; Pfluger, DH	Epi	Leukemia, brain tumors, and exposure to extremely low frequency electromagnetic fields in Swiss railway employees	AMERICAN JOURNAL OF EPIDEMIOLOGY	2001	153	825	835
Miyakoshi, J; Mori, Y; Yaguchi, H; Ding, GR; Fujimori, A	Mechanism/in vitro	Suppression of heat-induced hsp-70 by simultaneous exposure to 50 mT magnetic field	LIFE SCIENCES	2000	66	1187	1196
Miyakoshi, J; Yoshida, M; Shibuya, K; Hiraoka, M	Mechanism/in vitro	Exposure to strong magnetic fields at power frequency potentiates X-ray-induced DNA strand breaks	JOURNAL OF RADIATION RESEARCH	2000	41	293	302
Miyakoshi, J; Yoshida, M; Yaguchi, H; Ding, GR	Mechanism/in vitro	Exposure to extremely low frequency magnetic fields suppresses X-ray-induced transformation in mouse C3H10T1/2 cells	BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS	2000	271	323	327
Mizoue, T; Onoe, Y; Moritake, H; Okamura, J; Sokejima, S; Nitta, H	Epi	Residential proximity to high-voltage power lines and risk of childhood hematological malignancies	JOURNAL OF EPIDEMIOLOGY	2004	14	118	123
Morehouse, CA; Owen, RD	Mechanism/in vitro	Exposure of Daudi cells to low-frequency magnetic fields does not elevate MYC steady-state mRNA levels	RADIATION RESEARCH	2000	153	663	669
Moreno, JAR; Murillo, OR; Chiquero, JAM; Soler, ML; Pineyro, MG; Nacle, FA; Llivina, JAC; Morenilla, MTP	Mechanism/in vitro	Somatic alterations in chick embryo exposed to low frequency magnetic fields	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2003	22	55	61
Moretti, M; Villarini, M; Simonucci, S; Fatigoni, C; Scassellati-Sforzolini, G; Monarca, S; Pasquini, R; Angelucci, M; Strappini, M	Mechanism/in vitro	Effects of co-exposure to extremely low frequency (ELF) magnetic fields and benzene or benzene metabolites determined in vitro by the alkaline comet assay	TOXICOLOGY LETTERS	2005	157	119	128
Moulder, JE	Review	The Electric and Magnetic Fields Research and Public Information Dissemination (EMF-RAPID) Program	RADIATION RESEARCH	2000	153	613	616
Murabayashi, S; Yoshikawa, A; Murabayashi, S	Mechanism/in vitro	Functional modulation of activated lymphocytes by time-varying magnetic fields	THERAPEUTIC APHERESIS AND DIALYSIS	2004	8	206	211
Nakasono, S; Ikehata, M; Koana, T; Saiki, H	Mechanism/in vitro	A 50 Hz, 14 mT magnetic field is not mutagenic or co-mutagenic in bacterial mutation assays	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2000	471	127	134
Nakasono, S; Saiki, H	Mechanism/in vitro	Effect of ELF magnetic fields on protein synthesis in Escherichia coli K12	RADIATION RESEARCH	2000	154	208	216
Navas-Acien A, Pollan M, Gustavsson P, Floderus B, Plato N, Dosemeci M.	Epi	Interactive effect of chemical substances and occupational electromagnetic field exposure on the risk of gliomas and meningiomas in Swedish men.	CANCER EPIDEMIOL BIOMARKERS PREV.	2002	11	1678	1683

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Negishi, T; Imai, S; Itabashi, M; Nishimura, I; Sasano, T	Animal Studies	Studies of 50 Hz circularly polarized magnetic fields of up to 350 mu Ton reproduction and embryo-fetal development in rats: Exposure during organogenesis or during preimplantation	BIOELECTROMAGNETICS	2002	23	369	389
Neutra, RR	Review/Commentary	Panel exploring pro and con arguments as to whether EMFs cause childhood brain cancer	BIOELECTROMAGNETICS	2001		S144	S149
Neutra, RR; Del Pizzo, V	Exposure	A richer conceptualization of "exposure" for epidemiological studies of the "EMF mixture"	BIOELECTROMAGNETICS	2001		S48	S57
Nguyen, DH; Richard, L; Burchard, JF	Exposure	Exposure chamber for determining the biological effects of electric and magnetic fields on dairy cows	BIOELECTROMAGNETICS	2005	26	138	144
Nie, K; Henderson, A	Mechanism/in vitro	MAP kinase activation in cells exposed to a 60 Hz electromagnetic field	JOURNAL OF CELLULAR BIOCHEMISTRY	2003	90	1197	1206
Nindl, G; Hughes, EF; Johnson, MT; Spandau, DF; Vesper, DN; Balcavage, WX	Mechanism/in vitro	Effect of ultraviolet B radiation and 100 Hz electromagnetic fields on proliferation and DNA synthesis of Jurkat cells	BIOELECTROMAGNETICS	2002	23	455	463
Oh, SJ; Lee, MK; Lee, SH; Lee, JH; Kim, DJ; Park, YS; Lee, HY	Mechanism/in vitro	Effect of electromagnetic fields on growth of human cell lines	JOURNAL OF MICROBIOLOGY AND BIOTECHNOLOGY	2001	11	749	755
Okazaki, R; Ootsuyama, A; Uchida, S; Norimura, T	Animal Studies	Effects of a 4.7 T static magnetic field on fetal development in ICR mice	JOURNAL OF RADIATION RESEARCH	2001	42	273	283
O'Leary, ES; Schoenfeld, ER; Henderson, K; Grimson, R; Kabat, GC; Kaune, WT; Gammon, MD; Leske, C	Epi	Wire coding in the EMF and Breast Cancer on Long Island Study: Relationship to magnetic fields	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL EPIDEMIOLOGY	2003	13	283	293
Olivares-Banuelos, T; Navarro, L; Gonzalez, A; Drucker-Colin, R	Mechanism/in vitro	Differentiation of chromaffin cells elicited by ELF MF modifies gene expression pattern	CELL BIOLOGY INTERNATIONAL	2004	28	273	279
Olsson, G; Belyaev, IY; Helleday, T; Harms-Ringdahl, M	Mechanism/in vitro	ELF magnetic field affects proliferation of SPD8/V79 Chinese hamster cells but does not interact with intrachromosomal recombination	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2001	493	55	66
Oppenheimer, M; Preston-Martin, S	Epi	Adult onset acute myelogenous leukemia and electromagnetic fields in Los Angeles County: Bed-heating and occupational exposures	BIOELECTROMAGNETICS	2002	23	411	415
Panagopoulos, DJ; Karabarbounis, A; Margaritis, LH	Mechanism/in vitro	Mechanism for action of electromagnetic fields on cells	BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS	2002	298	95	102

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Pang, LJ; Traitcheva, N; Gothe, G; Gomez, JAC; Berg, H	Mechanism/in vitro	ELF-electromagnetic fields inhibit the proliferation of human cancer cells and induce apoptosis	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2002	21	243	248
Paniagua, JM; Jimenez, A; Rufo, M; Antolin, A	Exposure	Exposure assessment of ELF magnetic fields in urban environments in Extremadura (Spain)	BIOELECTROMAGNETICS	2004	25	58	62
Park RM, Schulte PA, Bowman JD, Walker JT, Bondy SC, Yost MG, Touchstone JA, Dosemeci M.	Epi	Potential occupational risks for neurodegenerative diseases.	AMERICAN JOURNAL OF INDUSTRIAL MEDECINE	2005	48	63	77
Pasquini, R; Villarini, M; Sforzolini, GS; Fatigoni, C; Moretti, M	Mechanism/in vitro	Micronucleus induction in cells co-exposed in vitro to 50 Hz magnetic field and benzene, 1,4-benzenediol (hydroquinone) or 1,2,4-benzenetriol	TOXICOLOGY IN VITRO	2003	17	581	586
Pearson, RL; Wachtel, H; Ebi, KL	Confounding exposures/Epi	Distance-weighted traffic density in proximity to a home is a risk factor for leukemia and other childhood cancers	JOURNAL OF THE AIR & WASTE MANAGEMENT ASSOCIATION	2000	50	175	180
Peck, SC; Kavet, R	Review/Commentary	Research strategies for magnetic fields and cancer	RISK ANALYSIS	2005	25	179	188
Pesic, V; Janac, B; Jelenkovic, A; Vorobyov, V; Prolic, Z	Animal Studies	Non-linearity in combined effects of ELF magnetic field and amphetamine on motor activity in rats	BEHAVIOURAL BRAIN RESEARCH	2004	150	223	227
Piacentini, MP; Fraternale, D; Piatti, E; Ricci, D; Vetrano, F; Dacha, M; Accorsi, A	Plant study	Senescence delay and change of antioxidant enzyme levels in Cucumis sativus L. etiolated seedlings by ELF magnetic fields	PLANT SCIENCE	2001	161	45	53
Piacentini, MP; Piatti, E; Fraternale, D; Ricci, D; Albertini, MC; Accorsi, A	Mechanism/in vitro	Phospholipase C-dependent phosphoinositide breakdown induced by ELF-EMF in Peganum harmala calli	BIOCHIMIE	2004	86	343	349
Pilger, A; Ivancsits, S; Diem, E; Steffens, M; Kolb, HA; Rudiger, HW	Mechanism/in vitro	No effects of intermittent 50 Hz EMF on cytoplasmic free calcium and on the mitochondrial membrane potential in human diploid fibroblasts	RADIATION AND ENVIRONMENTAL BIOPHYSICS	2004	43	203	207
Portaccio, M; De Luca, P; Durante, D; Rossi, S; Bencivenga, U; Canciglia, P; Lepore, M; Mattei, A; De Malo, A; Mita, DG	Mechanism/in vitro	In vitro studies of the influence of ELF electromagnetic fields on the activity of soluble and insoluble peroxidase	BIOELECTROMAGNETICS	2003	24	449	456
Prato, FS; Thomas, AW; Cook, CM	Clinical studies	Human standing balance is acted by exposure to pulsed ELF magnetic fields: light intensity-dependent effects	NEUROREPORT	2001	12	1501	1505
Preece, AW; Hand, JW; Clarke, RN; Stewart, A	Review/General	Power frequency electromagnetic fields and health. Where's the evidence?	PHYSICS IN MEDICINE AND BIOLOGY	2000	45	R139	R154
Raaschou-Nielsen, O; Hertel, O; Thomsen, BL; Olsen, JH	Confounding exposures/Epi	Air pollution from traffic at the residence of children with cancer	AMERICAN JOURNAL OF EPIDEMIOLOGY	2001	153	433	443
Rajkovic, V; Matavulj, M; Gledic, D; Lazetic, B	Animal Studies	Evaluation of rat thyroid gland morphophysiological status after three months exposure to 50 Hz electromagnetic field	TISSUE & CELL	2003	35	223	231

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Rajkovic, V; Matavulj, M; Lazetic, B	Animal Studies	Stereological analysis of thyroid mast cells in rats after exposure to extremely low frequency electromagnetic field and the following "off" field period	ACTA BIOLOGICA HUNGARICA	2005	56	43	51
Rankin, RF; Bracken, TD; Senior, RS; Kavet, R; Montgomery, JH	Exposure	Results of a multisite study of US residential magnetic fields	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL EPIDEMIOLOGY	2002	12	9	20
Rao, RR; Halper, J; Kisaalita, WS	Mechanism/in vitro	Effects of 60 Hz electromagnetic field exposure on APP695 transcription levels in differentiating human neuroblastoma cells	BIOELECTROCHEMISTRY	2002	57	9	15
Rao, RR; Kisaalita, WS	Exposure	A single magnetic field exposure system for sequential investigation of real time and downstream cellular responses	BIOELECTROMAGNETICS	2004	25	27	32
Repacholi, MH	Review	Who's health risk assessment of ELF fields	RADIATION PROTECTION DOSIMETRY	2003	106	297	299
Reynolds, P; Elkin, E; Scalf, R; Von Behren, J; Neutra, RR	Confounding exposures/Epi	A case-control pilot study of traffic exposures and early childhood leukemia using a geographic information system	BIOELECTROMAGNETICS	2001		S58	S68
Richard, D; Lange, S; Viergutz, T; Kriehuber, R; Weiss, DG; Simko, M	Mechanism/in vitro	Influence of 50 Hz electromagnetic fields in combination with a tumour promoting phorbol ester on protein kinase C and cell cycle in human cells	MOLECULAR AND CELLULAR BIOCHEMISTRY	2002	232	133	141
Riminesi, C; Andreuccetti, D; Fossi, R; Pezzati, M	Exposure	ELF magnetic field exposure in a neonatal intensive care unit	BIOELECTROMAGNETICS	2004	25	481	491
Robison, JG; Pendleton, AR; Monson, KO; Murray, BK; O'Neill, KL	Mechanism/in vitro	Decreased DNA repair rates and protection from heat induced apoptosis mediated by electromagnetic field exposure	BIOELECTROMAGNETICS	2002	23	106	112
Roda-Murillo, O; Roda-Moreno, JA; Pascual-Morenilla, MT; Guirao-Pineyro, M; Arrebola-Nacle, F; Morente-Chiquero, JA; Casanova-Llivina, JA; Lopez-Soler, M	Animal Studies	Effects of low-frequency magnetic fields on different parameters of embryo of gallus domesticus	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2005	24	55	62
Rodriguez, M; Petitclerc, D; Burchard, JF; Nguyen, DH; Block, E; Downey, BR	Animal Studies	Responses of the estrous cycle in dairy cows exposed to electric and magnetic fields (60 Hz) during 8-h photoperiods	ANIMAL REPRODUCTION SCIENCE	2003	77	11	20
Rollwitz, J; Lupke, M; Simko, M	Mechanism/in vitro	Fifty-hertz magnetic fields induce free radical formation in mouse bone marrow-derived promonocytes and macrophages	BIOCHIMICA ET BIOPHYSICA ACTA-GENERAL SUBJECTS	2004	1674	231	238
Romano-Spica, V; Mucci, N; Ursini, CL; Ianni, A; Bhat, NK	Mechanism/in vitro	Ets1 oncogene induction by ELF-modulated 50 MHz radiofrequency electromagnetic field	BIOELECTROMAGNETICS	2000	21	8	18

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Ronchetto, F; Barone, D; Cintorino, M; Berardelli, M; Lissolo, S; Orlassino, R; Ossola, P; Tofani, S	Clinical studies	Extremely low frequency-modulated static magnetic fields to treat cancer: A pilot study on patients with advanced neoplasm to assess safety and acute toxicity	BIOELECTROMAGNETICS	2004	25	563	571
Sakanishi, A; Takatsuki, H; Yoshikoshi, A; Fujiwara, Y	Mechanism/in vitro	Effects of extremely low frequency magnetic field on neurite outgrowth of PC12 and PC12D cells and evaluation by image analysis	JAPANESE JOURNAL OF APPLIED PHYSICS PART 1-REGULAR PAPERS SHORT NOTES & REVIEW PAPERS	2004	43	2761	2766
Sakurazawa, H; Iwasaki, A; Higashi, T; Nakayama, T; Kusaka, Y	Exposure	Assessment of exposure to magnetic fields in occupational settings	JOURNAL OF OCCUPATIONAL HEALTH	2003	45	104	110
Samuelsson, U; Gustafsson, B; Ludvigsson, J	Epi	Increased prevalence of malignant diseases in the close neighborhood of children with cancer	JOURNAL OF ENVIRONMENTAL HEALTH	2002	64	18	22
Santangelo, L; Di Grazia, M; Liotti, F; De Maria, E; Calabro, R; Sannolo, N	Epi	Magnetic field exposure and arrythmic risk: evaluation in railway drivers	INTERNATIONAL ARCHIVES OF OCCUPATIONAL AND ENVIRONMENTAL HEALTH	2005	78	337	341
Santini, MT; Ferrante, A; Rainaldi, G; Indovina, P; Indovina, PL	Review/Mechanism	Extremely low frequency (ELF) magnetic fields and apoptosis: a review	INTERNATIONAL JOURNAL OF RADIATION BIOLOGY	2005	81	1	11
Santini, MT; Ferrante, A; Romano, R; Rainaldi, G; Motta, A; Donelli, G; Vecchia, P; Indovina, PL	Mechanism/in vitro	A 700 MHz H-1-NMR study reveals apoptosis-like behavior in human K562 erythroleukemic cells exposed to a 50 Hz sinusoidal magnetic field	INTERNATIONAL JOURNAL OF RADIATION BIOLOGY	2005	81	97	113
Santini, MT; Rainaldi, G; Ferrante, A; Indovina, PL; Vecchia, P; Donelli, G	Mechanism/in vitro	Effects of a 50 Hz sinusoidal magnetic field on cell adhesion molecule expression in two human osteosarcoma cell lines (MG-63 and Saos-2)	BIOELECTROMAGNETICS	2003	24	327	338
Savitz, DA; Poole, C	Review	Do studies of wire code and childhood leukemia point towards or away from magnetic fields as the causal agent?	BIOELECTROMAGNETICS	2001		S69	S85
Saxena, A; Jacobson, J; Yamanashi, W; Scherlag, B; Lamberth, J; Saxena, B	Exposure	A hypothetical mathematical construct explaining the mechanism of biological amplification in an experimental model utilizing picoTesla (PT) electromagnetic fields	MEDICAL HYPOTHESES	2003	60	821	839
Scarfi, MR; Sannino, A; Perrotta, A; Sarti, M; Mesirca, P; Bersani, F	Mechanism/in vitro	Evaluation of genotoxic effects in human fibroblasts after intermittent exposure to 50 Hz electromagnetic fields: A confirmatory study	RADIATION RESEARCH	2005	164	270	276
Schlehofer B, Hettinger I et al	Epi	Occupational risk factors for low grade and high grade glioma: Results from an international case control study of adult brain tumours	INTERNATIONAL JOURNAL OF CANCER	2004	113	116	125

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Schoenfeld, ER; O'Leary, ES; Henderson, K; Grimson, R; Kabat, GC; Ahnn, S; Kaune, WT; Gammon, MD; Leske, MC	Epi	Electromagnetic fields and breast cancer on Long Island: A case-control study	AMERICAN JOURNAL OF EPIDEMIOLOGY	2003	158	47	58
Schuz, J; Grigat, JP; Brinkmann, K; Michaelis, J	Epi	Childhood acute leukaemia and residential 16.7 Hz magnetic fields in Germany	BRITISH JOURNAL OF CANCER	2001	84	697	699
Schuz, J; Grigat, JP; Brinkmann, K; Michaelis, J	Epi	Residential magnetic fields as a risk factor for childhood acute leukaemia: Results from a German population-based case-control study	INTERNATIONAL JOURNAL OF CANCER	2001	91	728	735
Schuz, J; Grigat, JP; Stormer, B; Rippin, G; Brinkmann, K; Michaelis, J	Exposure	Extremely low frequency magnetic fields in residences in Germany. Distribution of measurements, comparison of two methods for assessing exposure, and predictors for the occurrence of magnetic fields above background level	RADIATION AND ENVIRONMENTAL BIOPHYSICS	2000	39	233	240
Selmaoui, B; Aymard, N; Lambrozo, J; Touitou, Y	Clinical studies	Evaluation of the nocturnal levels of urinary biogenic amines in men exposed overnight to 50-Hz magnetic field	LIFE SCIENCES	2003	73	3073	3082
Sert, C; Akdag, MZ; Bashan, M; Buyukbayram, H; Dasdag, S	Animal Studies	Elf magnetic field effects on fatty-acid composition of phospholipid fraction and reproduction of rats' testes	ELECTROMAGNETIC BIOLOGY AND MEDICINE	2002	21	19	29
Shahidain, R; Mullins, RD; Sisken, JE	Mechanism/in vitro	Calcium spiking activity and baseline calcium levels in ROS 17/2.8 cells exposed to extremely low frequency electromagnetic fields (ELF EMF)	INTERNATIONAL JOURNAL OF RADIATION BIOLOGY	2001	77	241	248
Shaw, GM	Review/Epi	Adverse human reproductive outcomes and electromagnetic fields: A brief summary of the epidemiologic literature	BIOELECTROMAGNETICS	2001		S5	S18
Shcheglov, VS; Alipov, ED; Belyaev, IY	Mechanism/in vitro	Cell-to-cell communication in response of E-coli cells at different phases of growth to low-intensity microwaves	BIOCHIMICA ET BIOPHYSICA ACTA-GENERAL SUBJECTS	2002	1572	101	106
Shi, YJ; Bao, XQ; Huo, XL; Shen, Z; Song, T	Animal Studies	50-Hz magnetic field (0.1-mT) alters c-fos mRNA expression of early post implantation mouse embryos and serum estradiol levels of gravid mice	BIRTH DEFECTS RESEARCH PART B-DEVELOPMENTAL AND REPRODUCTIVE TOXICOLOGY	2005	74	196	200
Simko, M; Mattsson, MO	Mechanism/ in vitro	Extremely low frequency electromagnetic fields as effectors of cellular responses in vitro: Possible immune cell activation	JOURNAL OF CELLULAR BIOCHEMISTRY	2004	93	83	92
Simko, M; Richard, D; Kriehuber, R; Weiss, DG	Mechanism/in vitro	Micronucleus induction in Syrian hamster embryo cells following exposure to 50 Hz magnetic fields, benzo(a)pyrene, and TPA in vitro	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2001	495	43	50

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Skinner, J; Mee, TJ; Blackwell, RP; Maslanyj, MP; Simpson, J; Allen, SG; Day, NE	Epi	Exposure to power frequency electric fields and the risk of childhood cancer in the UK	BRITISH JOURNAL OF CANCER	2002	87	1257	1266
Soderberg, KC; Naumburg, E; Anger, G; Cnattingius, S; Ekbom, A; Feychting, M	Epi	Childhood leukemia and magnetic fields in infant incubators	EPIDEMIOLOGY	2002	13	45	49
Sommelet, D; Lacour, B; Clavel, J	Review	Epidemiology of cancer in childhood	BULLETIN DE L ACADEMIE NATIONALE DE MEDECINE	2003	187	711	737
Sommer, AM; Lerchl, A	Animal Studies	The risk of lymphoma in AKR/J mice does not rise with chronic exposure to 50 Hz magnetic fields (1 mu T and 100 mu T)	RADIATION RESEARCH	2004	162	194	200
Sonnier, H; Marino, AA	Mechanism/ in vitro	Sensory transduction as a proposed model for biological detection of electromagnetic fields	ELECTRO- AND MAGNETOBIOL OGY	2001	20	153	175
Stange, BC; Rowland, RE; Rapley, BI; Podd, JV	Plant study	ELF magnetic fields increase amino acid uptake into Vicia faba L. roots and alter ion movement across the plasma membrane	BIOELECTROMA GNETICS	2002	23	347	354
Stepansky, R; Jahn, O; Windischbauer, G; Zeitlhofer, J	Review	Biological effects of electromagnetic fields	ACTA MEDICA AUSTRIACA	2000	27	69	77
Stronati, L; Testa, A; Villani, R; Marino, C; Lovisolo, GA; Conti, D; Russo, F; Fresegna, AM; Cordelli, E	Mechanism/ in vitro	Absence of genotoxicity in human blood cells exposed to 50 Hz magnetic fields as assessed by comet assay, chromosome aberration, micronucleus, and sister chromatid exchange analyses	BIOELECTROMA GNETICS	2004	25	41	48
Stuchly, MA; Dawson, TW	Exposure	Interaction of low-frequency electric and magnetic fields with the human body	PROCEEDINGS OF THE IEEE	2000	88	643	664
Sun, WJ; Chiang, H; Fu, YT; Yu, YN; Xie, HY; Lu, DQ	Mechanism/ in vitro	Exposure to 50 Hz electromagnetic fields induces the phosphorylation and activity of stress-activated protein kinase in cultured cells	ELECTRO- AND MAGNETOBIOL OGY	2001	20	415	423
Sun, WJ; Yu, YN; Chiang, H; Fu, YD; Lu, DQ	Mechanism/ in vitro	Effects of 50 Hz magnetic field exposure on protein tyrosine phosphorylation in cultured cells	ELECTRO- AND MAGNETOBIOL OGY	2001	20	207	214
Sun, WJ; Yu, YN; Chiang, H; Fu, YT; Xie, HY; Lu, DQ	Mechanism/ in vitro	Exposure to 50Hz magnetic fields does not induce the phosphorylation of SEK1/MKK4 in cultured cells	ELECTROMAGN ETIC BIOLOGY AND MEDICINE	2002	21	97	102
Takashima, Y; Ikehata, M; Miyakoshi, J; Koana, T	Mechanism/ in vitro	Inhibition of UV-induced G1 arrest by exposure to 50 Hz magnetic fields in repair-proficient and -deficient yeast strains	INTERNATIONA L JOURNAL OF RADIATION BIOLOGY	2003	79	919	924
Teichmann, EM; Hengstler, JG; Schreiber, WG; Akbari, W; Georgi, H; Hehn, M; Schiffer, I; Oesch, F; Spiess, HW; Thelen, M	Mechanism/in vitro	Mutagenic or co-mutagenic effect of magnetic fields in the Ames test	ROFO-FORTSCHRITTE AUF DEM GEBIET DER RONTGENSTRA HLEN UND DER BILDGEBENDEN VERFAHREN	2000	172	934	939

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Testa A, Cordelli E, Stronati L, Marino C, Lovisolo GA, Fresegna AM, Conti D, Villani P.	Mechanism/in vitro	valuation of genotoxic effect of low level 50 Hz magnetic fields on human blood cells using different cytogenetic assays.	BIOELECTROMAGNETICS	2004	25	613	619
Tofani, S	Exposure	Electromagnetic field exposure system for the study of possible anti-cancer activity	IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY	2002	44	148	151
Tofani, S; Barone, D; Berardelli, M; Berno, E; Cintorino, M; Foglia, L; Ossola, P; Ronchetto, F; Toso, E; Eandi, A	Animal Studies	Static and ELF magnetic fields enhance the in vivo anti-tumor efficacy of cis-platin against lewis lung carcinoma, but not of cyclophosphamide against B16 melanotic melanoma	PHARMACOLOGICAL RESEARCH	2003	48	83	90
Tofani, S; Barone, D; Cintorino, M; de Santi, MM; Ferrara, A; Orlassino, R; Ossola, P; Peroglio, F; Rolfo, K; Ronchetto, F	Mechanism/in vitro and in vivo	Static and ELF magnetic fields induce tumor growth inhibition and apoptosis	BIOELECTROMAGNETICS	2001	22	419	428
Tofani, S; Barone, D; Peano, S; Ossola, P; Ronchetto, F; Cintorino, M	Animal Studies	Anticancer activity by magnetic fields: Inhibition of metastatic spread and growth in a breast cancer model	IEEE TRANSACTIONS ON PLASMA SCIENCE	2002	30	1552	1557
Tofani, S; Cintorino, M; Barone, D; Berardelli, M; De Santi, MM; Ferrara, A; Orlassino, R; Ossola, P; Rolfo, K; Ronchetto, F; Tripodi, SA; Tosi, P	Animal Studies	Increased mouse survival, tumor growth inhibition and decreased immunoreactive p53 after exposure to magnetic fields	BIOELECTROMAGNETICS	2002	23	230	238
Tokalov, SV; Gutzeit, HO	Mechanism/in vitro	Weak electromagnetic fields (50 Hz) elicit a stress response in human cells	ENVIRONMENTAL RESEARCH	2004	94	145	151
Touitou, Y; Lambrozo, J; Camus, FO; Charbuy, H	Clinical studies	Magnetic fields and the melatonin hypothesis: a study of workers chronically exposed to 50-Hz magnetic fields	AMERICAN JOURNAL OF PHYSIOLOGY-REGULATORY INTEGRATIVE AND COMPARATIVE PHYSIOLOGY	2003	284	R1529	R1535
Touitou, Y; Selmaoui, B; Lambrozo, J; Auzeby, A	Mechanism/in vitro	Assessment of the effects of magnetic fields (50 Hz) on melatonin secretion in humans and rats. A circadian study	BULLETIN DE L ACADEMIE NATIONALE DE MEDECINE	2002	186	1625	1639
Traitcheva, N; Angelova, P; Radeva, M; Berg, H	Mechanism/in vitro	ELF fields and photooxidation yielding lethal effects on cancer cells	BIOELECTROMAGNETICS	2003	24	148	150
Trock, DH	Review/Treatment	Electromagnetic fields and magnets - Investigational treatment for musculoskeletal disorders	RHEUMATIC DISEASE CLINICS OF NORTH AMERICA	2000	26	51	+
Trosko, JE	Review	Human health consequences of environmentally-modulated gene expression: Potential roles of ELF-EMF induced epigenetic versus mutagenic mechanisms of disease	BIOELECTROMAGNETICS	2000	21	402	406

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Turgeon, A; Bourdages, M; Levallois, P; Gauvin, D; Gingras, S; Deadman, JE; Goulet, DL; Plante, M	Exposure	Experimental validation of a statistical model for evaluating the past or future magnetic field exposures of a population living near power lines	BIOELECTROMAGNETICS	2004	25	374	379
Tuschl H, Neubauer G, Schmid G, Weber E, Winker N.	Occupational/Biological markers	Occupational exposure to static, ELF, VF and VLF magnetic fields and immune parameters.	INTERNATIONAL JOURNAL OCCUPATIONAL MEDICINE ENVIRONMENTAL HEALTH	2000	13	39	50
Tworoger, SS; Davis, S; Schwartz, SM; Mirick, DK	Exposure	Stability of Wertheimer-Leeper wire codes as a measure of exposure to residential magnetic fields over a 9-to 11-year interval	JOURNAL OF EXPOSURE ANALYSIS AND ENVIRONMENTAL EPIDEMIOLOGY	2002	12	448	454
Tynes T, Haldorsen T.	Epi	Residential and occupational exposure to 50 Hz magnetic fields and hematological cancers in Norway.	CANCER CAUSES CONTROL	2003	14	715	720
Tynes, T; Klaeboe, L; Haldorsen, T	Epi	Residential and occupational exposure to 50 Hz magnetic fields and malignant melanoma: a population based study	OCCUPATIONAL AND ENVIRONMENTAL MEDICINE	2003	60	343	347
UK Childhood Cancer Study Investigators.	Epi	Childhood cancer and residential proximity to power lines.	BRITISH JOURNAL OF CANCER	2000	83	1573	1580
Ushiyama, A; Ohkubo, C	Mechanism/in vitro	Acute effects of low-frequency electromagnetic fields on leukocyte-endothelial interactions in vivo	IN VIVO	2004	18	125	132
Vallejo, D; Sanz, P; Picazo, ML	Animal Studies	A hematological study in mice for evaluation of leukemogenesis by extremely low frequency magnetic fields	ELECTRO- AND MAGNETOBIOLOGY	2001	20	281	298
Van Den Heuvel, R; Leppens, H; Nemethova, G; Verschaeve, L	Mechanism/in vitro	Haemopoietic cell proliferation in murine bone marrow cells exposed to extreme low frequency (ELF) electromagnetic fields	TOXICOLOGY IN VITRO	2001	15	351	355
van der Woord, MP; Kromhout, H; Barregard, L; Jonsson, P	Exposure	Within-day variability of magnetic fields among electric utility workers: Consequences for measurement strategies (vol 60, pg 713, 1999)	AMERICAN INDUSTRIAL HYGIENE ASSOCIATION JOURNAL	2000	61	31	38
van Tongeren, M; Mee, T; Whatmough, P; Broad, L; Maslanyj, M; Allen, S; Muir, K; McKinney, P	Exposure	Assessing occupational and domestic ELF magnetic field exposure in the UK Adult Brain Tumour Study: Results of a feasibility study	RADIATION PROTECTION DOSIMETRY	2004	108	227	236
Vazquez-Garcia, M; Elias-Vinas, D; Reyes-Guerrero, G; Dominguez-Gonzalez, A; Verdugo-Diaz, L; Guevara-Guzman, R	Animal Studies	Exposure to extremely low-frequency electromagnetic fields improves social recognition in male rats	PHYSIOLOGY & BEHAVIOR	2004	82	685	690
Ventura, C; Maioli, M; Pintus, G; Gottardi, G; Bersani, F	Mechanism/in vitro	Elf-pulsed magnetic fields modulate opioid peptide gene expression in myocardial cells	CARDIOVASCULAR RESEARCH	2000	45	1054	1064

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Verdugo-Diaz, L; Olivares-Banuelos, T; Navarro, L; Drucker-Colin, R	Mechanism/in vitro	Effects of extremely low frequency electromagnetic field stimulation on cultured chromaffin cells	CHROMAFFIN CELL: TRNSMITTER BIOSYNTHESIS, STORAGE, RELEASE, ACTIONS, AND INFORMATICS	2002	971	266	268
Verrier, A; Souques, M; Wallet, F	Exposure	Characterization of exposure to extremely low frequency magnetic fields using multidimensional analysis techniques	BIOELECTROMAGNETICS	2005	26	266	274
Vijayalaxmi; Obe, G	Review/Mechanism	Controversial cytogenetic observations in mammalian somatic cells exposed to extremely low frequency electromagnetic radiation: A review and future research recommendations	BIOELECTROMAGNETICS	2005	26	412	430
Villeneuve PJ , Agnew DA et al.	Epi	Brain cancer and occupational exposure to magnetic fields among men: Results from a Canadian population-based case-control study.	INTERNATIONAL JOURNAL OF EPIDEMIOLOGY	2002	31	210	217
Vincze, G; Szasz, N; Szasz, A		On the thermal noise limit of cellular membranes	BIOELECTROMAGNETICS	2005	26	28	35
von Winterfeldt, D; Eppel, T; Adams, J; Neutra, R; DelPizzo, V	Review/Commentary	Managing potential health risks from electric powerlines: A decision analysis caught in controversy	RISK ANALYSIS	2004	24	1487	1502
Wakeford, R	Review	The cancer epidemiology of radiation	ONCOGENE	2004	23	6404	6428
Warman, GR; Tripp, H; Warman, VL; Arendt, J	Clinical studies	Acute exposure to circularly polarized 50-Hz magnetic fields of 200-300 mu T does not affect the pattern of melatonin secretion in young men	JOURNAL OF CLINICAL ENDOCRINOLOGY AND METABOLISM	2003	88	5668	5673
Warman, GR; Tripp, HM; Warman, VL; Arendt, J	Review	Circadian neuroendocrine physiology and electromagnetic field studies: Precautions and complexities	RADIATION PROTECTION DOSIMETRY	2003	106	369	373
Wartenberg, D	Epi	Residential EMF exposure and childhood leukemia: Meta-analysis and population attributable risk	BIOELECTROMAGNETICS	2001		S86	S104
Wartenberg, D	Review/Commentary	The potential impact of bias in studies of residential exposure to magnetic fields and childhood leukemia	BIOELECTROMAGNETICS	2001		S32	S47
Way, HE; Conover, DP; Mathias, P; Toraason, M; Lotz, WG	Mechanism/in vitro	50-hertz magnetic field and calcium transients in Jurkat cells: Results of a research and public information dissemination (RAPID) program study	ENVIRONMENTAL HEALTH PERSPECTIVES	2000	108	135	140
Wertheimer, N	Exposure	d'Arsonval address: Adequacy of wire codes and other proxies used to assess historic magnetic field exposure	BIOELECTROMAGNETICS	2000	21	2	7
Willett, EV; McKinney, PA; Fear, NT; Cartwright, RA; Roman, E	Epi	Occupational exposure to electromagnetic fields and acute leukaemia: analysis of a case-control study	OCCUPATIONAL AND ENVIRONMENTAL MEDICINE	2003	60	577	583

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Winker, R; Ivancsits, S; Pilger, A; Adlkofer, F; Rudiger, HW	Mechanism/in vitro	Chromosomal damage in human diploid fibroblasts by intermittent exposure to extremely low-frequency electromagnetic fields	MUTATION RESEARCH-GENETIC TOXICOLOGY AND ENVIRONMENTAL MUTAGENESIS	2005	585	43	49
Wolf, FI; Torsello, A; Tedesco, B; Fasanella, S; Boninsegna, A; D'Ascenzo, M; Grassi, C; Azzena, GB; Cittadini, A	Mechanism/in vitro	50-Hz extremely low frequency electromagnetic fields enhance cell proliferation and DNA damage: Possible involvement of a redox mechanism	BIOCHIMICA ET BIOPHYSICA ACTA-MOLECULAR CELL RESEARCH	2005	1743	120	129
Woods, M; Bobanovic, F; Brown, D; Alexander, DR	Mechanism/in vitro	Lyn and Syk tyrosine kinases are not activated in B-lineage lymphoid cells exposed to low-energy electromagnetic fields	FASEB JOURNAL	2000	14	2284	2290
Wu, RY; Chiang, H; Hu, GL; Zeng, QL; Bao, JL	Mechanism/in vitro	The effect of 50 Hz magnetic field on GCSmRNA expression in lymphoma B cell by mRNA differential display	JOURNAL OF CELLULAR BIOCHEMISTRY	2000	79	460	470
Yamazaki, K; Fujinami, H; Shigemitsu, T; Nishimura, I	Exposure	Low stray ELF magnetic field exposure system for in vitro study	BIOELECTROMAGNETICS	2000	21	75	83
Yamazaki, K; Iwamoto, T; Kawamoto, T; Fujinami, H	Mitigation	Investigation of shielding method of ELF magnetic field generated from conductors	ELECTRICAL ENGINEERING IN JAPAN	2000	131	12	19
Yamazaki, K; Kawamoto, T	Exposure	Simple estimation of equivalent magnetic dipole moment to characterize ELF magnetic fields generated by electric appliances incorporating harmonics	IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY	2001	43	240	245
Yamazaki, K; Kawamoto, T; Fujinami, H; Shigemitsu, T	Exposure	Investigation of ELF magnetically induced current inside the human body: Development of estimation tools and effect of organ conductivity	ELECTRICAL ENGINEERING IN JAPAN	2001	134	1	10
Yokus, B; Cakir, DU; Akdag, MZ; Sert, C; Mete, N	Animal Studies	Oxidative DNA damage in rats exposed to extremely low frequency electromagnetic fields	FREE RADICAL RESEARCH	2005	39	317	323
Yoshizawa H, Tsuchiya T, Mizoe H, Ozeki H, Kanao S, Yomori H, Sakane C, Hasebe S, Motomura T, Yamakawa T, Mizuno F, Hirose H, Otaka Y.	Mechanism/ in vitro	No effect of extremely low-frequency magnetic field observed on cell growth or initial response of cell proliferation in human cancer cell lines.	BIOELECTROMAGNETICS	2002	23	355	368
Zapponi, GA; Marcello, I	Review	Recent experimental data on extremely low frequency (ELF) magnetic field carcinogenic risk: Open questions	JOURNAL OF EXPERIMENTAL & CLINICAL CANCER RESEARCH	2004	23	353	364
Zeng, GL; Chiang, H; Hu, GL; Mao, GG; Fu, YT; Lu, DQ	Mechanism/in vitro	ELF magnetic fields induce internalization of gap junction protein connexin 43 in Chinese hamster lung cells	BIOELECTROMAGNETICS	2003	24	134	138

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Zeni, O; Lioi, MB; D'Alisa, A; Sorrentino, M; Salvemini, F; Scarfi, MR	Mechanism/in vitro	Combined exposure to extremely low frequency (ELF) magnetic fields and chemical mutagens: Lack of genotoxic effects in human lymphocytes	ELECTRO- AND MAGNETOBIOLOGY	2001	20	331	341
Zhou, JL; Li, CL; Yao, GD; Chiang, HA; Chang, ZL	Mechanism/in vitro	Gene expression of cytokine receptors in HL60 cells exposed to a 50 Hz magnetic field	BIOELECTROMAGNETICS	2002	23	339	346
Zhou, JL; Yao, GD; Zhang, JS; Chang, ZL	Mechanism/in vitro	CREB DNA binding activation by a 50-Hz magnetic field in HL60 cells is dependent on extra- and intracellular Ca2+ but not PKA, PKC, ERK, or p38 MAPK	BIOCHEMICAL AND BIOPHYSICAL RESEARCH COMMUNICATIONS	2002	296	1013	1018