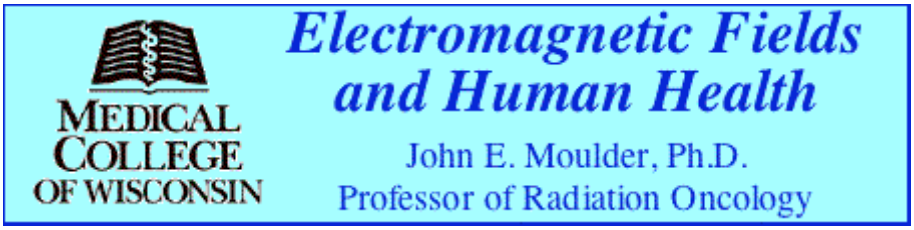

Power Lines and Cancer FAQs

Summary: Questions and answers on the connection between power lines, electrical occupations and cancer; includes discussion of the biophysics of interactions, summaries of the laboratory and human studies, information on standards, and a bibliography.
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WARNING:
This document is no longer being maintained.
Last complete update: 11-Jul-2005
Last update of "What's New": 13-Aug-2006
Conversion to PDF: 30-Sep-2007

- This FAQ is derived from an FAQ of the same name that was developed in the sci.med.physics newsgroup of USENET in the early 90's.

Table of Contents

Bibliography

What's New

This section summarizes relevant material published between 11-Jul-05 and 13-Aug-06.

- Government reports and academic reviews:
  - A review of genotoxicity studies done with power-frequency fields found that 46% of studies found no effects, 22% found evidence for DNA damage and 32% were inconclusive.
    - Vijayalaxmi and G Obe: 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.
  - A review of the epidemiology of childhood leukemia and residential exposure to magnetic fields concludes that: "The recent studies, using the exposure methods and the cut-off levels set a priori, each concluded that there was little evidence of any association. The pooled analyses, using different exposure measures and different cut-offs, conclude that an association exists at high exposure levels. It is not clear if the results of the pooled analysis are more valid than those of the recent major studies, although this has been often assumed in influential reviews."
    - JM Elwood: Childhood leukemia and residential magnetic fields: Are pooled analyses more valid than the original studies? Bioelectromag 27:112-118, 2006.
- Epidemiological studies and experimental studies in humans:
  - Occupations exposure to power-frequency fields did not increase the risk of acoustic neuromas (a benign brain cancer)
    - UM Forssén, S Lonn et al: Occupational magnetic field exposure and the risk of acoustic neuroma. Amer J Indust Med 49:112-118, 2006.
  - A series of letters criticizing, or commenting on, the study by Draper and colleagues [C74 and Q19N] and a response from the authors.
    - Br Med J 331-634-637, 2005.
- Animal studies:
  - Long-term exposure to a 1000 microT power-frequency field did not promote (enhance the incidence of)

chemically-induced lymphoma in mice.
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- Exposure of adult rats, adult mice and immature mice to power-frequency magnetic fields caused no DNA damage in their brain cells.
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  - Power-frequency magnetic fields did not induce heat shock proteins.
- LA Coulton, PA Harris et al: Effect of 50 Hz electromagnetic fields on the induction of heat-shock protein gene expression in human leukocytes. Rad Res 161:430-434, 2004.
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- C Ulcer, CD Fillip et al: Extremely low-frequency electromagnetic fields do not affect DNA damage and gene expression profiles of yeast and human lymphocytes. Rad Res 164:277-285, 2005;
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- C Luceri, CD Filippo et al: Extremely low-frequency electromagnetic fields do not affect DNA damage and gene expression profiles of yeast and human lymphocytes. Rad Res 164: 277-285, 2005.
  - Power-frequency magnetic fields had no effect on proliferation or activation of human lymphocytes.
- M Capri, P Mesirca et al: 50 Hz sinusoidal magnetic fields do not affect human lymphocyte activation and proliferation in vitro. Physical Biology 1:211-219, 2004.
- Biophysics and dosimetry
  - A review of the biophysical mechanisms whereby power-frequency fields could interaction with biological material concluded that: "effects below 5 μT [50 mG] are implausible. At about 50 μT [500 mG], no specific mechanism has been identified, but the basic problem of implausibility is removed. Above about 500 μT [5000 mG], there are established or likely effects from accepted mechanisms. The absence of a plausible biophysical mechanism at lower fields cannot be taken as proof that health effects of environmental electric and magnetic fields are impossible. Nevertheless, it is a relevant consideration in assessing the overall evidence on these fields."
- J Swanson and L Kheifets: Biophysical mechanisms: a component in the weight of evidence for health effects of power-frequency electric and magnetic fields. Rad Res 165:470-478, 2006.

Acknowledgments

This FAQ sheet owes much to the many readers of USENET who sent me comments and suggestions during the 1990's.

Initial conversion of the FAQ into html was done by Bob Mueller and Dennis Taylor of the General Clinical Research Center at the Medical College of Wisconsin, and server space for these documents is provided by the General Clinical Research Center of the Medical College of Wisconsin.

Questions and Answers

Organizational notes:

- Cross references to other questions are indicated by the letter Q followed by the question number; for example, (Q16A) indicates that further information is found in Question 16A.
- Bibliographic references are shown in brackets, for example [A2] is a reference to the second entry in section A of the bibliography.

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1) Is there a concern about power lines and cancer?

The concern about power lines and cancer comes largely from studies of people living near power lines (see Q12) and people working in "electrical" occupations (see Q15). Some of these studies appear to show a weak association between exposure to

power-frequency magnetic fields and the incidence of some cancers.

However:

- the more recent epidemiological studies show little evidence that either power lines or "electrical occupations" are associated with an increase in cancer (see Q19);
- laboratory studies have shown little evidence of a link between power-frequency fields and cancer (see Q16);
- an extensive series of studies have shown that life-time exposure of animals to power-frequency magnetic fields does not cause cancer (see Q16B);
- a connection between power line fields and cancer is physically implausible (see Q18).

The International Commission on Non-Ionizing Radiation Protection (2001):

> "In the absence of evidence from cellular or animal studies, and given the methodological uncertainties and in many cases inconsistencies of the existing epidemiologic literature, there is no chronic disease for which an etiological [causal] relation to [power-frequency fields] can be regarded as established". (See B12)

The International Agency for Research on Cancer (2001):

> "There is limited evidence in humans for the carcinogenicity of extremely low-frequency magnetic fields in relation to childhood leukaemia.... There is inadequate evidence in humans for the carcinogenicity of extremely low-frequency magnetic fields in relation to all other cancers [and] there is inadequate evidence in humans for the carcinogenicity of extremely low-frequency electric fields." (see Q27J)

The U.S. National Institutes of Health (2002):

> "The overall scientific evidence for human health risk from [exposure to power-frequency fields] is weak. No consistent pattern of biological effects from exposure to [power-frequency fields] has emerged from laboratory studies with animals or with cells. However, epidemiological studies... had shown a fairly consistent pattern that associated potential [exposure to power-frequency fields] with a small increased risk of leukemia in children and chronic lymphocytic leukemia in adults... For both childhood and adult leukemias interpretation of the epidemiological findings has been difficult due to the absence of supporting laboratory evidence or a scientific explanation linking [exposure to power-frequency fields] with leukemia."(see Q27G).

The U.K. National Radiological Protection Board (2004):

> "The epidemiological evidence indicates that exposure to power-frequency magnetic fields above 0.4 microT [4 milliG] is associated with a small absolute raised risk of leukaemia in children... However, the epidemiological evidence is not strong enough to justify a firm conclusion that [power-frequency magnetic] fields cause leukemia in children. There is little evidence to suggest... that cancer risks of other types, in children and adults, might arise from exposure to [power-frequency magnetic] fields... The results of epidemiological studies, taken individually or as collectively reviewed by expert groups, cannot be used as a basis for derivation of quantitative restrictions on exposure to [power-frequency magnetic] fields." (see Q27H)

Overall, most scientists consider that the evidence that power line fields cause or contribute to cancer is weak to nonexistent.

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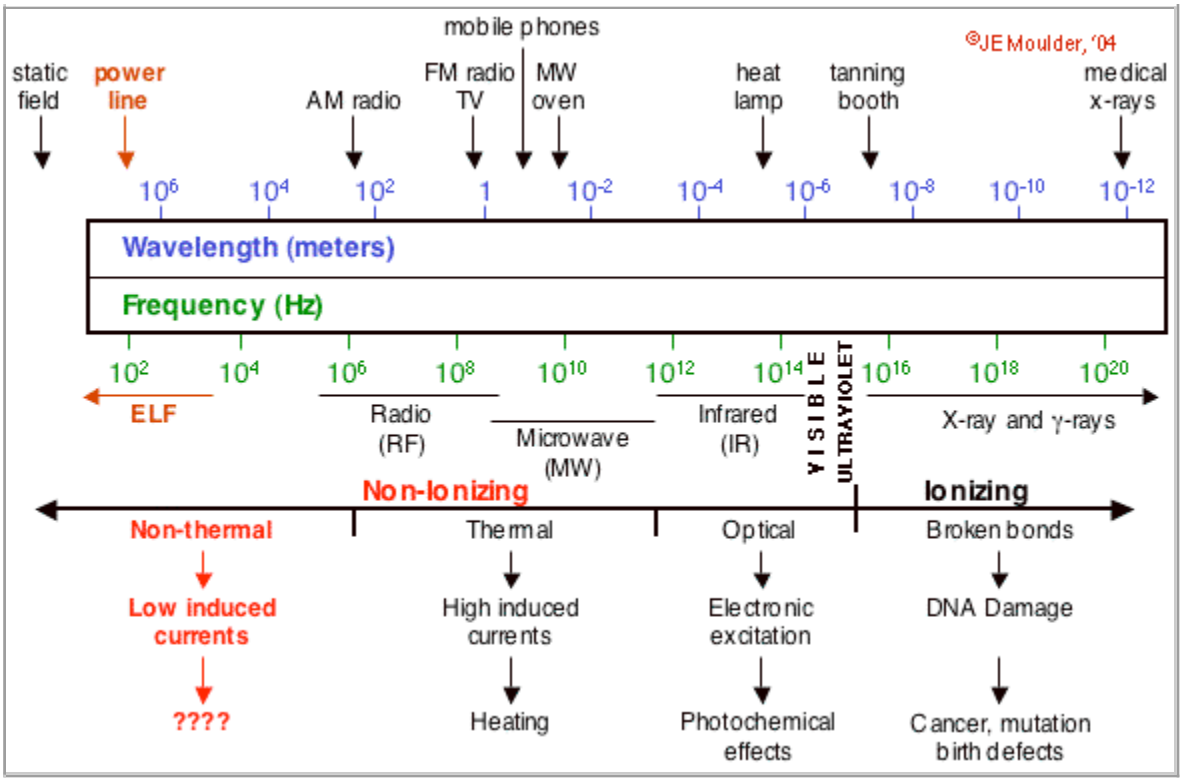
2) What is the difference between the electromagnetic (EM) energy associated with power lines and other forms of electromagnetic energy such as microwaves or x-rays?

X-rays, ultraviolet (**UV**) light, visible light, infrared light (**IR**), microwaves (**MW**), radio-frequency (**RF**) energy, and magnetic fields from electric power systems are all parts of the electromagnetic (**EM**) spectrum. The parts of the electromagnetic spectrum are characterized by their frequency or wavelength. The frequency and wavelength are related, and as the frequency rises the wavelength gets shorter. The frequency is the rate at which the electromagnetic field goes through one complete oscillation (cycle) and is usually given in Hertz (**Hz**), where one Hz is one cycle per second.

The Electromagnetic Spectrum



Power-frequency fields in the US vary 60 times per second (**60 Hz**), and have a wavelength of 5,000 km. Power in most of the rest of the world is at 50 Hz. Broadcast AM radio has a frequency of around 10^6 (1,000,000) Hz and a wavelength of around 300 m. Most microwave ovens have a frequency of 2.54 x 10^9 Hz, and a wavelength of about 12 cm. X-rays have frequencies above 10^15 Hz, and wavelengths of less than 100 nanometers.

This FAQ sheet will use the term "**power frequency**" to refer to both the 50- and 60-Hz alternating current (**AC**) frequencies used in electric power systems, and the term "**power frequency field**" to refer to the sinusoidal electric and magnetic fields produced by 50- and 60-Hz lines and devices. The phrase "**EMF**" will be avoided since it is an imprecise term that could apply to many very different types of fields, and because the term has a long-standing usage in physics to refer to an entirely different quantity, electromotive force. The terms "**electromagnetic radiation**" and "**nonionizing radiation**" will be avoided since power-frequency sources produce no appreciable radiation (see Q5).

Power-frequency fields are also properly referred to as extremely low frequency (or **ELF**) fields.

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3) Do different types of electromagnetic sources produce different biological effects?

The interaction of biological material with an electromagnetic source depends on the frequency of the source. We usually talk about the electromagnetic spectrum as though it produced waves of energy. However, sometimes electromagnetic energy acts like particles rather than waves, particularly at high frequencies. The particle nature of electromagnetic energy is important because it is the energy per particle (or photons, as these particles are called) that determines what biological effects electromagnetic energy will have [A4].

At the very high frequencies characteristic of "vacuum" UV and X-rays (less than 100 nanometers), electromagnetic particles (photons) have sufficient energy to break chemical bonds. This breaking of bonds is termed ionization, and this part of the electromagnetic spectrum is termed ionizing. The well-known biological effects of X-rays are associated with the ionization of molecules. At lower frequencies, such as those characteristic of visible light and radio-frequencies, the energy of a photon is very much below those needed to disrupt chemical bonds. This part of the electromagnetic spectrum is termed non-ionizing. Because non-ionizing electromagnetic energy cannot break chemical bonds there is no analogy between the biological effects of ionizing and nonionizing electromagnetic energy [A4].

Non-ionizing electromagnetic sources can produce biological effects. Many of the biological effects of ultraviolet (UV), visible, and infrared (IR) frequencies depend on the photon energy, but they involve electronic excitation rather than ionization, and do not occur at frequencies below that of infrared (IR) light (below 3 x 10^11 Hz). Radio-frequency and microwaves sources can cause

effects by inducing electric currents in tissues, which cause heating. The efficiency with which a nonionizing electromagnetic source can induce electric currents, and thus produce heating, depends on the frequency of the source, and the size and orientation of the object being heated. At frequencies below that used for broadcast AM radio (about 10^6 Hz), electromagnetic sources couple poorly with the bodies of humans and animals, and thus are very inefficient at inducing electric currents and causing heating [A4].

Thus in terms of potential biological effects the electromagnetic spectrum can be divided into four portions (see diagram of electromagnetic spectrum):

1. The ionizing radiation portion, where direct chemical damage can occur (X-rays, "vacuum" ultraviolet light).
2. The non-ionizing portion of the spectrum, which can be subdivided into:
    a. The optical radiation portion, were electron excitation can occur (ultraviolet light, visible light, infrared light).
    b. The portion where the wavelength is smaller than the body, and heating via induced currents can occur (microwaves and higher-frequency radiofrequency energy).
    c. The portion where the wavelength is much larger than the body, and heating via induced currents seldom occurs (lower-frequency radiofrequency energy, **power frequencies fields** and static fields).

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4) What is difference between electromagnetic radiation and electromagnetic fields?

In general, electromagnetic sources produce both radiant energy (**radiation**) and non-radiant **fields**. Radiation travels away from its source, and continues to exist even if the source is turned off. In contrast, some electric and magnetic fields exist near an electromagnetic source that are not projected into space, and that cease to exist when the energy source is turned off.

The fact that exposure to power-frequency fields occurs at distances that are much shorter than the wavelength of 50/60-Hz radiation has important implications, because under such conditions (called "**near-field**"), the electric and magnetic fields can be treated as independent entities. This is in contrast to electromagnetic radiation, in which the electric and magnetic fields are linked.

---

5) Do power lines produce electromagnetic radiation?

To be an effective radiation source an antenna must have a length comparable to its wavelength. Power-frequency sources are clearly too short compared to their wavelength (5,000 km) to be effective radiation sources. Calculations show that the typical maximum power radiated by a power line would be less than 0.0001 microwatts/cm^2, compared to the 0.2 microwatts/cm^2 that a full moon delivers to the Earth's surface on a clear night. The issue of whether power lines could produced ionizing radiation is covered in Q21B.

This is not to say that there is no loss of power during transmission. There are sources of loss in transmission lines that have nothing to do with "radiation" (in the sense as it is used in electromagnetic theory). Much of the loss of energy is a result of resistive heating; this is in sharp contrast to radiofrequency and microwave antennas, which intentionally "lose" energy to space by radiation. Likewise, there are many ways of transmitting energy that do not involve radiation; electric circuits do it all the time.

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6) How do ionizing electromagnetic sources cause biological effects?

Ionizing electromagnetic radiation carries enough energy per photon to break bonds in the genetic material of the cell, the DNA. Severe damage to DNA can kill cells, resulting in tissue damage or death. Lesser damage to DNA can result in permanent changes which may lead to cancer. If these changes occur in reproductive cells, they can also lead to inherited changes (mutation). All of the known human health hazards from exposure to the ionizing portion of the electromagnetic spectrum are the result of the breaking of chemical bonds in DNA. For frequencies below that of hard UV, DNA damage does not occur because the photons do not have enough energy to break chemical bonds.

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7) How do radio-frequency and microwave sources cause biological effects?

A principal mechanism by which radiofrequency radiation and microwaves cause biological effects is by heating (**thermal effects**). This heating can kill cells. If enough cells are killed, burns and other forms of long-term, and possibly permanent tissue damage can occur. Cells which are not killed by heating gradually return to normal after the heating ceases; permanent non-lethal cellular damage is not known to occur. At the whole-animal level, tissue injury and other thermally-induced effects can be expected when the amount of power absorbed by the animal is similar to or exceeds the amount of heat generated by normal body processes. Some of these thermal effects (also see Q9) are very subtle, and do not represent biological hazards [A4].

Since thermal effects are produced by induced currents, not by the electric or magnetic fields directly, they can be produced by

fields at many different frequencies. Well-accepted safety standards exist to prevent significant thermal damage to persons exposed to radiofrequency energy and microwaves (see Q31C), and also for persons exposed to lasers, infrared (IR) and ultraviolet (UV) light [M1].

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8) How do the power-frequency electromagnetic fields cause biological effects?

The electric fields associated with the power-frequency sources exist whenever voltage is present, and regardless of whether current is flowing. These electric fields have very little ability to penetrate buildings or even skin. The magnetic fields associated with power-frequency sources exist only when current is flowing. These magnetic fields are difficult to shield, and easily penetrate buildings and people. Because power-frequency electric fields do not penetrate the body, it is generally assumed that any biologic effect from residential exposure to power-frequency fields must be due to the magnetic component of the field, or to the electric fields and currents that these magnetic fields induce in the body [A4].

The argument that biological effects of power-frequency fields must be due to the magnetic component of the field was the subject of some debate in the late 1990's [A5]. In particular, King [F18] argued that the electrical fields from power lines do penetrate most buildings, and that the electrical currents induced in the body by power line electrical fields may be greater than those induced by power line magnetic fields. This issue is discussed further in Q16G and Q19L.

At power frequencies, the photon energy is a factor of 10^10 smaller than that needed to break even the weakest chemical bond. There are, however, well-established mechanisms by which power-frequency electric and magnetic fields could produce biological effects without breaking chemical bonds [A4, F1, F15, M4, M7, M8]. Power-frequency electric fields can exert forces on charged and uncharged molecules or cellular structures within a tissue. These forces can cause movement of charged particles, orient or deform cellular structures, orient dipolar molecules, or induce voltages across cell membranes. Power-frequency magnetic fields can exert forces on cellular structures; but since biological materials are largely nonmagnetic these forces are usually very weak.

Power-frequency magnetic fields can also cause biological effects via the electric fields that they induce in the body. These electric and magnetic forces occur in the presence of random thermal agitation (thermal noise) and electric noise from many sources; and to cause significant changes in a biological system applied fields must generally far exceed those that exist in typical environmental exposure conditions [A4, F1, F9, F15, F24, M4].

In general, the fields or currents that are induced in the body by power-frequency electric or magnetic fields are too low to be hazardous; and well-accepted safety standards exist to protect persons from exposure to power-frequency fields that would induce hazardous currents [M3, M4, M6, M7, M8]. These safety standards for fields (as opposed to those that protect against shock from contact with conductors) are set to limit induced currents in the body to levels below those that occur naturally in the body. The well-known hazards of electric power, shock and burns, generally require that the subject directly contact a charged surface (e.g., a "hot" conductor and ground) allowing current to pass directly into the body.

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9) Do non-ionizing electromagnetic sources cause non-thermal as well as thermal effects?

One distinction that is often made in discussions of the biological effects of non-ionizing electromagnetic sources is between "nonthermal" and "thermal" effects. This refers to the mechanism for the effect: non-thermal effects are a result of a direct interaction between the field and the organism (for example, photochemical events like vision and photosynthesis); and thermal effects are a result of heating (for example, heating with microwave ovens or IR light). There are many reported biological effects of non-ionizing electromagnetic sources whose mechanisms are totally unknown, and it is difficult (and not very useful) to try to draw a distinction between "thermal" and "nonthermal" mechanisms for such effects [A4].

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10) What sort of power-frequency fields are common in residences and work places?

In the US magnetic fields are often still measured in **Gauss (G)** or **milligauss (mG)**, where:

1,000 mG = 1 G.

In the rest of the world and in the scientific community, magnetic fields are measured in **tesla (T)**, were:

10,000 G = 1 T
1 G = 100 microT (μT)
1 microT = 10 mG

In the FAQ **magnetic fields** will generally be specified in microT.

Electric fields are measured in volts/meter (V/m).

Measurement techniques are discussed in Q29 and Q30.

Within the path of a power line (known in the U.S. as a right-of-way or **ROW**) of a high-voltage (115-765 kV, 115,000-765,000 volt) transmission line, fields can approach 10 microT and 10,000 V/m. At the edge of a high-voltage transmission ROW, the fields will be 0.1-1.0 microT and 100-1,000 V/m. Ten meters from a 12 kV (12,000 volt) distribution line fields will be 0.2-1.0 microT and 2-20 V/m. Actual magnetic fields depend on distance, voltage, design and current; actual electric fields are affected only by distance, voltage and design (not by current flow) [F5].

Fields within residences vary from over 150 microT and 200 V/m a few cm from certain appliances to less than 0.02 microT and 2 V/m in the center of many rooms. Appliances that have the highest magnetic fields are those with high currents or high-speed electric motors (e.g., vacuum cleaners, microwave ovens, electric washing machines, dishwashers, blenders, can openers, electric shavers) [F14]. Electric clocks, and clock radios, which have been mentioned as major sources of night-time exposure of children, do not have particularly high magnetic fields (0.04-0.06 microT at 50 cm [F14]). Appliance fields decrease rapidly with distance [F5, F14]. Of the appliances assessed in British homes, only microwave ovens, electric washing machines, dishwashers and can openers produced fields greater than 0.20 microT at 1 meter [F14].

A 2002 analysis of power-frequency field levels in Spanish primary schools found a median level in classrooms of 0.012 microT with a maximum of 0.88 microT [F28]. In playgrounds, the median level was 0.0095 microT and the maximum was 0.46 microT [F28]. In urban environments in Spain, median power-frequencies field levels were between 0.04 and 0.11 microT with 5% of the measurements being greater than 0.76 microT [F30].

Because electric fields from powerlines have little ability to penetrate buildings, there is little correlation between electric and magnetic fields within homes [C11, C12]. In particular, while magnetic fields are elevated inside buildings near powerlines, electric fields do not appear to be similarly elevated [C11, C12].

Occupational exposures in excess of 100 microT and 5,000 V/m have been reported (e.g., in arc welders and electrical cable splicers). In "electrical" occupations typical mean exposures range from 0.5 to 4 microT and 100-2,000 V/m [F5, F6, F8, D9]. Exposure to power-frequency electric and magnetic fields are poorly correlated in occupational settings [F8].

Electric trains can also be a major source of exposure, as power-frequency fields at seat height in passenger cars can be as high as 60 microT [F19]

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11) Can power-frequency fields in homes and work places be reduced?

There are engineering techniques that can be used to decrease the magnetic fields produced by power lines, substations, transformers and even household wiring and appliances. Once the fields are produced, however, shielding is very difficult. Small areas can be shielded by the use of Mu metal (a nickel-iron-copper alloy) but Mu metal shields are very expensive. Larger area can be shielded with less expensive metals; but such shielding is still expensive, and successful use requires considerable technical knowledge.

Increasing the height of towers, and thus the height of the conductors above the ground, can reduce the field intensity at the edge of a power line corridor. The size, spacing and configuration of conductors can be modified to reduce magnetic fields, but this approach is limited by electrical safety considerations. Placing multiple circuits on the same set of towers can also lower the field intensity at the edge of the ROW, although it generally requires higher towers. Replacing lower voltage lines with higher voltage ones can also lower the magnetic fields.

Burying transmission lines can reduce their magnetic fields. The reduction in the magnetic field occurs because the underground lines use rubber, plastic or oil for insulation rather than air; this allows the conductors to be placed much closer together and allows greater phase cancellation. The reduction in magnetic fields for underground lines is not due to shielding, and the reduction in magnetic fields from burying a line is greatest at a distance from the line. However, placing high voltage lines underground is expensive; it is also difficult, time-consuming and expensive to repair underground transmission lines when they break (and they do break).

Different methods of household wiring can greatly affect magnetic fields inside houses. For example, the tube-and-knob method of wiring older houses produces higher fields than modern methods that use conduit or other methods that put the wires very close together; the fields are lower because the conductors are closer together and there is greater phase cancellation. Other strategies for reducing fields from household wiring include avoidance of ground loops, and care in how circuits with multiple switches are wired. In general conformance with modern electrical wiring codes will result in decreased magnetic fields.

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12) What is known about the relationship between power lines and cancer rates?

Some studies have reported that children living near certain types of power lines (high-current distribution lines and high-voltage transmission lines) have higher than average rates of leukemia [C1, C6, C12, C18, C47], brain cancers [C1, C6] and/or overall cancer [C5, C16]. The correlations are not strong, and the studies have generally not shown dose-response relationships. When power-frequency fields are actually measured, the association generally vanishes [C6, C12, C18, C36, C45]. Many other studies have shown no correlations between residence near power lines and risks of childhood leukemia [C3, C5, C9, C10, C15, C16, C34, C36, C45, C46, C49, C51, C53], childhood brain cancer [C5, C9, C15, C16, C18, C29, C30, C34], or overall childhood cancer [C15, C18, C34].

All but one of the newer studies of powerlines and either childhood leukemia or brain cancer [C29, C30, C34, C36, C44, C45] have failed to show significant associations. The exception is a Canadian study [C46, C47] which showed an association between the incidence of childhood leukemia and some measures of exposure (see full discussion in Q19J).

With two exceptions [C2, C33] all studies of correlations between adult cancer and residence near power lines have been negative [C4, C7, C9, C13, C17, C21, C32, C33, C38, C40, C48, C61]. The exception are Wertheimer et al [C41] who reported an excess of total cancer and brain cancer, but no excess of leukemia; and Li et al [C34] who reported excess leukemia, but no excess breast cancer or brain cancer.

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13) Is there a "cancer risk" associated with living next to a power line?

The excess cancer found in epidemiologic studies is usually quantified in a number called the relative risk (**RR**). This is the incidence of cancer in a group of "exposed" people divided by the incidence of cancer in a group of "unexposed" people. Since no one is unexposed to power-frequency fields, the comparison is actually "high exposure" versus "low exposure". A relative risk of 1.0 means no effect, a relative risk of less the 1.0 means a decreased incidence in exposed groups, and a relative risk of greater than one means an increased incidence in exposed groups. Relative risks are generally given with 95% confidence intervals, and relative risks between about 0.6 and 1.8 are almost never significant. These 95% confidence intervals are almost never adjusted for multiple comparisons (see Q21E) even when multiple types of cancer and multiple indices of exposure are studied (see Olsen et al, [C16], Fig. 2 for an example of a multiple-comparison adjustment).

13A) Cancer in general

No simple overview of the epidemiology is possible because the epidemiologic techniques and the exposure assessment in the various studies are so different. Meta-analysis, a method for combining studies [L9], has been attempted [B4, B10, C54, C57], but the results are problematical because of a lack of consensus as to the correct way to measure exposure.

The following table summarizes the relative risks (RR) for the studies of residential exposure.

Cancer and Residential Exposure to Power Line Fields

Type of Cancer	Number of Studies	Median RR	Range of RR's
childhood leukemia	20+	1.20	0.80-1.90
childhood brain cancer	10+	1.20	0.80-1.70
childhood lymphoma	8	1.80	0.80-4.00
all childhood cancer	7	1.30	0.90-1.60
adult leukemia	6	1.15	0.85-1.65
adult brain cancer	5	0.95	0.70-1.30
all adult cancer	8	1.10	0.80-1.35

13B) Childhood leukemia

Most public and scientific attention has focused on childhood leukemia, with lesser attention given to adult leukemia, childhood and adult brain cancer, lymphoma and overall childhood cancer (see table in Q13A). The original studies which suggested an association between power lines and childhood cancer used a combination of the type of wiring and the distance to the residence as a surrogate measure of exposure, a system called "wire codes" [C1, C3, C6]. Other studies have used distance from transmission lines or substations as measures of exposure, and some studies have used contemporary measured fields or calculated historic fields. In general, the different methods of exposure assessment do not agree with each other, or with contemporary measured fields; none of these measures of exposure is obviously superior, and none is common to all the major studies (see figure below).

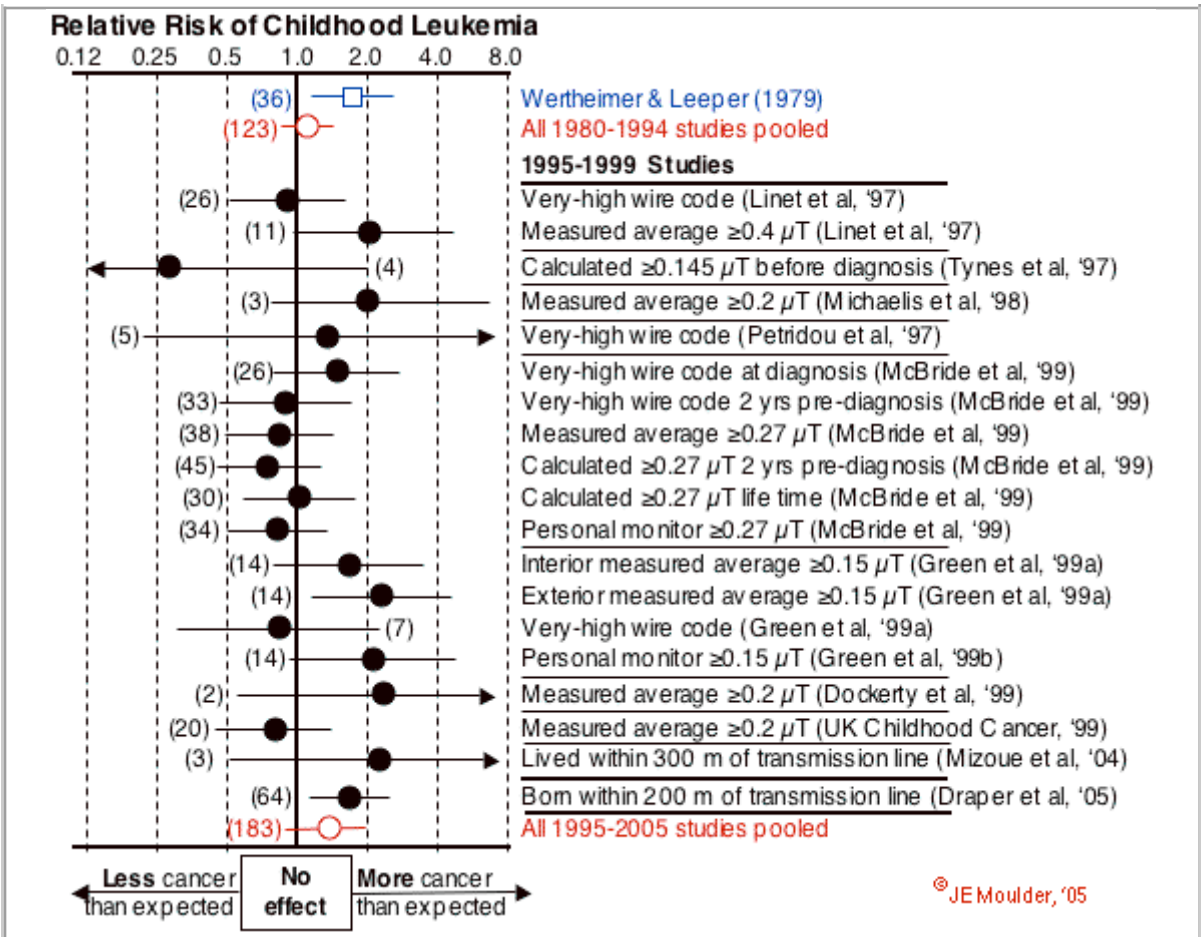
Historically, one of the more puzzling features of the childhood leukemia studies was that the correlation of "exposure" with cancer incidence appeared to be higher when wire codes or proximity to power lines were used as an exposure metric, than when fields were directly measured in the homes (see figure below). This led to the suggestion that the association of childhood cancer with residence near power lines might be due to a factor other than the power-frequency field (such as socioeconomic class). However, in 1997 and 1999 the largest studies to that date of power lines and childhood leukemia [C36, C45] found no association of leukemia with either wire codes or measured fields, and the more recent studies of brain cancer [C29, C30] have found no correlation with wire codes. These latest studies indicate that the "wire code paradox" does not actually exist.

The figure below shows the variety of endpoints that have been used in the childhood leukemia studies. Attempts to provide an overview of these diverse data have been frustrated by the fact that no "unique" analysis can be produced. Rather one gets a family of analyses based on different definitions of exposure, all of which exclude some of the studies, and no one of which can be assumed to be the best.

The childhood leukemia studies as a whole show no consistent association between residence near power lines and the incidence of leukemia. However, two meta-analyses published in 2000 [C54, C57,C72] found that if certain reports were pooled and certain exposure metrics were chosen, there appeared to be an increased incidence of leukemia in the highest exposure group.

- Ahlbom et al [C54] reported that if the nine studies that included long-term measurements of magnetic fields were pooled, a statistically significant association (relative risk = 2) could be found for childhood leukemia in the children with average exposures of 0.4 microT or greater. For children with lower average exposures, no significant elevation of childhood leukemia was found in the pooled studies. Average magnetic fields of greater than 0.4 microT are found in about 0.8% of homes [C54]. If this analysis is taken literally, then exposure to power-frequency magnetic fields could account for about 1% of childhood leukemia deaths (that is, 6-8 cases per year in the United States).
- Greenland et al [C57] reported that if the 15 studies for which magnetic fields were measured (or could be estimated) were pooled, a statistically significant association (relative risk = 1.7) could be found for childhood leukemia in the children with average exposures of 0.3 microT or greater. For children with lower average exposures, no significant elevation of childhood leukemia was found in the pooled studies. According to the authors this data indicates that exposure to power-frequency magnetic fields could account for 1-6% of childhood leukemia deaths in the United States (this number is called the "attributable fraction"). In a 2004 followup [C72], Greenland reported that if all the uncertainties are taken into account the association is no longer statistically significant. Specifically the "attributable fraction" is now estimated to be between -1% and +9%.

Estimated Relative Risk of Childhood Leukemia



Relative risks are shown with 95% confidence intervals and the expected number of exposed cases (a measure of the statistical power of the study) is shown in parentheses. Where more than one exposure cut-point was used by the authors, the highest cut-point with more than 5 expected exposed cases is shown. The summary weights each study on the basis of the numbers of expected exposed cases, and treats all exposure measures equally. Pooled 1980-1994 data is from Moulder [A4].

In a 2003 review of the epidemiology and laboratory studies relevant to whether power-frequency electric or magnetic fields could be a risk factor for childhood leukemia, Brain et al [A17] concluded that:

> "Epidemiological associations between [power-frequency electric or magnetic fields] 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. 'Contact voltages' have been proposed as a novel exposure metric..."
> [see 21B for a discussion of the "contact voltage" theory]"

In a 2003 review of the epidemiology and laboratory studies relevant to whether power-frequency electric or magnetic fields could be a risk factor for childhood leukemia, Linet et al [A18] concluded that:

> "After publication of results from relatively small investigations linking... measures of residential 60-Hz power-frequency magnetic fields with small increases in risk of childhood leukemia, data from rigorous large epidemiologic investigations using more sophisticated exposure assessment methods... did not support a causal relationship... When data from several epidemiologic studies were combined or pooled, childhood leukemia risks did not increase steadily with increasing residential magnetic field or wire code levels (i.e., no consistent dose response); instead, risks did not increase with increasing exposure until estimated magnetic field exposure reached [greater than] 0.3 microT. In the pooled analysis, a very small proportion of children with high residential

> magnetic field exposures had modest excess risks of leukemia (i.e., the strength of association was weak). The results of experimental studies did not support the biological plausibility of the association... Finally, some of the modest increase in risk among US children was likely attributable to selection bias...Results of post-hoc [after the fact] analyses should be interpreted cautiously and questioned, because such results can be based on cutoff points that would yield the most extreme outcomes."

In a 2003 review of the epidemiology and laboratory studies relevant to whether power-frequency magnetic fields could be a risk factor for childhood leukemia, Ahlbom and Feychting [A19] concluded that:

> "Given the small amount of energy that is deposited in connection with exposure to ELF fields, any health effects due to weak long-term exposure would have to be produced by a to-date unknown biophysical mechanism..."
>
> "To date, close to 20 studies on childhood cancer and residential exposure to ELF fields have been published. The studies have generally been of increasing methodological strengths... To assess the overall evidence, a pooled analysis was carried out based on primary data from the subgroup of nine studies fulfilling certain quality criteria. The principal finding of the pooled analysis was that residential magnetic field exposure in excess of 0.4 μT was associated with about a doubling in the relative risk of childhood leukaemia. It was concluded that chance was an unlikely explanation, but that systematic error could explain some of the observed excess risk..."
>
> "In parallel with the epidemiological research, extensive in vivo and in vitro research has also been carried out. Despite intense efforts, this has not resulted in the detection of any new mechanisms of interaction between ELF fields and the human body beyond the induction of electric current, nor a strong candidate for such a mechanism. As a consequence, the epidemiological evidence stands alone..."
>
> "Over the years, the childhood leukaemia results have increased in strength. At the same time, the exposure level above which effects are seen has been pushed upwards, implying that only a small proportion of homes are exposed at those levels. Based on the combined control groups in the pooled analysis, this percentage was estimated at less than 1%, and considerably less in the European subset. The evidence for other diseases seems instead to have decreased in strength over the years..."

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14) How close do you have to be to a power line to be considered exposed?

The studies that show an association between cancer and power lines do not provide any consistent guidance as to what distance or exposure level might be associated with increased cancer incidence. The studies have used a wide variety of techniques to measure exposure, and they differ in the type of lines that are studied. The US studies have been based predominantly on neighborhood distribution lines, whereas the European studies have been based strictly on high-voltage transmission lines and/or transformers.

Since no human health hazards from residential exposure to power-frequency fields have been proven to exist, it is impossible to rationally define a **safe distance** or **safe exposure level**. To develop a rational (science-based) human safety standard, it is necessary to have a specific confirmed or strongly suspected hazard to protect people from. It is also necessary to have some concept of the mechanistic basis for the hazard, so that there is a rational basis for deciding what to measure.

Field measurements: A number of studies have measured power-frequency fields in residences [C6, C7, C12, C18, C21, C30, C35, C36, C45, C46, C47, C59]. Both one-time (spot), peak, 24-hour and 48-hour average measurements have been made. Two of the studies [C47, C59] using measured fields have shown a statistically-significant relationship between exposure and childhood leukemia. No other types of cancer in either adults of children have been show to be associated with measured fields.

A report published in 2000 by Ahlbom et al [C54] calculated that if all the studies that included long-term measurements of magnetic fields were pooled, a statistically significant association could be found for children with 24-48 hr average exposures of 0.4 microT or greater. A second study published in 2000 by Greenland et al[C57] reported that if all the studies for that included estimated or measured magnetic fields were pooled, an association could be found for children with exposures of 0.3 microT or greater. A 2004 analysis by Greenland [C72] indicates that the association reported in 2000 is not statistically significant. No elevation of childhood leukemia was found in either analysis for children with average exposures below 0.3 microT.

A 2002 report [C64] found that measured electric fields had no significant association with overall childhood cancer or with any subtype of childhood cancer including leukemia, lymphoma or brain cancer.

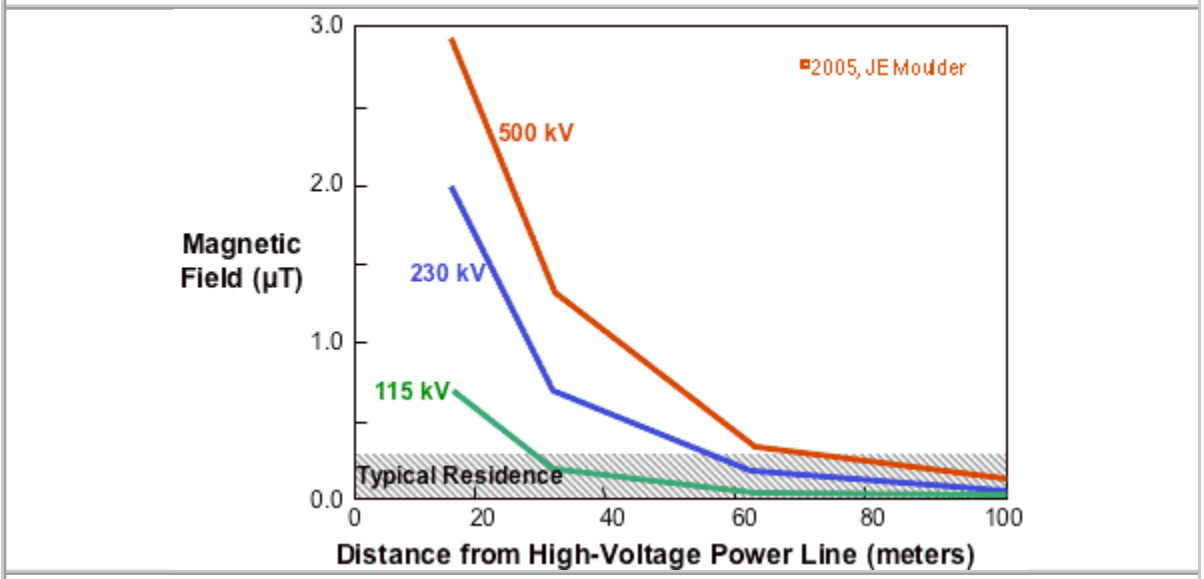
Distance from lines: Many studies have used the distance from the power line to the residence as a measure of power-frequency fields [C4, C5, C9, C10, C13, C18, C20, C21, C33, C34, C53, C58, C74]. Four [C5, C18, C33, C74] of these studies have shown an association between distance from transmission lines and cancer rates. On particular note are:

- 1993: A childhood cancer study [C18] reported an increase in leukemia incidence for residence within 50 m of

high-voltage transmission lines.
- 1997: An adult study [C33] reported an increase in leukemia incidence for residence within 100 m of high-voltage transmission lines.
- 2000: A childhood cancer study [C58] found no association with any kind of cancer in children living within 50 m of power lines or substations.
- 2005: A childhood cancer study [C74] reported an increase in leukemia incidence for birth addresses within 600 m of high-voltage transmission lines. See Q19N for a further discussion of this study.

If there is a human health hazard from residential exposure to power-frequency fields it is highly unlikely to depend on anything as simple as the distance of the residence from the nearest powerline. Depending of the type of line and its current, magnetic fields from power lines become less than those produced by the typical residence at a distance of 20-70 meters (see figure below).

Power-Frequency Fields and Distance from High-Voltage Power Lines



Power-frequency fields and distance from high-voltage power lines in comparison to typical fields in residences that are not near high-voltage power liens. Data is from the US National Research Council [A1].

Wire codes: The original US power line studies used a combination of the type of wiring (distribution vs transmission, number and thickness of wires) and the distance from the wiring to the residence as a surrogate measure of exposure [C1, C2, C3, C6, C7, C12, C29, C30, C36, C45, C46, C47]. This technique is known as "wire coding" [F13]. Three studies using wire codes [C1, C6, C12] have reported a relationship between childhood cancer and "high-current configuration" wire codes. Two of these studies [C6, C12] failed to show a relationship between exposure and cancer when actual measurements were made, the third study [C1] made no actual measurements. The more recent studies of wire codes and childhood cancer [C29, C30, C36, C45, C46, C47] have found no significant associations.

Wire codes are stable over time [F4], but correlate poorly with measured fields [A1, F4, F5, F13]. The wire code scheme was developed for urban areas in the U.S., and is not readily applicable elsewhere. Wire codes correlate strongly with things that have nothing to do with magnetic fields (such as age of houses, traffic density and socioeconomic status) [C40].

Calculated Historic Fields: Some studies have used utility records and maps to calculate what fields would have been produced by high voltage power lines in the past [C15, C16, C18, C21, C27, C32, C33, C34, C45]. These calculated exposures explicitly exclude contributions from other sources such as distribution lines, household wiring, or appliances. There is no way to check the accuracy of these calculated historic fields. See Jaffa et al [F26] for a discussion of some of the reasons to question the accuracy of these calculations.

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15) What is known about "electrical occupations" and cancer rates?

Some studies have reported that people who work in some electrical occupations have higher than expected rates of some types of cancer. The original studies were only of leukemia. Some later studies also implicated brain, lymphoma and/or breast cancer. As with the residential studies, the associations found are weak, there are many negative studies, and there are no consistent

dose-response relationships. Additionally, many these studies are based on job titles, not on measured exposures.

Meta-analysis [L9] of the occupational studies is even more difficult than for the residential studies. First, a variety of epidemiologic techniques are used, and studies using different techniques should not be combined. Second, a wide range of definitions of "electrical occupations" are used, and very few studies actually measured exposure. Lastly, there is little consensus as to the appropriate exposure metric. The following table summarizes the relative risks for the studies of occupational exposure.

Epidemiological Studies of Cancer and Occupational Exposure to Power-Frequency Fields

Type of Cancer	Number of Studies	Median RR	Range of RR's
leukemia:	about 45	1.20	0.80-2.10
brain:	about 35	1.15	0.90-1.90
lymphoma:	about 12	1.20	0.90-1.80
lung:	about 15	1.05	0.65-1.45
female breast:	about 10	1.10	0.85-1.50
male breast:	about 10	1.25	0.65-2.80
all cancer:	about 15	1.05	0.85-1.15

Also see Q19 and the reviews by Kheifets et al [B9] and Ahlbom et al [B12].

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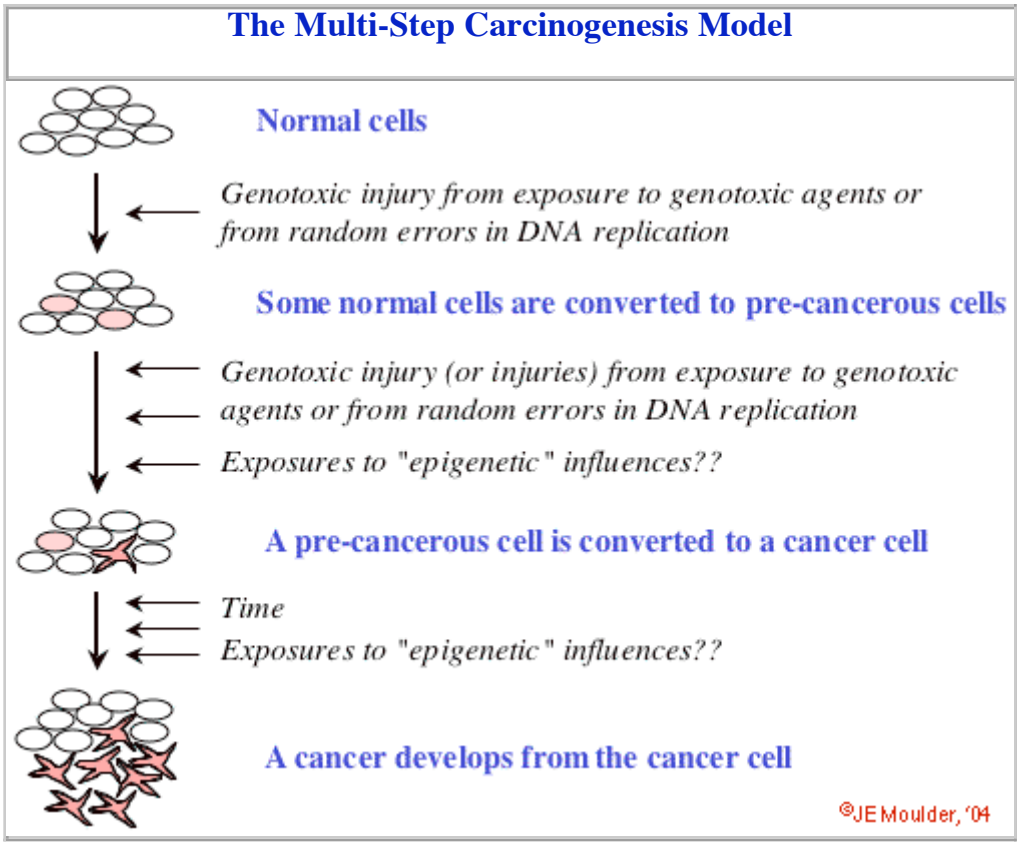
16) Do laboratory studies indicate that power-frequency fields can cause cancer?

While the causes of specific cancers in individuals are still poorly understood, the mechanisms of carcinogenesis are sufficiently well understood that cellular and animal studies can provide information relevant to determining whether an agent causes or contributes to cancer [A2, A4, L13, L15]. Current research indicates that carcinogenesis is a multi-step process driven by a series of injuries to the genetic material of cells. Not surprisingly, this model of carcinogenesis is referred to as the **multi-step carcinogenesis model**.



This multi-step model replaced an earlier model, called the **initiation-promotion model**. The initiation-promotion model proposed that carcinogenesis was a two-step event, with the first step being a genotoxic injury (called **initiation**) and the second step being a non-genotoxic event (called **promotion**). It is now clear that this two-step model was too simple. In particular, it is clear that multiple genotoxic injuries are involved in many (in not all) types of cancer; and that promotion may not be involved in all types of cancer.

Our current understanding of cancer is that it is initiated by damage to the genetic information of a cell (the DNA). Agents which cause such injury are called **genotoxins**. It is extremely unlikely that a single genetic injury to a cell will result in cancer; rather it appears that a series of genetic injuries are required. Genotoxic carcinogens may not have thresholds for their effect; so as the dose of the genotoxin is lowered the risk of cancer induction gets smaller, but it may never reach zero. Genotoxins may affect many types of cells, and may cause more than one kind of cancer. Thus, evidence for genotoxicity of an agent at any exposure level, in any recognized test for genotoxicity, is relevant to assessing carcinogenic potential in humans [A4, A2, L13, L15].

There are many approaches to measuring genotoxicity:

- **Studies of occupational-exposed humans** can be done to look for genotoxic injury in white blood cell (Q16A).
- **Animal exposure studies** can be used to see whether exposure causes cancer, mutations or chromosomal injury in mammalian or non-mammalian systems (Q16B).
- **Cellular studies** can be done to detect DNA or chromosomal damage (mammalian or non-mammalian systems, see Q16C) or to detect neoplastic cell transformation (mammalian systems, see Q16D).

There are also many different types of laboratory tests that can be used to look for evidence of genotoxic activity:

Laboratory Tests for Genotoxic Activity

Test	Description
Cancer induction (in vivo)	Animals are exposed to an agent for long periods of time (often for lifetime) and examined for an increase in cancer.
Mutagenesis (in vivo)	Animals are exposed to the agent and then mated, and their offspring are examined for inherited defects. Alternatively, the off-spring are examined for changes in the sex ratio, since mutations are more likely to kill male than female offspring.
Mutagenesis (in vitro)	Cells are exposed to an agent, and their progeny (daughter cells) are examined for inherited changes.
Sister chromatid exchanges, SCEs (in vivo or in vitro)	Test for the presence of breakage and rejoining of pieces of chromosomes. The test can be applied to white blood cells from exposed organisms (including humans) or to cells exposed in cell culture.
Micronucleus formation (in vivo or in vitro)	Test for the presence of pieces of chromosomes that have become detached as a result of damage to the genetic apparatus of the cell. The test can be applied to white blood cells from exposed organisms (including humans) or to cells exposed in cell culture.
DNA strand breaks (in vivo or in vitro)	Test for the presence of breaks in the genetic material of cells (the DNA), as opposed to breaks in the chromosomes.
Cell transformation (in vitro)	Tests for whether cells growing in cell culture undergo a set of changes when exposed to an agent that resemble their response to a carcinogen. These changes include loss of density-dependent inhibition of cell growth (loss of "contact inhibition") which causes cells to pile up ("focus formation"), and acquisition of the ability to grow in soft agar ("anchorage-independent cell growth").

Non-genotoxic (**epigenetic**) agents can contribute to the development of cancer, even though they may not be able to cause cancer by themselves. Epigenetic agents (**non-genotoxic carcinogens**) affect carcinogenesis indirectly, by increasing the probability that other genotoxic agents will cause genotoxic injury, or that genotoxic injury caused by other agents will lead to cancer. For example, an epigenetic agent might inhibit repair of potentially-genotoxic damage, affect the DNA in such a way as to make it more vulnerable to genotoxic agents, allow a cell with genotoxic injury to survive, or stimulate cell division in a previously non-dividing cell that had genotoxic injury [A2, A4, L13, L15].

The actions of epigenetic agents may be tissue- and species-specific, and evidence exists that epigenetic agents have thresholds for their effects. Thus evidence that an agent has epigenetic activity must be evaluated carefully for its relevance to human carcinogenicity under real-world exposure conditions. This is significant for the issue of possible cancer risks from power-frequency fields, as the evidence, to the extent that it implicates such fields at all, suggests an epigenetic rather than genotoxic mechanism [A2, L13, L15].

Promoters are a specific class of epigenetic agents. In a **classical promotion assay**, animals are exposed to a known genotoxin at a dose that will cause cancer in some, but not all animals. Another set of animals are exposed to the genotoxin, plus the agent to be tested for promotional activity. If the agent plus the genotoxin results in more cancers than are seen for the genotoxin alone, then that agent is a promoter. Promotion assays are discussed in Q16E. Some types of cellular studies are relevant to the carcinogenic potential of agents, but are neither classic genotoxicity nor promotion tests. For example, cellular systems have been used to test whether an agent enhances the activity of known genotoxins, or whether an agent inhibits repair of DNA damage. These **cellular studies of epigenetic activity** can be regarded as the cellular equivalent of a promotion study, and are discussed in Q16D and Q16F.

16A) Do power-frequency fields show genotoxic activity in humans?

In studies which blur the boundary between epidemiology and laboratory science, the white blood cells (lymphocytes) from workers with occupational exposure to an agent can be examined for chromosome aberrations, sister chromatid exchanges (**SCE**s) or micronuclei formation. The interpretation of these studies is complex, as they have all of the problems of exposure assessment, confounding and bias that characterize epidemiological studies. A number of such studies have been published [A4, E15]. At first glance these studies appear very contradictory with some studies reporting "significant" effects and others not.

A major statistical issue that must be considered is that all of the studies examine multiple endpoints and subgroups, creating a massive multiple comparison problem (see Q21E). Skyberg et al [E7], for example, reports chromosomal damage in exposed workers; but this increase was found in only one subgroup, only for one of several assays, and has a p-value of only 0.04. With any adjustment for multiple comparison, the statistical significance of the genotoxicity effect reported by Skyberg et al vanishes. The multiple comparison problem also applies to the "positive" findings reported by Valjus et al [E6].

Even with the multiple comparison problems, several patterns emerge. The effects that are reported are predominantly seen in smokers, groups in which excess chromosomal abnormalities are expected. The effects are also seen predominantly in workers exposed to spark discharges [spark discharges are a phenomena that is unique to the electrical environment of high-voltage sources, where electric fields can reach intensities of up to 20 kV/m, and body currents can reach several amps. Finally, the reported increases are limited to increased chromosomal aberrations, with no effects on SCEs; this is somewhat surprising, as the SCE assay is generally considered to be more sensitive to genotoxic agents than the chromosome aberration assay.

In summary, the cytogenetic studies of workers exposed to strong power-frequency electric and magnetic fields provides no consistent evidence that these fields are genotoxic. The unreplicated evidence for genotoxic effects is largely confined to current and former smokers, and to workers exposed to spark discharges.

16B) Do power-frequency fields cause cancer (or genetic damage) in animals?

Animal carcinogenesis studies

Since 1997, over a dozen studies have been published that looked at cancer in animals that were exposed to power-frequency for all of, or most of, their lives. These studies have found no evidence that power-frequency fields cause any specific types of cancer in rats or mice. The types of cancer that have been evaluated include:

- **Total cancer:** Yasui et al [G58], Mandeville et al [G59], McCormick et al [G65], Boorman et al [G64]
- **Leukemia:** Bellossi et al [G12], Rannug et al [G20], Yasui et al [G58], Mandeville et al [G59], McCormick et al [G65], Boorman et al [G64], Vellejo et al [G104]
- **Lymphoma:** Fam and Mikhail [G46], Yasui et al [G58], Harris et al [G62], McCormick et al [G31], McCormick et al [G65], Boorman et al [G64], Babbitt et al [G77], Sommer and Lerchl [G120]
- **Lung cancer:** Rannug et al [G20], Mandeville et al [G59], Yasui et al [G58]
- **Skin cancer:** Rannug et al [G20], Yasui et al [G58]
- **Breast cancer:** Beniashvili et al [G14], Yasui et al [G58], Mandeville et al [G59], McCormick et al [G65], Boorman et al [G64]
- **Brain cancer:** Yasui et al [G58], McCormick et al [G65], Boorman et al [G64], Kharazi et al [G81]

1991: Bellossi et al [G12] exposed leukemia-prone mice to 6000 microT fields for 5 generations (lifetimes) and found no effect on leukemia rates. The study used 12 and 460 Hz pulsed fields, so the relevance of this to power-frequency exposure is unclear.

1991: Beniashvili et al [G14] reported that exposure of mice for two years at 20 microT resulted in an increased incidence of mammary tumors. The study is difficult to assess, as it was reported with incomplete information about exposure conditions and experimental design.

1993: Rannug et al [G20] reported that exposure of mice for 2 years to 50 and 500 microT fields did not significantly increase the

incidence of skin tumors, lung tumors, or leukemia.

1996: Fam and Mikhail [G46] reported that mice exposed for three generations to a 60-Hz field at 24,000 microT had an increased incidence of lymphoma. The experiments were not conducted blind (that is, the experimenters knew which animals had been exposed and which had not), and the controls may not have been housed under conditions comparable to those of the exposed animals. When these data were presented at scientific meetings, concerns about noise, hyperthermia (overheating) and vibration were raised.

1997: Yasui et al [G58] reported the absence of increased cancer incidence and mortality in male and female rats after two years of exposure to 50-Hz fields at 500 and 5000 microT. In addition to finding no changes in overall cancer rates, they found no differences in the rates of individual types of cancer, including leukemia, lymphoma, brain cancer and breast cancer.

1997: Mandeville et al [G59] reported that two years of exposure of female rats to 60-Hz fields at 2, 20, 200 or 2000 microT had no effect on survival, leukemia incidence, breast cancer incidence or other solid tumor incidence. In addition to finding no overall changes in survival or cancer incidence, Mandeville et al found no evidence for any dose-related trends in survival or cancer incidence.

1998-2004: Harris et al [G62] found that 1.5 years of exposure of lymphoma-prone mice to 50-Hz fields at 1, 100 or 1000 microT had no effect on lymphoma incidence. In addition to testing continuous exposure, Harris et al also showed that exposure of mice to intermittent (15 min on, 15 min off) fields at 1000 microT had no effect on lymphoma incidence. Similar results were reported by McCormick et al [G31], and by Sommer and Lerchl [G120].

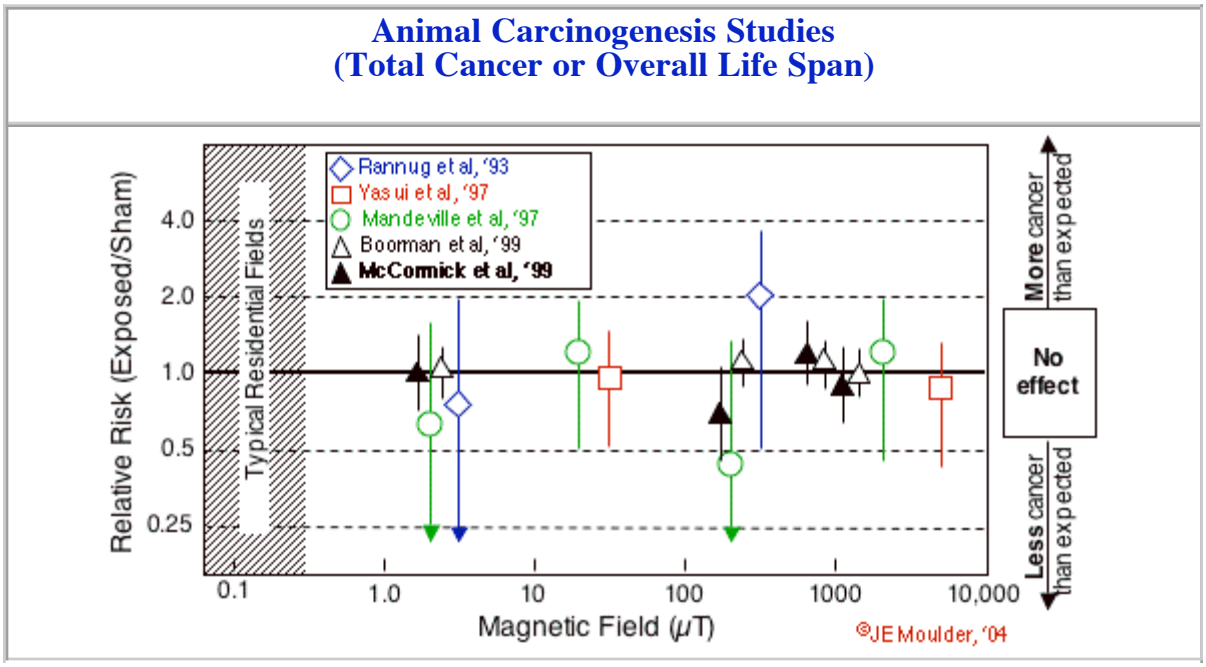
1999: The U.S. National Toxicology Program (NTP) reported that two years of exposure of mice (McCormick et al [G65]) and rats (Boorman et al [G64]) to 60-Hz fields at 2, 200 or 1000 microT had no effect on survival or cancer incidence. In addition to testing continuous exposure, NTP showed that exposure to intermittent (1 hr on, 1 hr off) fields at 1000 microT had no effect on cancer incidence. No effects on overall cancer, leukemia, brain cancer, lymphoma or breast cancer were observed, and no exposure-response trends were found.

1999: Kharazi et al [G81] reported that life-time exposure of mice to a 1420 microT field had no effect on brain tumor incidence.

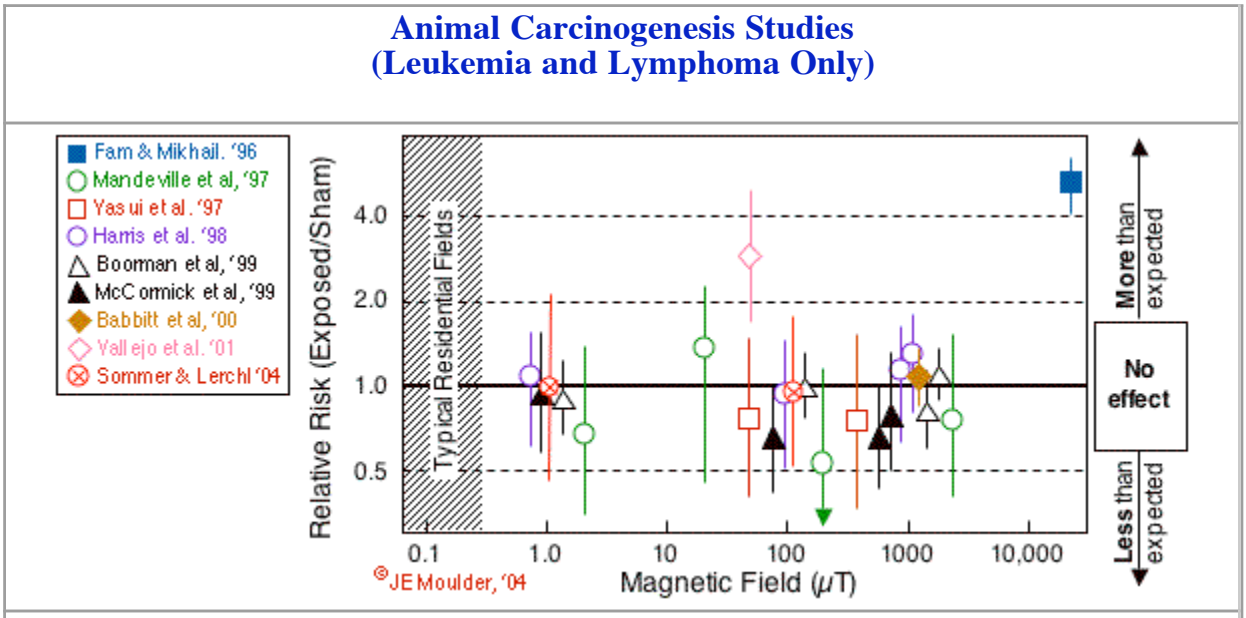
2000: Babbitt et al [G77] reported that life-time expose of mice to a 1420 microT field had no effect on lymphoma incidence. The study also found that this field had no effect on the incidence of lymphoma induced by ionizing radiation (see Q16E).

2001: Vellejo et al [G104] reported that exposure of mice for 15 or 52 weeks to a 50-Hz field at 15 microT resulted in a significant increase in leukemia.

The long-term animals exposure studies with power-frequency fields are summarized in the following figures.



Animal carcinogenesis studies that 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. Typical 24-hour average residential fields are shown for comparison [F5, F14].



Animal carcinogenesis studies that assessed lymphoma and/or leukemia. The figure shows the ratios (exposed/sham) of the number of animals with lymphoma or leukemia at the end of the experiment. All data are shown with 95% confidence intervals. Typical 24-hour average residential fields are shown for comparison [F5, F14]. Also see Boorman et al [K4] for a summary of these studies.

Whole organism mutagenesis and genotoxicity studies

Whole organism exposure studies can be relevant to carcinogenic potential even when the end point is not cancer. The ability of an agent to cause mutations or chromosome aberrations in an organism is an indication that the agent is genotoxic, and hence potentially carcinogenic. Such whole animal studies include:

- 1987: Benz et al [G4] reported that mice exposed for multiple generations 300 microT (plus 15 kV/m) or 1,000 microT (plus 50 kV/m) showed no increase in mutation rates, fertility, or sister chromatid exchanges (SCEs).
- 1993: Zwingelberg et al [G21] reported that exposure to a 30,000 microT field did not increase SCE rates.
- 1995: Kowalczuk and Saunders [G37] reported that mice exposed to 10,000 microT fields showed no increase in mutations.
- 1998: Kikuchi et al [G88] reported that exposure of fruit flies to 500 or 5000 microT fields for 40 generations had no effect on the mutation rate.
- 2001: Abramsson-Zetterberg and J Grawé [G99] found no evidence of chromosome injury in adult or fetal mice exposed for 18 days to a 14 microT power-frequency field.
- 2004: Heredia-Rojas et al [G114] reported that exposure of mice to a 2000 microT 60-Hz field (24 hrs/day for 3 days or 8 hrs/day for 10 days) did not cause chromosome damage to their germ cells.

The only positive reports of genotoxicity from whole organism studies are of DNA strand breaks in brain cells of rats [G52,G116] and mice [G100] that had been exposed to 10-500 microT fields. It is difficult to determine what weight to give these studies in a cancer risk evaluation for an number of reasons:

- In 2002, McNamee et al [G102] reported that they could find no evidence for such genotoxic injury in the brain cells of immature mice that had been exposed to a 1000 microT field.
- Seven of eight attempts to detect DNA strand breaks after exposure of cultured mammalian cells to power-frequency fields have failed to find any significant excess (see Q16C section on DNA strand breaks).
- The group reporting DNA strand breaks in rat brain cells after exposure to power-frequency fields [G52,G116] have also reported similar effects after exposure of rats to radio-frequency (RF) energy and the RF claim has failed multiple independent confirmation attempts. See Q23C of Cell Phone Base Antennas and Human Health FAQs for details.

- Finally, four different groups (Yasui et al [G58], McCormick et al [G65], Boorman et al [G64], Kharazi et al [G81]) have found that prolonged (near lifetime) exposure of rodents to more intense power-frequency fields does not cause brain cancer. This implies that the DNA strand break reports are either an experimental artifact, or that the DNA strand breaks do not have any long-term carcinogenic consequences for the animals.

In summary, the long-term animals exposure studies conducted to date provide no confirmed evidence that long-term exposure to power-frequency fields causes cancer in animals and no consistent evidence that they cause genotoxic injury in animals. Also see What's New.

16C) Do power-frequency fields show genotoxic activity in cell culture?

Cellular genotoxicity studies of power-frequency fields have been massive in scope. Published studies have spanned many different models, from plasmids and bacteria to human cells. All major genotoxicity endpoints have been assessed in multiple models and multiple labs. A wide range of exposure conditions have also been assessed, including combined electric and magnetic fields, pulsed as well as sinusoidal fields, non-power-frequency fields and field intensities ranging from less than 1 microT to greater than 1000 microT.

Mutagenesis assays: Studies using a wide range of exposure conditions and assay systems have shown that power-frequency fields are not generally mutagenic. Six studies have found that power-frequency electric and magnetic fields are not mutagenic in bacteria or yeast [A4, G94, G119]. Studies of power-frequency fields and mutagenesis in mammalian cells done at field intensities of 50,000 microT and below have also been negative [A4, G76, G85, G87]; but some studies [G49, G76] have suggested that 400,000 microT fields may be mutagenic.

Chromosome aberration assays: Of 15 studies of the ability of power-frequency fields to cause chromosome aberrations, 12 [A4, G33, G35, G68, G89, G92, G112, G115, G121, G123] have found no consistent evidence of genotoxic effects. The remaining three studies showed some unreplicated evidence that power-frequency fields could cause chromosome aberrations. In 1984, Nordenson et al [E2] reported that exposure of human lymphocytes to spark discharges caused chromosome aberrations; but in 1995, Paile et al [G35] found no evidence for this effect. In 1991, Khalil and Qassem [G15] reported that a pulsed 1050 microT field caused chromosome aberrations in humans lymphocytes, but a similar 1994 study by Scarfi et al [G33] found no such effect. Finally, in 1994 Nordenson et al [G29] reported that exposure of mammalian cells to an intermittent 30 microT field caused chromosome aberrations, but that continuous exposure did not.

Sister chromatid exchanges (SCEs): Of the 12 studies of the ability of power-frequency fields to cause SCEs, 11 [A4, G92, G95, G111, G115, G123] have found no evidence of genotoxic effects. The only "positive" study is Khalil and Qassem [G15] who reported in 1991 that a pulsed 1050 microT fields caused an increase in SCE's in humans lymphocytes; the study has never been replicated.

DNA strand breaks: Of the 11 studies of the ability of power-frequency fields to cause DNA strand breaks in cultured mammalian cells, 9 have found no evidence of genotoxic effects [A4, G92, G97, G103, G115, G123, G124]. One study [G108] reported that exposure to a 50-Hz field caused DNA strand breaks if the exposure was intermittent, but not if the exposure was continuous. Another study [G125] reported that 24 or 72 hours of exposure to a 50 Hz field at 750 or 1000 microT caused DNA damage, but 48 hr exposures or exposures at 500 microT did not.

DNA repair: If power-frequency fields damaged DNA you would expect to see the activity of DNA repair genes and enzymes to increase. In 2003, Nakasono et al [H58] reported that yeast cells exposed to 50-Hz fields at 10,000-300,000 microT showed no significant changes in the activity of genes or proteins that are involved in DNA repair.

Micronucleus formation assays: Of the 18 studies of the ability of power-frequency fields to enhance micronucleus formation, 11 [A4, G57, G101, G105, G110, G111, G115, G123] found no evidence for such effects. The recent (post-1997) positive reports include:

- 1998-2001: Simkó et al [G69, G86] reported that 48-72 hours of exposure to 800-1000 microT fields enhanced micronucleus formation in human tumor cells, but that no such effects were found for lower field intensities, shorter exposure times or in normal human cells. In a separate study [G71], they reported that 1000 microT fields enhanced micronucleus formation under some conditions, but not under many others. Later [G101] they reported that a 1000 microT power-frequency field did not enhance micronucleus formation in normal cells. The scattered positive genotoxicity results reported by Simkó et al [G69, G71, G86, G101] show no obvious pattern, and their significance is difficult to assess.
- 2003: Pasquini et al [G118] reported that exposure of mammalian cells to a 50-Hz field at 5000 microT for 24 hrs caused chromosome damage, but a 1-hr exposure did not.

Pulsed fields: A number of studies have also examined pulsed power-frequency fields. Pulsed fields do not cause leukemia in

leukemia-prone mice [G12], do not cause mutation in bacteria [G18, G54] or mammalian cells [G18], do not cause SCEs [G5, G15], do not cause DNA strand breaks [G32], do not cause micronucleus formation [G33], and do not cause cell transformation [G54]. One study has reported that 1050 microT pulsed fields cause chromosome aberrations [G15], but the report cannot be replicated [G33, G54].

Late in 2004, the European Union released a report summarizing cellular studies of the genotoxic potential of both power-frequency fields and radiofrequency energy (the REFLEX report) [G122]. Some evidence for genotoxicity was seen under some conditions and for some endpoints in some cell lines. Most of the work has not yet appeared in the peer-reviewed literature. In summary:

- The report covers multiple projects from at least 12 different groups looking at multiple endpoints (genotoxicity, proliferation, differentiation, apoptosis, gene expression) in cell culture.
- No animal studies are included.
- The exposures include both power-frequency fields and radiofrequency energy, in a wide range of exposure regimens.
- For power-frequency fields, some investigators report evidence of genotoxicity (DNA strand breaks and micronucleus formation) in some, but not all, cell lines.
- The increases in DNA strand breaks and micronucleus formation were dependent on dose, duration and frequency (tests covered 3-1000 Hz), with no obvious pattern.
- The minimum field intensity for the genotoxic effects appears to be in 35-70 microT range.
- The genotoxic effects seem to be for intermittent exposures only.
- All of the positive findings are contradicted by multiple previous peer-reviewed studies.
- Whether the positive findings were more common than expected from random chance is hard to tell (false positive rates from cellular genotoxicity tests can be as high as 20%).

The conclusion of the report is:

> "Taken together, the results of the REFLEX project were exclusively obtained in in vitro studies and are, therefore, not suitable for the conclusion that ELF-EMF exposure below the presently valid safety limits causes a risk to the health of people. They move, however, such an assumption nearer into the range of the possible. Furthermore, there exists no justification anymore to claim, that we are not aware of any pathophysiological mechanisms which could be the basis for the development of functional disturbances and any kind of chronic diseases in animal and man."

In a 2005 review of the cellular genotoxicity studies, Vijayalaxmi and Obe wrote [K6]:

> "Research on the potential genotoxic effects of [exposure to power-frequency fields] in mammalian cells has been underway for many years. Among the total of 63 reports published during 1990-2003, the conclusions from 29 investigations (46%) did not identify increased cytogenetic damage following [exposure to power-frequency fields] per se while those from 14 studies (22%) indicated a genotoxic potential... The observations in 20 other reports (32%) were inconclusive... Most of the reports that indicated an absence of genotoxic effect have described the exposure conditions and experimental protocols in detail so that the observations could be verified by independent researchers. The data are not in conflict with the other established characteristics of [power-frequency fields]. On the other hand, the interpretations presented for the presence of a genotoxic effect were not substantiated by experimental data. Considering the "weight of scientific evidence" approach for genotoxicity investigations, as adopted by [the International Agency for Research on Cancer], the preponderance of data thus far available in the literature shows that [exposure to power-frequency fields] per se is not genotoxic... in mammalian cells."

Summary of genotoxicity studies: There are over 70 published studies of power-frequency fields and genotoxicity that include over 200 separate tests for genotoxicity activity. These assays are overwhelmingly negative, despite the fact that many have used huge field strengths. Of the studies that do report evidence for genotoxicity, most contain either a mix of positive and negative results, or ambiguous results. Since most of these publications contains multiple sub-studies, the presence of some studies with positive or mixed results would be expected from random chance. Several of the positive reports of genotoxicity have failed direct attempts at replication. Many of the positive reports have also used exposure conditions (e.g., spark discharges, pulsed fields, fields of 20,000 microT and above) that are very different from those encountered in real-world exposure conditions. Also see What's New.

16D) Do power-frequency magnetic fields cause or enhance neoplastic cell transformation?

Cell transformation assays have been widely used to study mechanisms of carcinogenesis. In a transformation assay, normal cells (typically fibroblasts) growing in cell culture undergo a set of changes when exposed to a carcinogen. These changes include loss

of density-dependent inhibition of cell growth (loss of "contact inhibition") which causes cells to pile up ("focus formation"), and acquisition of the ability to grow in soft agar ("anchorage-independent cell growth"). The ability of an agent to induce transformation is a indication that the agent may be a genotoxic carcinogen. The ability of an agent to enhance transformation by a known carcinogen is an indication that the agent may have epigenetic activity.

1993-1994: Cain et al [G25] reported that a 60-Hz field at 100 microT did not induce transformation, but that the field enhanced transformation induced by TPA (a known promoter). However, at meetings in 1993 and 1994 Cain reported that the observation of enhanced TPA-induced transformation could not be repeated.

1994-1996: West et al [G30, H18] reported that 60-Hz fields induced cell transformation at field intensities from 1 to 1100 microT.

1996: Balcer-Kubiczek et al [G48] attempted to confirm the studies of West et al [G30, H18] (above) and found that a 200 microT 60-Hz field did not cause transformation in two different transformation models, even with co-exposure to TPA.

1997: Saffer et al [G56] attempted to confirm the studies of West et al [G30, H18] (above) and found that 60-Hz fields did not induce cell transformation at field intensities from 1 to 1100 microT, even with co-exposure to TPA.

1997: Jacobson-Kram et al [G54] have reported that pulsed magnetic fields do not cause cell transformation.

1999 Snawder et al [G74] attempted to confirm the studies of West et al [G30, H18] (above) and found that 100 and 960 microT fields did not induce cell transformation, even with co-exposure to TPA.

1999: In an assay that is closely related to the transformation assay, Gamble et al. [G80] showed that exposure to 10-1000 microT fields did not "immortalize" normal cells or enhance the ability of ionizing radiation to "immortalize" cells.

2000: Miyakoshi et al [G83] reported a lack of effect on cell transformation for fields of 5000 to 400,000 microT, but that these fields could inhibit transformation induced by ionizing radiation.

In summary, there is no replicated evidence that power-frequency fields can induce or enhance neoplastic cell transformation.

16E) Are power-frequency magnetic fields cancer promoters?

While the evidence that power-frequency fields do not induce cancer in animals is quite strong (see Q16B), there were some studies in the early-mid 1990's that suggested that exposure to power-frequency fields might make other carcinogens more effective in causing cancer (particularly breast and skin cancer). Such studies are called **promotion assays** (see Q16).

Promotion of mammary tumors

1991: Beniashvili et al [G14] reported that a 20 microT field could promote mammary tumors induced in rats by a chemical carcinogen (NMU). This study is difficult to evaluate, as critical experimental details are missing and no one has yet attempted to replicate it.

1993-2004: Löscher, Mevissen and colleagues [A4, G23, G34, G42, G43, G67, G79, G117] have conducted a series of breast cancer promotion studies in rats using a different chemical carcinogen (DMBA) (see Figure below). Some of these studies suggest that power-frequency magnetic fields enhanced chemically-induced breast cancer at field intensities as low as 100 microT. Interpretations of these studies is complicated by several factors (see also Boorman et al [K2] and Anderson et al [K5]):

1. The dose of DMBA used in most of these studies is so high that essentially all animals develop breast cancer, even without promotion. As a result, the studies must be stopped before all tumors induced by DMBA have appeared, making it difficult to distinguish between induction of more tumors (promotion) and an increase in the growth rate of the tumors.
2. The authors use multiple endpoints for determining the presence of a promoting effect. In all studies, they assess the number of animals that have macroscopically-visible tumors. In some studies, the animals have also been examined histopathologically for the presence of smaller tumors; and in some of those studies, promotion was observed that was not seen when only macroscopically-visible tumors were assessed. Conversely, at least one study which showed promotion based on macroscopically-visible tumors did not show promotion when the assessment was based on the histopathological determinations.
3. The authors often use a test for significance that assesses the time to development of tumors, rather than the number of animals with tumors. In some cases, the authors report that tumors develop sooner in the animals exposed to power-frequency fields even though the number of animals with tumors was not significantly different. While such an effect may indicate an influence on tumor growth, it is not evidence for promotion (see Q17A).
4. In 2004, Fedrowitz, Kamino and Löscher [G117] reported that 18 weeks of exposure to a 100 microT 50-Hz field resulted

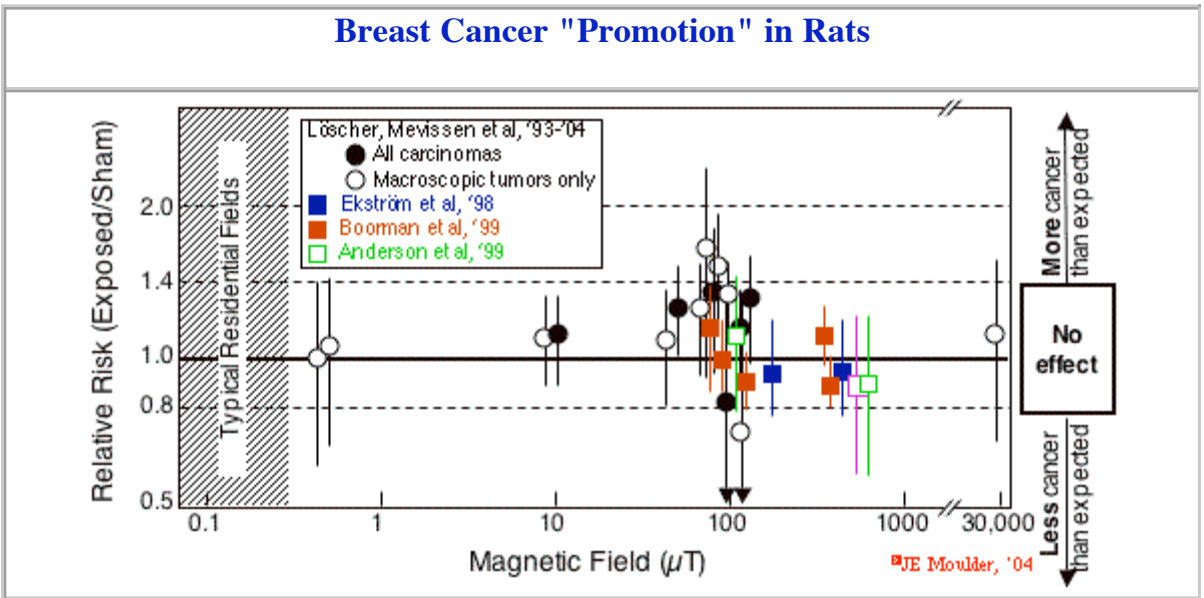
in an increase in chemically-induced breast cancer in one strain of rats and a decrease in a second strain. If the results from the two strains are combined, no overall breast cancer promotion is evident.

1998: Ekström et al [G61] reported on the first independent attempt to replicate the Löscher and Mevissen studies. They found no evidence of breast cancer promotion at either 250 or 500 microT.

1998: The U. S. National Toxicology Program (Boorman et al) [G66] reported on a second independent attempt to replicate the Löscher and Mevissen studies. NTP found no evidence of breast cancer promotion at either 100 or 500 microT, with 3-4 independent studies at each exposure level. .

1999: A third independent replication attempt by Anderson et al [G78] found no significant promotion of mammary tumors at either 100 or 500 microT.

See Boorman et al [K2] and Anderson et al [K5] for a detailed review of the animal breast cancer studies.



The breast cancer promotion studies of Löscher, Mevissen and colleagues [A4, G23, G34, G42, G43, G67, G79, G117], Ekström et al [G61], Boorman et al [G66], and Anderson et al [G78]. The figure shows the ratios (exposed/sham) of the number of rats with tumors at the end of each study (with 95% confidence intervals). Where Löscher, Mevissen et al reported data for both macroscopic and pathologically-confirmed tumors, both are shown. Typical 24-hour average residential fields are shown for comparison [F5, F14].

Promotion of skin tumors

Of nine published studies of promotion of chemically-induced skin cancer [A4, G70, G75, G109], only one [G38] has reported statistically-significant promotion. The negative studies have used field intensities from 40 to 2,000 microT and exposure durations from 21-105 weeks, have tested both continuous and intermittent fields, and have used both promotion and co-promotion endpoints. The one positive study, by McLean et al [G38], exposed animals to 2,000 microT fields for 30 hours per week for 52 weeks.

Kumin et al [G63] reported that exposure of rats to 100 microT fields for 10.5 months enhanced UV-induced skin carcinogenesis. In contrast, Heikkinen et al [G98] reported that life-time exposure of mice to 1-130 microT fields did not increase the incidence of skin cancer induced by X-rays.

See figure below for a summary of the skin cancer promotion data.

Promotion of lymphoma, brain and liver cancer:

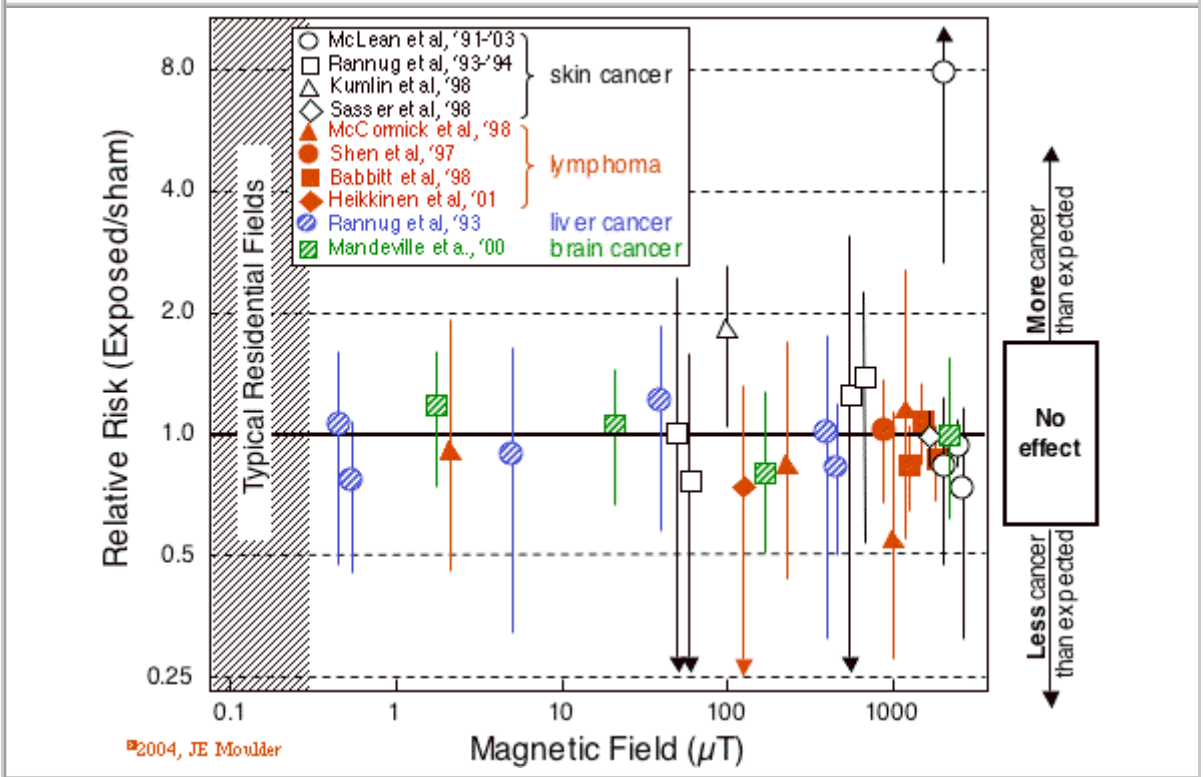
Studies of promotion of chemically-induced **lymphoma** by 2-1000 microT fields have found no evidence for promotion [G31, G53]. The two studies of promotion of lymphoma induced by ionizing radiation have also found no evidence for promotion at 130-1420 microT [G77, G98]. The Babbitt et al study [G77] is sufficiently large that promotion of lymphoma by greater than a factor of 1.10 can be ruled out.

Studies of promotion of chemically-induced **liver cancer** by 0.5 to 500 microT fields have found no evidence for such promotion [G24, G22].

Kharazi et al [G81] reported that life-time exposure of mice to a 1420 microT field did not promote **brain cancers** induced by ionizing radiation, however the number of brain tumors in all groups (exposed and unexposed) was very low. Mandeville et al [G82] reported that 65 weeks of exposure of rats to 60 Hz fields at 2-2000 microT did not promote chemically-induced brain cancer.

See figure below for a summary of the lymphoma, brain and liver cancer promotion data.

Promotion of Lymphoma, Liver Cancer, Skin Cancer and Brain Cancer in Animals



The vertical axis shows the ratio (exposed/sham) of the number of animals with tumors at the end of the experiment (except for the liver cancer promotion data where the ratio is the number of cancer foci at the end of the experiment). Skin tumor promotion data are from McLean and colleagues [A4, G109], Rannug et al [A4], Kumlin et al [G63], and Sasser at al. [G70]. Lymphoma promotion data are from Shen et al [G53], McCormick et al [G31], Babbitt et al [G77], and Heikkinen et al [G98]. Liver tumor promotion data are from Rannug et al [G22, G24]. Brain tumor promotion data are from Mandeville et al [G82]. All data are shown with 95% confidence intervals. Typical 24-hour average residential fields are shown for comparison [F5, F14].

Co-promotion

It has been suggested that power-frequency fields might be co-promoters; that is, that they could enhance the activity of other promoters, even though they have no genotoxic or promotional activity on their own. Published studies of co-promotion have shown little evidence for such activity [G10, G22, G26, G51, G70, G109].

Promotion vs. growth enhancement

Interpretation of the tumor promotion studies is complicated by the observation in several studies that exposure to power-frequency fields appears to speed the growth of chemically-induced tumors, or decrease the latent period for their appearance, rather than increase the actual number of tumors. Such an effect on growth would be of interest if it occurred at the field intensities to which people were actually exposed, but it would not be evidence for promotion [see Q17A].

Summary of promotion studies

There is no independently confirmed evidence that power-frequency fields are promoters or co-promoters; and the few studies that have shown evidence for promotion have used field intensities far above those encountered in real-world settings. Also see What's New.

16F) Do power-frequency magnetic fields enhance the effects of other genotoxic agents?

Inhibition of DNA repair

Six published studies of the ability of power-frequency fields to inhibit the repair of DNA damage [G8, G9, G16, G40, G45,G115] have found no evidence for such activity. These studies have used magnetic fields from 0.2 to 2500 microT, electric fields from 0.001 to 20 kV/m, and combined electric and magnetic fields. Both pulsed and sinusoidal fields have been assessed, and exposure durations have ranged from 10 minutes to 6 days.

Three other studies have reported that power-frequency fields could either enhance or inhibit DNA repair:

- 2000: Chow et al [G90] reported that 400-1200 microT fields could enhance the repair of chemically-induced DNA damage in bacteria (this is the opposite of what an epigenetic carcinogen would do).
- 2002: Robison et al [G107] reported that a 150 microT field inhibited repair of chemically-induced DNA damage in two out of three cell lines assessed.
- 2003: Takashima et al [G113] reported that exposure of yeast cells to a 30,000 microT field inhibited repair of DNA damage induced by UV-radiation.

Enhancement of genotoxicity

Of 27 published studies of the ability of power-frequency fields to enhance genotoxic damage produced by known carcinogens, 19 [A4, G57, G71, G76, G86, G87, G92, G94, G95, G105, G110, G112, G114, G115, G118, G121, G123] reported no consistent evidence for such activity.

The studies which showed some evidence for enhancement of genotoxic activity are:

- 1989: Rosenthal and Obe [G7] reported that 2500-5000 microT fields enhanced the cytogenetic damage produced in human lymphocytes by some chemical carcinogens; no such enhancement was seen at lower field intensities or for other chemical carcinogens.
- 1997: Lagroye and Poncy [G55] reported that a 100 microT field enhanced cytogenetic damage produced in two of three mammalian cell lines by high doses of ionizing radiation.
- 1999: Walleczek et al [G72] reported that a 230-700 microT enhanced mutagenesis produced in mammalian cells by ionizing radiation. In 2004, LLoyd et al [G121] reported that they could not confirm this effect.
- 1999-2000: Miyakoshi et al [G85, G97] reported enhancement of x-ray induced mutagenesis at 5000 to 400,000 microT.
- 2001: Simkó et al [G101] reported that a 1000 microT field could enhance micronucleus formation induced in normal cells by a chemical carcinogen.
- 2003: Cho and Chung [G111] reported that exposure of human lymphocytes exposed to a 800 microT field for 24 hours enhanced the amount of chromosome injury caused by the chemical carcinogen.
- 2004: Koyama et al [G119] reported that exposure of bacteria to a 5000 microT 60-Hz field enhanced the incidence of mutations induced by exposure to hydrogen peroxide.
- 2005: Moretti et al [G124] reported that exposure to human tumor cells to a 1000 microT field for 1 hour increased the frequency of DNA strand breaks caused by one of three benzene compounds.

Enhancement of neoplastic transformation see Q16D.

Other

In 2000, Chen et al [G91] reported that exposure of leukemia cells to 5-100 microT fields inhibited chemically-induced differentiation (an indicator of possible epigenetic activity); a 1993 study of the same system by Revoltella et al [Electro. Magnetobio. 1993; 12:135-146] had found no such effect at 200 microT.

Summary

In a 2005 review of the cellular studies of epigenetic potential, Vijayalaxmi and Obe wrote [K6]:

> "Research on the potential genotoxic effects of [exposure to power-frequency fields] in mammalian cells has been

> underway for many years... Among the 23 combination exposure investigations, the data from 10 studies did not identify epigenetic effects of [power-frequency fields], while the data from one study indicated such an effect. The results from 12 other reports were inconclusive... Considering the "weight of scientific evidence" approach...as adopted by [the International Agency for Research on Cancer] the preponderance of data thus far available in the literature shows little evidence for epigenetic influences [of power-frequency fields] in mammalian cells."

Thus there is little evidence that power-frequency fields have epigenetic activity in cell culture, and no evidence at all for epigenetic activity under real-world exposure conditions. Also see What's New.

16G) Could power-frequency *electric* rather than *magnetic fields* have genotoxic or epigenetic activity?

The magnetic fields associated with power lines, transformers and electrical appliances easily penetrate buildings or tissue and are difficult to shield. By contrast, power-frequency electric fields are easily shielded by conductive objects and have little ability to penetrate buildings or tissue. Because power-frequency electric fields have little ability to penetrate, it is generally assumed that any biologic effect from residential exposure to power-frequency fields must be due to the magnetic component of the field, or to the electric fields and currents that these magnetic fields induce in the body (for an opinion to the contrary, see King [F18] and Ashley [L18]). In addition, the epidemiology that suggests that power-frequency fields might be associated with some types of cancer implicates the magnetic, rather than the electric, component of the field (see Q19L). As a result, most laboratory research has focused on power-frequency magnetic rather than electric fields, although there are some [L18, F18] who advocate that the electric, rather than the magnetic fields might be causally associated with cancer incidence.

Nevertheless, there have been laboratory studies of the genotoxic and epigenetic potential of power-frequency electric fields and combined power-frequency electric and magnetic fields [A5].

Genotoxicity Assays: There have been over a dozen studies of whether power-frequency electric or electric plus magnetic fields have genotoxic activity. Within this body of work, there is no replicated evidence for genotoxicity. These studies include:

- Benz et al [G4]; Kowalczuk and Saunders [G13]: electric fields or electric plus magnetic fields are not mutagenic in mice.
- Morandi et al [G44]; Jacobson-Kram et al [G54]: electric fields or electric plus magnetic fields do not cause mutations in bacteria.
- Nordenson et al [E2]; Jacobson-Kram et al [G54]; Cohen et al [G2, G3]: electric fields or electric plus magnetic fields do not cause chromosome aberrations or SCEs in mammalian cells.
- Reese et al [G6]; Fiorani et al [G17]; Novelli et a [G11]; D'Agruma et al [G28]: electric fields or electric plus magnetic fields do not cause DNA strand breaks in mammalian cells.
- Scarfi et al [G19]: exposure of human lymphocytes to electric fields does not enhance micronucleus formation.
- Jacobson-Kram et al [G54]: electric fields do not cause transformation in mammalian cells.
- Nordenson et al [E2]: exposure of human lymphocytes to spark discharges caused chromosome aberrations, but Paile et al [G35] found no evidence for this effect in a replication study.

Assays for Epigenetic Activity: The studies of power-frequency electric or electric plus magnetic fields show no evidence of epigenetic activity. These studies include:

- Whitson et al [G1]: electric fields do not inhibit repair of DNA damage induced by UV radiation.
- Frazier et al [G9]: electric fields and electric plus magnetic fields do not inhibit repair of DNA damage induced by ionizing radiation.
- Cantoni et al [G40, G45]: electric fields and electric plus magnetic fields do not inhibit repair of DNA damage induced by peroxides, UV radiation or chemical carcinogens.
- Scarfi et al [G19]: exposure of human lymphocytes to electric fields does not increase the incidence of micronuclei induced by a chemical carcinogen.

For further details on these and other studies of power-frequency electric fields, see Moulder and Foster [A5].

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17) Do laboratory studies indicate that power-frequency fields have any biological effects that might be relevant to cancer?

There are biological effects other than genotoxicity and promotion that might be related to cancer. In particular, agents that have dramatic effects of cell growth, on the function of the immune system, or on hormone balances might contribute to cancer without meeting the classic definitions of genotoxicity or promotion [A2, A4].

17A) How do studies of cell and tumor growth relate to the question of cancer risk?

There have been some reports that power-frequency fields might affect cell or tumor growth. Many essentially harmless agents (e.g., temperature, pH, nutrients) affect the growth rates of cells and tumors, so effects of cell growth, by themselves, are not evidence for hazards [A2, A4, L13]. However, it could be relevant to assessment of carcinogenic potential if an agent caused previously non-dividing normal (as opposed to tumor or transformed) cells to begin to divide, if the growth stimulation effect persisted after the agent was removed, and/or if the effect occurred at levels to which people were actually exposed.

Most recent (post-1995) studies of the effects of power-frequency magnetic fields on **tumor growth** have shown no effect [G42, G50, G73, G84, G93, G96]; but one study reported enhanced tumor growth after exposure to a 50 microT field [G43].

Of particular note are the studies by Sasser et al [G50], Morris et al [G73], Devevey et al [G84] and Anderson et al [G96] which found that prolonged exposure of leukemic animals to 2-2000 microT 50- or 60-Hz fields had no effect on leukemia progression or animal survival.

Most recent (post-1995) studies of effects of power-frequency magnetic fields on **growth of normal cells or tumor cells** have also shown no effect [G47, H16, H25, H26, H44, G86, G92, H50, G106, H57, H58, H63, G123]; but some have reported increased [H46, H54, G91, G95, G105, G110, H59, H61, G125] or decreased [G41, H56, H57, G115] cell growth after exposure to strong (90 microT or above) fields.

The more recent reports of effects of power-frequency fields on cell growth include:

- 2001: Heredia-Rojas et al [G95] reported that growth of human lymphocytes was slightly enhanced by 72 hours of exposure to 60-Hz fields at 1000-2000 microT.
- 2001: Zeni et al [G105] reported that growth of human lymphocytes was slightly enhanced by 72 hours of exposure to 50-Hz fields at 1000 microT.
- 2002: Fedrowitz et al [H54] reported that exposure of rats to a 100 microT field for two weeks increased the growth rate of breast epithelial cells.
- 2002: Pang et al [H56] reported that growth of human tumor cells was inhibited by fields of 6000 microT and stronger, but no effect was seen at lower field strengths.
- 2003: Verheyen et al [G110] reported enhanced mitotic activity in human white blood cells at 800 microT, but not at 80 microT and not if a genotoxic drug was present.
- 2003: Santini et al [H57] reported that 7 days of exposure of human cancer cells to a 500 microT field caused decrease cell growth. The decrease in growth was not seen after 14 days of exposure or in a different human cancer cell line.
- 2003: Pirozzoli et al [H59] reported that multi-day exposure of a human tumor cell line to a 1000 microT field at 50Hz slightly increased cell growth.
- 2004: Grassi et al [H61] reported that exposure of mammalian cells to a 50-Hz field at 500-1000 microT field for 24-72 hours increased cell growth, but that lower intensities had no effect.
- 2004: Stronati et al [G115] reported that exposure of human blood cells for 2 hours to a 1000 microT field at 50 Hz caused a "slight but significant decrease of cell proliferation".
- 2005: Wolf et al [G125] reported that exposure to 500-1000 microT fields for 24-72 hours caused an increase in proliferation in three mammalian cell lines.

Of particular interest is a study by Zhao et al [H33] which found that both sham exposure and exposure to 100-800 microT fields enhanced cell growth. The effect was shown to be due to a 0.1-0.8 °C rise in temperature caused by the double-wound coils used for the sham exposure. Whether other reports of effects on cell growth might be due to heating is unknown, but temperature rises from sham exposures have been reported by others (e.g., Rosenthal and Obe [G7]).

In summary, there have been no reported effects on cell proliferation or tumor progression that suggest a potential for carcinogenesis, and there have been no reports of effects at all for fields below about 50 microT.

17B) How do studies of immune function relate to the question of cancer risk?

In the 1970's there was speculation that the immune system had a major role in preventing the development of cancer; this theory was known as the "immune surveillance hypothesis". If this hypothesis were true, then damage to the immune system could effectively cause cancer. Subsequent studies have shown that this hypothesis is not generally valid [E4]. Suppression of the immune system in animals and humans is associated with increased rates of only certain types of cancer, particularly lymphomas [E4]. Immune suppression has not been associated with an excess incidence of leukemia, except for viral-induced leukemia in animals. Immune suppression has not been associated with brain or breast cancer in either animals or humans [E4].

Some pre-1992 studies suggested that power-frequency fields could have effects on cells of the immune system, but no studies have shown the type or magnitude of immune suppression that is associated with an increased incidence of lymphomas. More recent studies include:

- 1995: a study of primates that found that combined electric (6 or 30 kV/m) and magnetic (50 or 100 microT) fields had no consistent effects on the immune system [H12];
- 1996: a study of human volunteers that showed no effects of a 10 microT field on immune function [E9];
- 1996: a comprehensive study in mice [H21] that found that neither continuous (2-1000 microT) nor intermittent (1000 microT) fields had any effect on immune function;
- 1996: a study of mice [H22] that found some effects on immune function at 2000 microT, less effects at 200 microT, and no significant effects at 2 or 20 microT.
- 2002: a study of electric arc welding (exposures of 100-250 microT) that found no "clinically important" effects on hematologic or immunologic parameters [E22].
- 2003: a study that reported that exposure of human immune system cells to 2-500 microT fields at 50 or 60 Hz for up to 72 hours had no effects on their immunological function [H55].

In summary, there is no evidence that power-frequency fields contribute to cancer via immune suppression, and no reports of any effects on the immune system below 200 microT.

17C) How do studies of the pineal gland and melatonin relate to the question of cancer risk?

In the early 1990's some investigators speculated that power-frequency fields might suppress the production of hormone melatonin, and that melatonin might have "cancer-preventive" activity [L2].

Effects of power-frequency magnetic fields on melatonin in humans

- Over a dozen experimental studies in humans have found no evidence that either continuous or intermittent fields at 1-200 microT affect night-time melatonin levels. The more recent (post-1999) of these studies include: Graham et al [E12, E17, E18]; Hong et al [E14]; Levallois et al [E19]; Griefahn et al [E20]; Crasson et al [E21]; Youngstedt et al [E23]; Selmaoui et al [E35]; Kurokawa et al [E24]; Warman et al [E36].
- One experimental study [E10] reported that the night-time melatonin peak was delayed by exposure to a 20 microT field, but that overall melatonin levels were not affected.
- The results of occupational exposure studies have been more varied:
  - A study of female Finnish garment workers (who are exposed to power-frequency fields from sewing machines) showed some ambiguous evidence for a decrease in night-time melatonin production [E13].
  - A study of workers on Swiss electric railroads (which operate at 16.7 Hz) found that evening melatonin levels were somewhat lower on work days than on leisure days; but it cannot be determined whether this was due to magnetic field exposure at work or to "differential exposure to day light at work" (these were mostly shift workers) [E28].
  - Burch et al [E29, E30, E31] have reported some evidence that power-frequency field exposure affects melatonin, but the conditions under which the effect is reported to occur are quite variable.
- One study of residential exposure showed a decrease in melatonin levels in women with higher residential power-frequency magnetic field exposures [E16], but the other residential exposure study showed no evidence for such an effect [E19].
- A 2002 study of men with both occupational and residential exposure to power-frequency fields found no effects of the exposure on blood melatonin, melatonin excretion or on the circadian rhythm of melatonin [E32].
- In a 2002 review, Karasek and Lerchl [L42] concluded that: "at present there are no convincing data showing a distinct effect of magnetic fields on melatonin secretion in [human] adults".

Effects of power-frequency magnetic fields on melatonin in non-human primates

In a large study in baboons, Rogers et al [H13] found that exposure to combined 60-Hz electric (6 or 30 kV/m) and magnetic fields (50 or 100 microT) had no affect on night-time melatonin. However, in a two-monkey pilot study, they found some evidence that the exposure might be effective in decreasing night-time melatonin if the fields were turned on and off very rapidly [H13].

Effects of power-frequency magnetic fields on melatonin in non-primates

- **Rats:** Kato et al [H3] reported that 1 microT fields caused small (20-25%) but inconsistent decreases in night-time melatonin levels. Löscher, Mevissen and colleagues reported that 0.3-10 microT fields produced small (15-25%) decreases in night-time melatonin [G27, G42], but that larger fields did not [G43, H54]. Huuskonen et al [J10] reported that exposure of pregnant rats to 13 or 130 microT fields caused a decrease in night-time melatonin. Seven other studies in rats exposed to 1-100 microT fields for 1 hr to 13 wks showed no consistent effects (Bakos et al [H9, H37, H53]; John et al [H27]; Löscher et al [H31]; Selmaoui and Touitou, [H10, H36]).
- **Mice:** Heikkinen et al [H35] found that 17 months of exposures to 1.3 to 130 microT fields at 50 Hz had no effect on melatonin levels; and de Bruyn et al [H52] found that lifetime exposure to a 2.75 microT field had no effect on melatonin levels.
- **Djungarian (Siberian) hamsters:** Yellon and colleagues [H4, H19, H20, H24, H30] studied the effects of 10 and

100 microT fields on melatonin levels. In some experiments, decreases of night-time melatonin of 20-50% were observed; but in most experiments no effects at all were seen, and in one experiment an increase was observed. Niehaus et al [H23], working with the same hamsters, found that neither sinusoidal or pulsed fields affected night-time melatonin levels. Also in these hamsters, Wilson et al [H34] reported that some exposure regimens caused decreases in night-time melatonin at 100 microT, but found no effects at 50 microT. The 1998 (final?) Djungarian hamster study from Yellon et al [H30] concluded that: "recent evidence in the Siberian hamster suggests that magnetic field exposure effects on the melatonin rhythm... cannot be distinguished from normal variation between replicate studies in sham-exposed controls."

- **Sheep:**Lee et al [H7] found that 4 microT plus 6 kV/m had no effect on night-time melatonin levels.
- **Cows:**Rodriguez et al [H62] found that 30 microT plus 10 kV/m had no effect on night-time melatonin levels, but caused a decrease in day-time melatonin levels.

Summary of the animal studies:

Overall, the 30+ animal studies of power-frequency fields and nocturnal melatonin show that the effect (if it is real at all) is small, inconsistent and unrelated to field strength. The majority of the studies, including the largest non-human primate study, have found no effect at all. In a 2002 review, Karasek and Lerchl [L42] reported the results of 60 separate assessments in animals of power-frequency fields and nocturnal melatonin. Of these assessments, 54% reported no effect or inconsistent effects, 43% reported decreased melatonin and 3% reported increased melatonin.

Melatonin and anti-cancer activity

Since the 1970's there has been sporadic interest in using melatonin as an anti-cancer agent, but clinical trials of melatonin show that it is largely ineffective. There are reports that melatonin levels are decreased in some cancer patients; but in 2004, a large prospective clinical study [E37] found no evidence that melatonin levels were associated with female breast cancer risk.

There is some evidence that melatonin can inhibit the induction of breast cancer by chemical carcinogens; and that inhibition of melatonin production can enhance the induction of breast cancer by chemical carcinogens. However, some studies have not found one or both of these effects, and at least one group has reported that melatonin enhanced the chemical induction of breast cancer. There is also evidence that melatonin can retard the growth of transplanted immunogenic tumors, and that inhibition of melatonin production can enhance the growth of such tumors. However, there are also reports of stimulation of the growth of immunogenic tumors by melatonin. There are no reports that melatonin affects the development of spontaneous tumors, or that it affects the induction or progression of leukemia or brain cancer.

In cell culture there is evidence that melatonin can inhibit cell growth in some breast cancer cell lines [H49], but melatonin does not appear to have a general growth inhibitory effect on tumor cells [H29]. There is also evidence that melatonin is an effective free-radical scavenger and that it can protect cells from the genotoxic effects of ionizing radiation and chemical carcinogens.

Summary

Neither component of the melatonin hypothesis, that power-frequency fields suppress melatonin, or that decreased melatonin causes an increase in cancer, have strong experimental support. In humans, there is little evidence to support either component of the hypothesis.

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18) Do power-frequency fields show any reproducible biological effects in laboratory studies?

While the laboratory evidence does not suggest a link between power-frequency magnetic fields and cancer, numerous studies have reported that these fields do have "bioeffects", particularly at high field strength [A1, M2, M4, M7]. Power-frequency fields intense enough to induce electric currents in excess of those that occur naturally (above 500 microT, see Q8) have shown reproducible effects, including effects on humans [M4].

18A) Do power-frequency fields of the intensity encountered in occupational and residential settings show reproducible biological effects?

If a reproducible biological effect is defined as one that has been reported in the peer-reviewed literature by more than one laboratory, without contradictory data appearing elsewhere; then there may be no reproducible effects below 50 microT [A1, A4, A6, K3]. While there are reports of effects for fields as low as about 0.5 microT, none of these reports have been validated.

The lack of validation of the "positive" laboratory studies could be due to many factors:

- Some reports on the biological effects of power-frequency fields have never been published in the peer-reviewed literature, and cannot be scientifically evaluated.

- No attempts have ever been made to independently confirm some of the published reports of biological effects; and one positive report, standing in isolation, is impossible to evaluate.
- When attempts have been made to confirm many of the published studies, these confirmation attempts have often failed to show the effect [see for example: H2, H4, H5, H6, H11, H32, H38, A6, H43-H45, H47, K3, H51].
- The investigators in this field use a wide variety of biological systems, endpoints, and exposure conditions, which makes studies extremely hard to compare and evaluate.
- The lack of adequate exposure details [F11] make many reports impossible to reproduce.
- The possibility that some of the positive reports were fabrications in the first place cannot be overlooked [L24].

18B) Have mechanisms been proposed that could explain how power-frequency fields could cause biological effects?

There are known biological mechanisms through which high-amplitude (greater than 500 microT) power-frequency magnetic fields can cause biological effects. These high-field effects involve induced electric currents, and the currents induced in the body by fields of less than 50 microT are qualitatively similar to, but much weaker than, the currents that occur naturally [A1, A4, A5, F1, F9, F15, F24, M4, M6]. Therefore, if sinusoidal power-frequency fields of the magnitude encountered in residential settings do have biological effects, they are unlikely to be mediated by induced electric currents.

If sinusoidal power-frequency fields below 5 microT do actually have biological effects, the mechanisms must be found, in Adair's [F1, F7] words: "outside the scope of conventional physics".

Also see What's New.

18C) Are there speculations about novel mechanisms by which power-frequency fields of the intensity encountered in occupational and residential settings could cause biological effects?

The considerations discussed in Q18B show that the interactions of sinusoidal power-frequency fields with the human body are very weak at typical environmental field levels. Numerous investigators have speculated about how power-frequency fields might overcome signal-to-noise problems via resonance or signal amplification mechanisms [F2, F9, H15].

Magnetic Biological Material:

Small magnetic particles (magnetite, Fe3O4) have been found in bacteria that orient in the Earth's static magnetic field, and these particles may also exist in fish, honeybees and birds [F2]. The presence of magnetite in mammalian cells is still unproven. Kirschvink [F2] has suggested that power-frequency magnetic fields could cause biological effects by acting directly on such particles. However, calculations show that this would require 50/60 Hz fields of 2-5 microT or above [F2, F7, H3, F15].

Free Radical Reactions:

Static (DC) magnetic fields can affect the reaction rates of chemical reactions that involve free radical pairs [F10, F27]. Since the radicals involved have lifetimes in the microsecond range, and power-frequency fields have a cycle time in the millisecond range, a power-frequency field acts like a static field during the time scale in which these reactions occur. The effects of the power-frequency field would be additive with the Earth static field (30-70 microT), so no detectable biological effects would be expected below about 50 microT [F10, F15, F23]. In addition, if one were to hypothesize that biological effects mediated by such free radical reactions were involved in carcinogenesis, the relevant studies would be those using static fields; and studies of the genotoxic and epigenetic activity of static fields have been overwhelmingly negative (see Static Electromagnetic Fields and Cancer FAQs).

Eichwald and Walleczek [F22] have made a theoretical argument which suggests that biochemical effects mediated by the radical-pair mechanism could account for effects of power-frequency fields of 1000 microT or more. Eveson et al [F27] and Vink and Woodward [F33] have shown experimental evidence that magnetic fields as low as 1000 microT can have effects on free radical reactions. Adair [F23], on the other hand, has presented theoretical arguments that effects due to the radical-pair mechanisms are wildly implausible at levels of 5 microT or below.

Resonance Theories:

Some of the biophysical constraints could be overcome if there were resonance mechanisms that could make cells (or organisms) uniquely sensitive to power-frequency fields. Several such resonance mechanisms have been proposed, most recently by Lednev and Blanchard/Blackman [H15]. So far, none of these theories have survived scientific scrutiny [F1, F3, F15], and much of the experimental evidence that prompted the speculations cannot be independently reproduced [H2, H8, H60]. There are also severe incompatibilities between known biophysical characteristics of cells and the conditions required for such resonances [A1, F1, F3,

H15, F15, F17]. Note also that resonance theories would predict that biological effects would be different in North America (60 Hz) than in Europe (50 Hz).

18D) Could the presence of transients or higher-order harmonics in power-frequency fields provide a biophysical mechanism for biological effects?

The biophysical barriers to biological effects discussed in Q18B and Q18C presume that 50/60-Hz sinusoidal power-frequency fields are the only time-varying electromagnetic fields found in conjunction with the transmission, distribution, and use of electric power. If this presumption is not true, and large transients and/or higher-frequency harmonics are present; then it is possible that electric currents stronger than those that occur naturally in the body could be induced at field levels that are present in residential and occupational settings. Such large currents might provide a route to biological effects.

Transients and harmonic are found [F25, F30], but there is no evidence that they are powerful enough or frequent enough to cause biological effects.

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19) Recent epidemiological studies of power-frequency fields and cancer

New studies, particularly epidemiologic studies, have appeared frequently. When these studies show "positive" effects they often generate considerable media coverage. When they fail to show "positive" effects they are generally ignored. This section will cover the more recent (1993 to present) studies in some detail.

19A) Residence near power lines and cancer

Childhood Cancer

1993: Three European studies of residence near transmission lines [C15, C16, C18] found some associations with leukemia. The study from Sweden [C18] showed the highest relative risks, and drew the most attention. In contrast to the earlier US studies which assessed exposure from both distribution and transmission lines, these new studies were restricted to high voltage power lines and substations. Exposure was assessed by spot measurements [C18], calculated retrospective assessments [C15, C16, C18], and distance from power lines [C18]. The authors of the three studies produced a combined analysis of their data [B4]. That analysis was based on retrospective calculated fields, the only measure of exposure common to all three studies. The range of RRs from this meta-analysis were:

Meta-analysis of the Scandinavian childhood cancer studies [B 4]

Type of Cancer	Range of relative risks
Childhood leukemia	1.0-3.9
Childhood lymphoma	0.3-3.7
Childhood brain cancer	0.7-3.2
All childhood cancer	0.9-2.1

1996: Two US studies of childhood brain cancer and residence near powerlines [C29, C30] showed no evidence for an association with either measured fields or wire codes.

1997: A European study [C34] of childhood leukemia, lymphoma, brain cancer, and overall cancer showed no evidence for an association with either distance from transmission lines or calculated fields.

1997: A European study [C35] found a non-significant elevation of leukemia in children whose bedrooms had average fields above 0.2 microT.

1997: A US study [C36], which is discussed in detail in Q19H, found no association of childhood leukemia with either measured fields or wire-codes.

1999: Two Canadian studies [C45-C47], which are discussed in detail in Q19J, found no association of childhood leukemia with either measured fields or wire-codes.

1999-2000: Studies from the UK and New Zealand [C49, C51, C58] found no significant association of total childhood cancer (or

leukemia or brain cancer) with exposure to power line fields (including fields from substations and distribution lines). Assessment was based on both measured fields and distance from sources.

2001: A German study [C59] found no significant association of 24-hour average magnetic fields and childhood leukemia; but when pooled with previous German studies [C35], a statistically-significant association was seen for 24-hour average magnetic fields of 0.4 microT and above.

2004: A Japanese study [C71] found no significant association between living in district within 300 m of a transmission line and the incidence of childhood hematological malignancies (leukemia plus lymphoma).

2004-2005: There were press reports in Nov 2004 that an as-yet unpublished British study showed an association between residence near powerlines and the incidence of childhood leukemia, but the details of the study were not publicly known. One press report read "Living near a high-voltage power line roughly doubles the risk of childhood cancers such as leukaemia, scientists say", but then goes on to quote the author of the study as saying that "the link to childhood cancers was weak". These press reports are almost certainly in reference to the study that was published by Draper and colleagues in 2005 [C74]. The Draper et al study us discussed in a new Q19N.

Adult Cancer

1993-1996: Three Scandinavian studies of residential exposure [C17, C21, C32] showed no increases in overall cancer, leukemia, or brain cancer. Exposure was assessed by spot measurements [C21], calculated retrospective assessments [C21, C32], or distance from power lines [C17, C21].

1997: A study from Taiwan [C33] showed some evidence for an association of residence near transmission lines with adult leukemia, but not with brain cancer or female breast cancer.

2005: A Norwegian study [C75] of adults living near high-voltage lines found a non-significant increase in brain cancers for calculated fields above 0.05 microT. There was no tend of increasing incidence with increasing level of exposure.

19B) Occupational exposure to power-frequency fields and cancer

Since 1996, at least 24 major occupational studies of cancer and occupational exposure to power-frequency fields and cancer have been published. These studies deal with:

- leukemia [D28, D29, D31, D40, D43, D44, C62, D47, D50, D65]
- brain cancer [D27, D28, D31, D35, D42, D44, D45, D46,D47, D50, D51, D67, C75]
- male and female breast cancer [D31, D33, D34, C41, D47, D49, D50]
- lymphoma [D31, D39, D47, D49, D50]
- lung cancer [D30, D31, D47, D50]
- other cancers [D31, D47, D49, D50, C65, D52, D69]
- overall cancer rates [D31, D47, D50]

Unlike earlier studies that were based on job titles as listed on death certificates, many of the newer studies have used job descriptions supplemented by data from workers doing those jobs. No studies to date have performed dosimetry on the actual subjects of the study. Even if such dosimetry were available, there is no consensus as to the appropriate exposure metric; arguments have been made for time-weighted average fields, peak fields, rate of change of fields, or even transients [F25].

Of the 10 studies of **leukemia published** in 1997 or later, three [D28, D44, D50] showed some evidence for a statistically significant increase in at least one group that was "exposed to power-frequency magnetic fields". One other study [D40] reported increased leukemia incidence for electric field exposure, but not for magnetic field exposure; the other studies of occupational exposure to electric fields contradict this finding [D25, D29].

Of the 5 studies of **lymphoma** published in 1997 or later, none found evidence for a statistically significant increase in any groups exposed to power-frequency magnetic fields, but one study [D39] found an increase in workers exposed to power-frequency electric fields.

Of the 13 studies of **brain cancer** published in 1997 or later, four [D44, D46, D47, D50] showed evidence for a statistically significant increase in at least one group that was "exposed" to magnetic fields. A fifth [D51] reported that power-frequency magnetic fields were associated with brain cancer, but only if there was also exposure to lead, solvents or pesticide/herbicides. A sixth study [C75] found less brain cancer than expected in Norwegian workers with occupational exposure to power-frequency magnetic fields. Also see the 2001 review by Kheifets et al [B10].

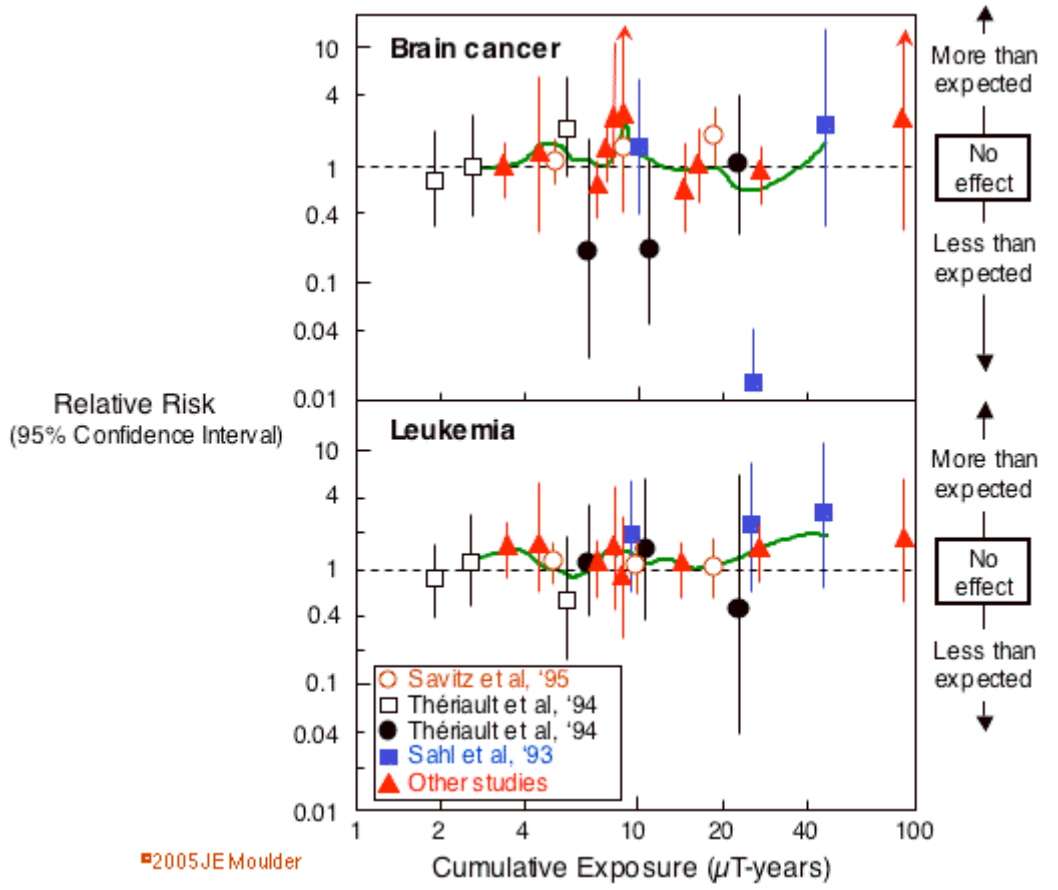
Many **other specific types of cancer** have been studied in "electrical occupations" and in workers with known or presumed exposure to power-frequency electric and/or magnetic fields. Some reports analyzed 12 or more different types of cancer. No obvious patterns emerge, although specific types of cancer have been reported to be associated with exposure in individual studies. Examples of such associations include a 2003 report that occupational exposure to power-frequency magnetic fields was associated with prostate cancer [D52]; and a 2005 report that adrenal and parathyroid gland tumors were associated with occupational exposure to power-frequency magnetic fields from certain types of welding [D69].

Of the 3 studies of **overall cancer** published in 1997 or later, one [D50] showed some evidence for increase in overall cancer in at least one "exposed" group.

The new studies of **lung cancer** (Q19D) and **breast cancer** (Q19C) are covered separately.

In 1999 Kheifets et al. [B9] published a combined reanalysis of 3 earlier (1994-1995) [D2, D4, D10] occupational exposure studies. The combined analysis (see Figure below) shows a weak association between exposure to power-frequency fields and both brain cancer and leukemia. However, even in the most highly-exposed groups, the associations are not strong or statistically significant.

Leukemia and Brain Cancer in Workers with Occupational Exposure to Power-Frequency Fields



Data is shown for brain cancer and leukemia as a function of cumulative expose to power-frequency fields in the electric utility industry (based on a combined analysis [B9] of three separate studies [D2, D4, D10]), supplemented by data from "other studies" that used somewhat comparable measures of exposure. The study by Thériault et al. [D4] included two distinct group of workers in Ontario and Quebec. The combined analysis of electric utility industry is adapted from Kheifets et al. [B9]. The additional points ("other studies") for brain cancer are from Miller et al [D24], Harrington et al [D27], Sorohan et al [D45] and Minder and Pfluger [D44]. The additional points ("other studies") for leukemia are from Miller et al [D24], Harrington et al [D43] and Minder and Pfluger [D44]. The data is shown as relative risks with 95% confidence intervals. The solid green lines are running averages that weight each point on

the basis of the number of exposed cases.

19C) Power-frequency fields and breast cancer

In the 1990's there were some laboratory studies [G14, G23, G43] that suggested that power-frequency fields might promote chemically-induced breast cancer (Q16B), and a biological mechanism has been proposed that could explain such a connection (Q17C). More recent studies have not supported this speculation.

Breast cancer and residence exposure to power line fields:

Studies have found little evidence that residential exposure to power-frequency fields is associated with either male or female breast cancer; some of the larger and more recent such studies are:

- 1996: Verkasalo et al [C32]: less breast cancer than expected in women with residential exposure to power-frequency fields.
- 1997: Li et al [C33]: no excess female breast cancer in adults living near transmission lines.
- 1998: Feychting et al [C38, C52]: no significant excess of male or female breast cancer in adults living near transmission lines.
- 1998: Coogan et al [C41]: no excess breast cancer in women with occupational and/or residential exposure to power-frequency fields.
- 2000: Forssén et al [C52]: neither occupational nor residential exposure to power-frequency fields were associated with increased risk of female breast cancer.
- 2002: Davis et al [C61]: residential exposure to power-frequency magnetic fields was not associated with excess female breast cancer.
- 2003: Schoenfeld et al [C66]: residential exposure to power-frequency magnetic fields or residence in high "wire-code" houses were not associated with excess female breast cancer. Exposure to ground currents was also not associated with excess female breast cancer.
- 2003: London et al [C69]: residential exposure to power-frequency fields was not associated with an increased risk of breast cancer among african-american, hispanic or caucasian women.
- 2004: Kliukiene et al [C70]: residential exposure to power-line magnetic fields was associated with an increased risk of breast cancer in Norwegian women; but occupational exposure to power-frequency magnetic fields was not associated with an increased risk of breast cancer in the same women.

Breast cancer and residence exposure to power-frequency fields from appliances:

One study [C68] reported an excess incidence of breast cancer in african-american women who used electric blankets. Numerous other studies have reported that there is no excess of breast cancer among women exposed to power-frequency fields from electric blankets; some of the larger and more recent such studies are: Gammon et al [C39]; Coogan et al [C41]; Laden et al [C55]; Zheng et al [C56]; McElroy et al [C60]; Kabat et al [C67].

Female breast cancer and occupational exposure to power-frequency fields:

There have been nearly 20 epidemiological studies of breast cancer in women who have occupational exposure to power-frequency fields. Of these, only the 1994 study by Loomis et al [D5] showed a clear association of female breast cancer with occupational exposure to power-frequency fields. The larger and more recent studies in this area include:

- 1996: A study by Coogan et al [D23] was preceded by a press release, whose title was "Occupational exposure to magnetic fields increases risk of breast cancer". The study itself did not support the title of the press release. This study is based on breast cancer registry data, with exposure assessed on the basis of the "most representative job". Occupations were grouped in categories according to "potential for exposure to 60-Hz magnetic fields", and no estimates of actual exposure levels or exposure duration were made. The incidence of breast cancer in the group with "high potential exposure" was elevated, but the elevation was not quite statistically significant.
- 1996: Fear et al [D48] reported that women in "electrical" occupations in the UK had a slightly lower incidence of breast cancer than expected.
- 1998: Johansen et al [D31] reported that occupational exposure to power-frequency fields in Denmark was not associated with excess female breast cancer.
- 1998: Coogan et al [C41] reported that occupational exposure to power-frequency fields in the USA was not associated with excess female breast cancer.
- 1998: Petralia et al [D34] reported that occupational exposure to power-frequency fields in China was not associated with excess female breast cancer.
- 1999: Floderus et al [D50] reported that women with occupation exposure to power-frequency fields had no significant

excess rate of breast cancer.
- 2000: Forssén et al [C52] reported that neither occupational nor residential, nor a combination of residential and occupational exposure to power-frequency fields were associated with increased risk of female breast cancer.
- 2002: Håkansson et al [D47] reported that occupational exposure to power-frequency fields was not associated with a statistically-significant excess of female breast cancer.
- 2004: Kliukiene et al [C70] reported that occupational exposure to power-frequency magnetic fields was not associated with an increased risk of female breast cancer.
- Forssén et al [D68]: occupational exposure to power-frequency fields in Sweden was not associated with breast cancer incidence; this is a very large study that is based on actual measurement of fields in various occupations.

Male breast cancer and occupational exposure to power-frequency fields:

In the early 1990's some studies reported an elevated incidence of male breast cancer in electrical workers. However, other studies and later studies have found no such excess. Because male breast cancer is relatively rare, these studied are generally much smaller than the studies of occupational exposure and female breast cancer. The larger and more recent studies in this area include:

- 1995: Savitz and Loomis [D10] found slightly less breast cancer (6 cases) than expected in male electrical workers with occupational exposure to power-frequency fields.
- 1996: Fear et al [D48] found 14 cases of breast cancer in 7500 male electrical workers, a number that is not significantly more than expected.
- 1997: Stenlund and Floderus [D49] found slightly less breast cancer than expected in men exposed above 0.29 microT based on 11 cases or above 0.41 microT based on 4 cases.
- 1998: Cocco et al [D33] found that male breast cancer was not associated with occupation exposure to power-frequency fields (based on 19 cases).
- 1999: Floderus et al [D50] found slightly more breast cancer than expected in men exposed above 0.116 microT, but even with 37 cases the excess is not statistically significant.
- 2002: Håkansson et al [D47] found an excess of male breast cancer in workers with a high level of exposure to power-frequency fields, but the finding is based on only 4 cases and is not statistically significant.

This area of research was reviewed in detail in 1999 by Kheifets and Matkin [B7] and Brainard et al [B8], and in 2001 by Erren [B11]. All three reviews concluded that no causal association of breast cancer and exposure to power-frequency fields has been established, but that the data was insufficient to prove that a small effect could not exist.

19D) Pulsed electric fields and lung cancer

In 1994, Armstrong et al [D6] reported that utility workers exposed to short-duration pulsed electromagnetic fields (**PEMF**s) had increased lung cancer. The association of lung cancer with PEMF was moderately strong, and there was evidence for a dose-response relationship. The workers with the highest exposure to PEMFs had an elevated lung cancer risk compared to workers with lower levels of exposure; but they had a lower lung cancer rate than members of the general public. No relationships were found between PEMF exposure and any other type of cancer. Subsequent studies found no consistent report for this association:

- 1994: Thériault et al [D4] found no excess lung cancer in electrical workers.
- 1996: Fear et al [D30] found no excess lung cancer in electrical workers.
- 1997: Savitz et al [D30] found no association of lung cancer with either exposure to power-frequency magnetic fields or exposure to PEMFs.
- 1999: Floderus et al [D50] found excess lung cancer in both men and women who had occupational exposure to lung cancer.
- 2002: Håkansson et al [D47] reported that exposure to power-frequency fields was not associated with a statistically-significant increase in lung cancer.

A difficult issue with the Armstrong report [D6], is the definition of "PEMF" exposure. The dosimetry is based on readings from a dosimeter that was designed to respond to signals having an electric field component greater than 200 V/m at 2-20 MHz; but this isn't what the dosimeter actually responds to [D7]. In the utility environment this dosimeter is exquisitely sensitive to radio transmissions near 150 MHz, a band that is now (but only since about 1990) used for portable radio communication [D7]. So the job categories in which the Armstrong report [D6] found excess lung cancer are actually the jobs that involve proximity to the use of portable radios; and the vast majority of the reported excess lung cancer occurred before the use of these radios became common.

19E) Electrical appliances and cancer

The fields close to appliances that contain AC electric motors or electric heating coils can exceed 100 microT and 200 V/m. If these appliances are used very close to the body, as electric razors and hair dryers are, there can be large exposures of small parts of the body. There have been epidemiologic studies that have looked at the relationship between the use of electric appliances and both adult and childhood cancer [C6, C8, C11, C12, C22, C23, C29, C30, C31, C37, C51, C55, C56, C60, C62, C63, C73]. These studies have shown little consistent association between the use of electric appliances and cancer incidence; although one of these studies [C22] has actually shown a decrease in adult leukemia among users of personal electric appliances.

A large study in this area is Hatch et al [C37], run in parallel with the Linet et al [C36] power line study discussed in Q19H. As with other studies, this study show no consistent association of childhood leukemia with use of electrical appliances.

19F) Have Sweden and/or Denmark decided to regulate power line fields?

It is frequently said that Sweden or Denmark have decided to regulate the magnetic fields produced by power lines, or have decided to move power lines away from schools. However, statements over the years from officials in both countries show no evidence that they are either regulating fields from the lines or ordering lines to be moved away from schools.

However, in 1996, the Swedish government did announced a "precautionary principle" [L14]:

> "The [Swedish] national authorities recommend a precautionary principle based primarily on non-discountable cancer risks..."
>
> "The research findings presented hitherto afford no basis for and cannot be said to justify any limit values or other compulsory restrictions on low-frequency electrical and magnetic fields..."
>
> "The national authorities join in recommending the following precautionary principle: If measures generally reducing exposure can be taken at reasonable expense and with reasonable consequences in all other respects, an effort should be made to reduce fields radically deviating from what could be deemed normal in the environment concerned. Where new electrical installations and buildings are concerned, efforts should be made already at the planning stage to design and position them in such a way that exposure is limited..."

19G) The idea that it is an interaction between power-frequency fields and the Earth's static field that causes cancer

The inherent biophysical problems (see Q18B) with explaining how environmental power-frequency fields could cause biological effects might be overcome if a biological mechanism for amplifying the fields could be identified. A number of such amplification models (see Q18C) have been proposed, most of which are based on some type of resonance between the power-frequency field and the Earth's static geomagnetic field.

In 1995, Bowman et al [C28] hypothesized that the risk of childhood leukemia might be related to specific combinations of static (geomagnetic) and power-frequency fields. Childhood leukemia data from the Los Angeles were analyzed on the basis of these combinations. No correlation of cancer with measured static or power-frequency fields were found; but the authors do claim a positive trend for the combined power-frequency and static field data. An issue not addressed by the authors is that all resonance theories require a specific orientation between the power-frequency and the static field. Thus it should not be the total static field that matters, but only the component of the static field with the right orientation to the power-frequency field.

19H) The 1997 U.S. National Cancer Institute study of power lines and childhood leukemia

A case-control study of power-lines and childhood cancer, done by the U.S. National Cancer Institute, was published in 1997 [C36]. This was the largest such study to that date, and found no association between measured fields and childhood leukemia, or between wire-codes and childhood leukemia.

- For a time-weighted average bedroom field above 0.2 microT, the study found a relative risk of 1.2 (0.9-1.8), with no statistically-significant dose trend.
- For a "very-high current configuration" wire code (as defined by Wertheimer and Leeper [C1]), the study found a relative risk of 0.9 (0.5-1.6).

From the authors' abstract [C36]

> "We enrolled 638 children with acute lymphoblastic leukemia (ALL)... and 620 controls in a study of residential exposure to magnetic fields generated by nearby power lines. In the subjects current and former homes... [we] measured magnetic fields for 24 hours in each child's bedroom... A computer algorithm assigned wire-codes to the

subject main residence... and to those where the family has lived during the mother's pregnancy with the subject..."

"The risk of childhood ALL was not linked to time-weighted average residential magnetic fields... The odds ratio for ALL was 1.24 (95% confidence interval 0.86-1.79) at exposures of 0.2 microT or greater... The risk of ALL was not increased among children whose residence was in the highest wire code category [odds ratio of 0.88 (0.48-1.63)]..."

"Our results provide little evidence that living in homes characterized by high measured magnetic field levels or by the highest wire code category increases the risk of acute lymphoblastic leukemia in children."

19J) The 1999 Canadian studies of power lines and childhood leukemia

Two separate Canadian studies of power line exposure and childhood leukemia were published in 1999. McBride et al [C45], the larger of the two studies, found no associations between any measures of exposure and the incidence of childhood leukemia. Green et al [C46 and C47], a smaller study, did find an association between childhood leukemia incidence and some measures of exposure.

McBride et al [C45] was the largest study to date (399 cases and 399 matched controls), and is notable for its size and for the wide range of exposure metrics tested. The findings of the McBride et al [C45] study:

- Fields measured with personal monitors (48-hr averages) were not associated with childhood leukemia:
  - a relative risk of 0.6 (0.3-1.2) for those with the highest magnetic field exposures (greater than 0.27 microT).
  - a relative risk of 0.8 (0.5-1.5) for those with the highest electric field exposures (greater than 25 V/m).
- Measured fields in residences were not associated with childhood leukemia:
  - a relative risk of 0.7 (0.4-1.3) for those with the highest magnetic field exposures (greater than 0.27 microT).
- Historic magnetic field reconstructions were not associated with childhood leukemia:
  - a relative risk of 0.6 (0.3-1.1) for those with the highest exposures two years prior to diagnosis (greater than 0.27 microT).
- Wire codes were not associated with childhood leukemia:
  - a relative risk of 1.2 (0.6-2.3) for those living at the time of diagnosis in a house with a "very high current configuration" (as defined by Wertheimer and Leeper [C1]).
  - a relative risk of 0.8 (0.4-1.6) for those living two years prior diagnosis in a house with a "very high current configuration" (as defined by Wertheimer and Leeper [C1]).

Green et al [C46, C47] is a smaller study (201 cases and 406 matched controls), that included a subset (88 cases and 133 controls) in which personal monitors were used to assess exposure. The study found no significant association between childhood leukemia incidence and wire codes, and no associations with electric or magnetic fields measured in the residences. The authors do report significant associations between childhood leukemia and magnetic fields measured by the personal monitors and magnetic fields measured outside the residence. The specific findings of the Green et al [C46, C47] study:

- Fields measured with personal monitors (48-hr averages) were associated with childhood leukemia:
  - a relative risk of 2.4 (1.0-5.5) for those with the highest magnetic field exposures (greater than 0.14 microT).
  - a relative risk of 0.3 (0.1-0.9) for those with the highest electric field exposures (greater than 12 V/m).
- Measured fields in residences were not associated with childhood leukemia:
  - a relative risk of 1.1 (0.3-4.1) for those with the highest bedroom magnetic fields (greater than 0.13 microT).
  - a relative risk of 1.5 (0.4-4.9) for those with the highest residential (all rooms) magnetic fields (greater than 0.15 microT).
- Measured fields outside residences were associated with childhood leukemia:
  - a relative risk of 3.5 (1.1-10.5) for those with the exterior measured magnetic fields (greater than 0.15 microT).
- Wire codes were not associated with childhood leukemia:
  - a relative risk of 0.8 (0.2-3.0) for those living prior to diagnosis in a house with a "very high current configuration" (as defined by Wertheimer and Leeper [C1]).

The significant association of childhood leukemia with magnetic fields measured with the personal monitors as reported by Green et al [C47] is in marked contrast to the lack of association seen for the same measure of exposure in the larger McBride et al [C45] study. For the same exposure cut-point at which Green et al report a relative risk of 2.4 based on 29 exposed cases, McBride et al report a relative risk of 0.85 based on 71 exposed cases.

These studies (along with the US study discussed in Q19H) are particularly important in view of the conclusion in the 1996 U.S. National Academy of Science (NAS) report (Q27E) that the only epidemiological evidence for a link between power lines and

cancer was the association between high wire codes and leukemia. The NAS report quoted a relative risk of 1.5 (1.2-1.8) for this association based on the four then-available studies. Merging NAS data with the four subsequent wire-code studies [C36, C44, C45, C46] gives a summary relative risk of 1.05 (0.90-1.22), with very high heterogeneity.

It should also be noted that some (such as the NIEHS "working group" [A3] discussed in Q27F) have reinterpreted the 1997 NCI study [C36] as positive, by reanalyzing the data based on 0.3 microT measured residential fields as the "cut-point" for determining who was exposed. An analogous assessment of the McBride et al [C45] data gives a relative risk of 0.7 (0.4-1.2). Green et al [C46] cannot be analyzed in this fashion, because data is not provided for cut-points above 0.15 microT.

19K) The 1999-2000 UK studies of power lines and childhood leukemia

In 1999, Lancet carried a report on a large study of powerlines and childhood cancer from the UK [C50], and a summary of a smaller study of power lines and childhood leukemia from New Zealand [C49, C51]. Both studies report that there is no significant association of childhood cancer with exposure to power line fields. In November 2000, the investigators published a follow-up study in which they looked at additional cases and at all external sources of power-frequency fields (that is, substations and distribution lines as well as transmission lines) [C58].

The UK study [C50, C58] is a case-control study of 3380 children with cancer and a similar number of matched controls. Power-frequency magnetic fields were measured in residences and schools, and this was used to calculate the average exposure for the year prior to diagnosis. According to the authors [C58]:

> "Our results provide no evidence that proximity to electricity supply equipment or exposure to magnetic fields associated with such equipment is associated with an increased risk for the development of childhood leukemia nor any other childhood cancer."

The UK study [C58] reports the following relative risks for children exposed to average fields of 0.2 microT and above:

- Total leukemia: 0.4 (0.1-1.9)
- Brain cancer: 0.5 (0.1-3.8)
- Other cancer: 0.9 (0.3-3.0)
- Total cancer: 0.6 (0.2-1.6)

Specific types of cancer could not be reliably analyzed for higher exposures because there were not enough exposed cases. However, there were enough total childhood cancer cases to calculate a relative risk for overall cancer in children exposed to average fields of 0.4 microT and above.

- Total cancer in children exposed to fields of 0.4 microT and above: 0.5 (0.2-1.6)

The second part of the UK study [C58] reports the following relative risks for children living less than 50 meters from an overhead line:

- Total leukemia: 0.8 (0.5-1.3)
- Brain cancer: 1.1 (0.6-2.1)
- Total cancer: 0.9 (0.6-1.3)

The New Zealand study [C49, C51] was much smaller (121 cases and matched controls), assessed only leukemia, and assessed exposure to both electric and magnetic fields. The relative risks were:

- Leukemia and magnetic fields greater than 0.2 microT: 3.3 (0.5-24)
- Leukemia and electric fields greater than 14 volts/meter: 1.3 (0.2-7)

19L) Could exposure to power-frequency *electric* rather than *magnetic fields* be linked with cancer?

Because power-frequency electric fields have little ability to penetrate, it is generally assumed that any biologic effect from residential exposure to fields from power lines must be due to the magnetic component of the field, or to the electric fields and currents that these magnetic fields induce in the body. For this reason, most epidemiological studies have focused on magnetic field exposure. However, there are some [L18, F18] who have advocated that the electric, rather than the magnetic fields might be causally associated with cancer incidence.

The existing residential epidemiology provides even less support for an association with electric fields than for an association with magnetic fields [A5]. First, residences along high-current distribution lines, where excess rates of childhood leukemia have been reported in some U.S. studies, do not have elevated electric fields [C6, C12, F5]. Second, all but one of the residential

epidemiological studies that have looked at both electric and magnetic fields have found that the association (where there is any) is with the magnetic, not the electric field [C6, C12, C34, C45, C47, C49, C51, C64].

The exception is a 1996 study by Coghill et al [C42], which measured electric and magnetic fields in bedrooms of 56 boys who had developed leukemia and an equal number of healthy controls. The investigators reported that the 24-hour mean electric fields in the bedrooms of the leukemic children was 14±13 V/m, compared with 7±13 V/m for the controls. The validity of the Coghill et al [C42] study can be questioned on several grounds. First, the study had an unblinded design, so that those doing the field measurements knew whether the homes were those of cases or controls. Second, the study recruited its subjects through media requests, and because of the great media attention to the possible hazards of power line fields, it is quite possible that parents of children with cancer, who lived near high voltage lines, would have been more likely to volunteer for the study. Finally, the huge standard deviations in the measured electric fields is an indication of extreme variability in exposure.

The latest studies of residential exposure to electric fields and childhood leukemia [C45, C47, C64] found average electrical field exposures as high as 25-65 V/m, but found no excess leukemia risk, and no trend for leukemia risk to increase with increasing electrical field strength. The 2002 study from the UK [C64] also found no excess risk for power-frequency electric fields and other types of childhood cancer.

The existing occupational epidemiology also does not support an association of cancer with power-frequency electric fields [A5]. Miller et al [D24] reported an increased risk of leukemia, but not brain cancer, for occupational exposure to power-frequency electric fields. Guénel et al [D25], on the other hand, reported an increased risk of brain cancer, but not leukemia, for similar occupational exposure to power-frequency electric fields. Villeneuve et al [D39, D40] reported an association of occupational electric field exposure with leukemia and lymphoma. Other studies of occupational exposure to power-frequency electric fields have not found associations with leukemia [D8, D25, D26, D29], brain cancer [D8, D24, D26], lymphoma [D8, D24, D25, D26], or overall cancer [D8, D24, D25, D26].

The suggestion that power-frequency cause cancer via the electric, rather than the magnetic component of the field, is a speculation that is not only poorly supported by epidemiological and laboratory studies; but is actually contradicted by a substantial body of epidemiological and laboratory (see Question 16G) evidence. For further details see Moulder and Foster [A5].

19M) Could parental exposure to power-frequency fields be linked to childhood cancer?

Some studies have suggested that occupational exposure to power-frequency fields might be associated with an increase in cancer in children who were conceived after that exposure, or who were exposed during pregnancy. Most studies have focused on paternal exposure. A few studies [D55, D56, D61, D62] have also assessed maternal exposure (before or during pregnancy).

Most of the studies have looked at childhood brain cancer. They include:

- 1985: Spitz and Johnson [D53] reported that children of fathers employed in "occupations with electromagnetic field exposure" had an increased incidence of neuroblastoma (a type of childhood brain cancer).
- 1988: Nasca et al [D55] reported that they could not find any consistent association between childhood brain cancer and paternal "occupational exposure to electromagnetic fields". Maternal "occupational exposure to electromagnetic fields" was too infrequent to allow analysis.
- 1989: In a followup to the 1985 Spitz and Johnson study [D53], Johnson and Spitz [D54] found an increase in childhood brain cancer, but the increase was smaller and was not statistically significant.
- 1990: Bunin et al [D56] reported that they could find no consistent association between childhood brain cancer and paternal employment in "jobs with electromagnetic field exposure". Maternal employment in "jobs with electromagnetic field exposure" was too infrequent to allow analysis.
- 1990: Wilkins and Hundley [D57] reported that they could find no consistent association between childhood brain cancer and paternal employment in "jobs linked with exposure to electromagnetic fields". They tested eight different definition of who had "jobs linked with exposure to electromagnetic fields" including some that were similar to that of Spitz and Johnson [D53, D54]. In a 1996 follow-up study, Wilkins and Wellage [D59] found a significant excess of childhood brain cancer in children whose fathers were welders. However they did not observe such an increased incidence in the larger group who had jobs with "EMF exposure".
- 1992: Kuitjten et al [D58] reported a significant excess incidence of childhood brain cancer when the fathers were employed as "electrical or electronic repairmen." However they did not observe such an increased incidence in the larger groups who had jobs with "definite or probable exposure to electromagnetic fields" (definitions similar to those used by Spitz and Johnson [D53, D54]).
- 2000: Feychting et al [D61] reported that children of mothers and fathers with "occupational magnetic field exposure" had a slightly lower incidence of brain cancer than expected. For maternal exposure, assessments were done both for exposure before pregnancy and exposure during pregnancy. In this study exposure assessment was based on actual measurements made with people with the same job titles.

Some studies have looked at childhood leukemia. They include:

- 2000: Feychting et al [D61] reported that children of fathers with "occupational magnetic field exposure" had a higher incidence of leukemia than expected. No association was found for childhood leukemia and maternal "occupational magnetic field exposure". No significant increase in overall cancer (or in 4 other cancer subtypes) was found for either maternal or paternal "occupational magnetic field exposure". For maternal exposure, assessments were done both for exposure before pregnancy and exposure during pregnancy. Exposure assessment was based on actual measurements made with people with the same job titles.
- 2003: Infante-Rivard and Deadman [D62] reported that "maternal occupational exposure to [power-frequency] electromagnetic fields" during pregnancy was associated with an excess incidence of childhood leukemia. Exposure assessment was based on actual measurements made with people with similar jobs. Preconception exposure was not assessed.

There is no experimental evidence for a connection between preconception or fetal exposure to power-frequency fields and subsequent cancer.

In 1998, Colt and Blair [D60] reviewed 48 published studies of parental occupational exposure and childhood cancer. They concluded:

> "Despite the large number of positive findings in the [studies of exposure to power-frequency fields], investigators have hesitated to conclude that the association is real. The biologic plausibility is uncertain and the findings are inconsistent... it is also possible that the positive findings are indicative of exposures other than [exposure to power-frequency fields]".

Overall, the evidence for a causal relationship between parental exposure to power-frequency fields and subsequent cancer is weak to nonexistent.

19N) The 2005 British study of childhood leukemia and birth address within 600 meters of a high-voltage power line.

A 2005 British study by Draper and colleagues [C74] reported that the incidence of childhood leukemia was increased if the address at birth was within 600 meters of a high-voltage transmission line. Overall childhood cancers were not significantly increased, and types of childhood cancer other than leukemia were not increased.

For childhood leukemia the relative risks (with 95% confidence intervals) were:

- 0-40 meters: 1.7 (0.4-6.9)
- 0-199 meters: 1.5 (0.5-4.8)
- 200-599 meters: 1.2 (1.0-1.5)

Details are shown in the figure below.

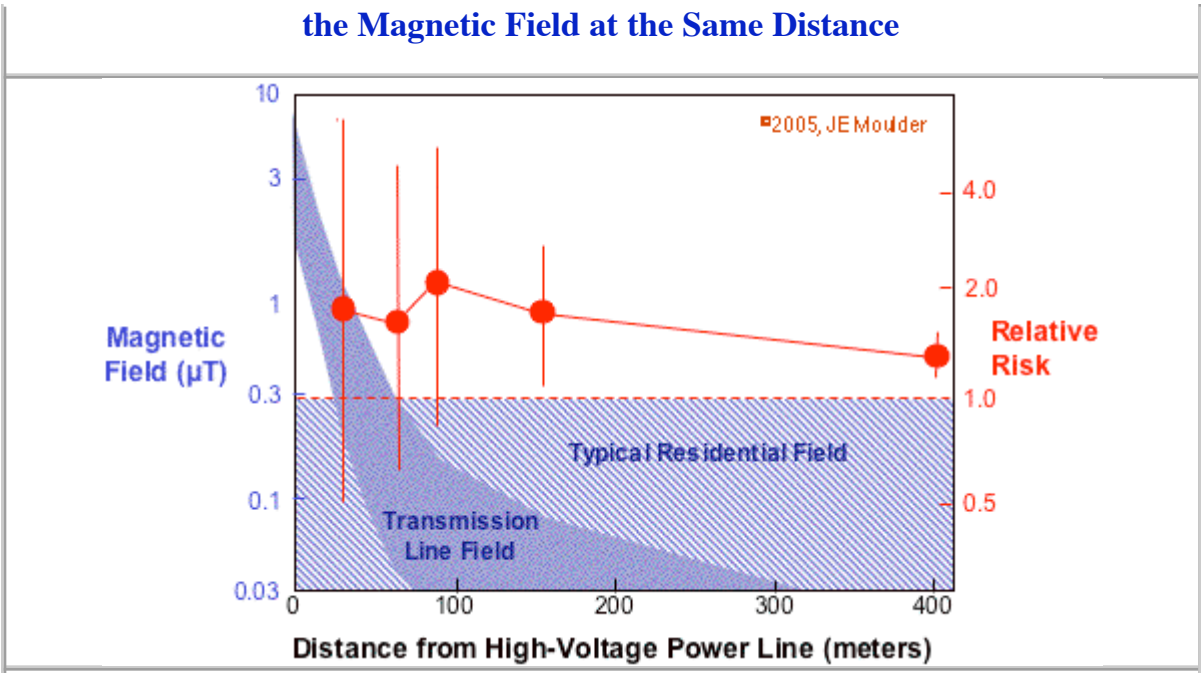
It is interesting to note that the excess incidence of childhood leukemia extends out to distances at which the power-frequency magnetic field becomes less than that found in a typical residence (see figure below). This is one of the factors which lead the authors to conclude that even if the increase in childhood leukemia was real, it was not due to power-frequency fields. In the authors own words:

> "Our increased risk seems to extend to at least 200 m, and at that distance typical calculated fields from power lines are <0.1 microT, and often <0.01 microT—that is, less than the average fields in homes from other sources. Thus our results do not seem to be compatible with the existing data... We have no satisfactory explanation for our results in terms of causation by magnetic fields, and the findings are not supported by convincing laboratory data or any accepted biological mechanism."

The accompanying editorial is interesting:

> "...the debate over power lines seems destined to be with us for a while yet. So, in these risk averse times, and before activists begin blowing up pylons, a bit of perspective might help. In 2002, according to the Child Accident Prevention Trust, more than 36,000 children were hurt in road accidents and around 200 were killed. Another 32 died in house fires. Draper and colleagues reckon that five cases annually of childhood leukaemia may be associated with power lines."

Relative Risks for Childhood Leukemia (Draper and Colleagues) Compared to



Relative risks for childhood leukemia as a function of distance from high-voltage transmission lines as reported by Draper and colleagues [C74] in comparison to the intensity of the magnetic field from high-voltage transmission lines at those distances (the magnetic field intensity data is from the US National Research Council [A1]). The elevated risk of childhood leukemia reported by Draper and colleagues [C74] extends much further than do the actual magnetic fields.

20) What criteria do scientists use to evaluate the laboratory and epidemiologic studies of power-frequency fields and cancer?

There are certain widely accepted criteria that are weighed when assessing epidemiologic and laboratory studies of agents that may pose human health risks [A2, A4, E1, A18]. These are often called the "Hill criteria" [E1]. Under the Hill criteria one examines the strength (Q20A) and consistency (Q20B) of the association between exposure and risk, the evidence for a dose-response relationship (Q20C), the laboratory evidence (Q20D) and the biological plausibility (Q20E).

The Hill criteria should be applied with caution:

- It is necessary to examine the entire published literature; it is not acceptable to pick out only those reports that support or contradict the existence of a health hazard.
- It is critical to directly review the important source documents; it is not adequate to base judgments solely on academic or regulatory reviews.
- Satisfying the individual criteria is not a yes-no matter; support for a criterion can range from strong to moderate to weak to nonexistent.
- It is important to distinguish lack of support for a criteria (e.g., relevant data does not exist) from data which indicates that the criteria is not met (e.g., data showing biological implausibility or laboratory data contradicting the existence of a hazard).
- The Hill criteria should be viewed as a whole; no individual criterion is either necessary or sufficient for concluding that there is a causal relationship between exposure to an agent and a disease.

Overall, application of the Hill criteria shows that the current evidence for a connection between power-frequency fields and cancer is weak to non-existent [A1-A4, A7-A8, A10, A14, A17, A18, A20]. A detailed evaluation of the criteria follows.

20A) Is there a strong association between exposure to power-frequency fields and the risk of cancer?

A strong association is one with a relative risk (RR) of 5 or more. Tobacco smoking, for example, shows a strong association, with the risk of lung cancer in smokers being 10-30 times that of non-smokers. A relative risk of less than about 3 indicates a weak association. A relative risk below about 1.5 is essentially meaningless unless it is supported by other data.

Most of the positive power-frequency studies have relative risks of two or less. The leukemia studies as a group have relative risks

of 0.8-1.9, while the brain cancer studies as a group have relative risks of 0.8-1.6. This is a weak association. Interestingly, as the sophistication of the studies has increased, the relative risks have not increased.

20B) How consistent are the studies of associations between exposure to power-frequency fields and the risk of cancer?

Do most studies show about the same risk for the same disease? Using the same smoking example, essentially all studies of smoking and cancer showed an increased risk for lung and head-and-neck cancers.

Many power-frequency studies show increased incidence of some types of cancers and some types of exposures, but many do not (see, for example Q19B). Even the positive studies are inconsistent with each other. For example, while a 1993 Swedish study [C18] shows an increased incidence of childhood leukemia for one measure of exposure, it contradicts prior studies that had shown an increase in brain cancer, and a parallel Danish study [C16] shows an increase in childhood lymphomas, but not in leukemia.

Many of the studies are internally inconsistent. For example, where a 1993 Swedish study [C18] shows a positive association of childhood leukemia with calculated retrospective fields, it shows a negative association with measured fields. This study also shows no overall increase in childhood cancer; since leukemia accounts for about one-third of all childhood cancer, this implies that the rates of other types of cancer were less than expected.

20C) Is there an exposure-response relationship between to power-frequency fields and the risk of cancer?

Does risk increase when the exposure increases? For example, the more a person smokes, the higher the risk of lung cancer.

No published power-frequency exposure study has shown a statistically-significant dose-response relationship between measured fields and cancer rates, or between distances from transmission lines and cancer rates. However, there is some indication of a dose-response in some of the older childhood leukemia studies when wire codes or calculations of historic fields are used as exposure metrics [B6, C54]. The lack of a clear relationship between exposure and increased cancer incidence is a major reason why most scientists are skeptical about the significance of much of the epidemiology.

Not all relationships between dose and risk can be described by simple linear no-threshold dose-response curves where risk is strictly proportional to dose. There are known examples of dose-response relationships that have thresholds, that are non-linear, or that have plateaus. Without an understanding of the mechanisms connecting dose and effect it is impossible to predict the shape of the dose-response relationship.

20D) Is there laboratory evidence for an association between exposure to power-frequency fields and the risk of cancer?

Epidemiologic associations are greatly strengthened when there is laboratory evidence for this type of health hazard.

Power-frequency fields show little evidence of the type of effects on cells, tissues or animals that point towards their being a cause of cancer (Q16A thru Q16D), or to their contributing to cancer (Q16D thru Q16G and Q17). In fact, the existing laboratory data provides strong evidence that power-frequency fields of the magnitude to which people are exposed are not carcinogenic.

20E) Are there plausible biological mechanisms that suggest an association between exposure to power-frequency fields and the risk of cancer?

When it is understood how something causes disease, it is much easier to interpret ambiguous epidemiology. For smoking, while the direct laboratory evidence connecting smoking and cancer was weak at the time of the Surgeon General's report, the association was highly plausible because there were known cancer-causing agents in tobacco smoke.

From what is known of the physics of power-frequency fields and their effects on biological systems (Q18) there is no reason to even suspect that they pose a risk to people at the exposure levels associated with the generation and distribution of electricity. In fact, the existence of such a health hazard is both physically and biophysically implausible.

See the 2003 review by Linet et al [A18] for a specific discussion of the biological plausibility argument as it applies to power line fields and childhood leukemia.

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21) If exposure to power-frequency magnetic fields does not explain the residential and occupations studies which show increased cancer incidence, what other factors could?

There are at least five factors that can result in false associations in the epidemiologic studies: inadequate dose assessment (Q21A), confounders (Q21B, Q21F), inappropriate controls (Q21C), publication bias (Q21D), and multiple comparison artifacts (Q21E).

21A) Could problems with dose assessment affect the validity of the epidemiologic studies of power-frequency fields and cancer?

If power-frequency fields are associated with cancer, we do not know what aspect of the field is involved. At a minimum, risk could be related to the peak field, the average field, or the rate of change of the field. The duration of exposure could also be a factor. It has even been suggested that harmonics, transients, and/or interactions with the Earth's static magnetic fields are involved. If we do not know what the correct measure of exposure is, then we do not know who is actually "exposed"; and we will usually (but not always) underestimate the true risk [C14].

An additional problem posed by the lack of knowledge of the correct dose metric is that this leads many epidemiological studies to use multiple dose metrics, and thus create a massive multiple comparison problem (see Q21E).

21B) Are there cancer risk factors that could be causing a false association between exposure to power-frequency fields and cancer?

Power lines (or electrical occupations) might be associated with cancer because of some factor other than magnetic fields. If such a risk factor were identified it would be called a "confounder" of the epidemiologic studies. An essential part of epidemiologic studies is to identify and eliminate possible confounders. In other words, you have to make sure that the "exposed" and "unexposed" groups have the same risk factors. This is a particular problem for the studies of "electrical occupations", because it would only require the presence of an unknown carcinogen in a few of those occupations to cause a false positive association with electromagnetic fields. The presence of an such unidentified carcinogen is some "electrical" occupations would create weak associations, inconsistencies, and a lack of dose-response when such occupations were merged with occupations lacking exposure to this carcinogen

Many possible confounders of the power line and/or the "electrical occupation" studies have been suggested, including: PCBs, herbicides, ozone and nitrogen oxides, traffic density, and socioeconomic class.

PCBs: Many transformers contain oil that is contaminated by polychlorinated biphenyls (PCBs) and it has been suggested that PCB contamination of power-line corridors might be the cause of the excess cancer. This is unlikely. First, there is little evidence for widespread PCB contamination of power line corridors. Second, transformers are not found along high-voltage transmission lines, so PCBs could not account for the linkage of childhood leukemia with transmission corridors [B4]. Three, the evidence that PCB exposure causes or promotes cancer in people is weak [L1]. Lastly, PCBs predominantly cause and promote liver cancer in animals; leukemia, brain and breast cancer have not been reported.

Herbicides: It has been suggested that herbicides sprayed on the power line corridors might be a cause of cancer. This is another unlikely explanation. Herbicide spraying would not affect distribution systems in urban areas, where many of the "positive" childhood cancer studies have been done; and would not explain increased cancer in electrical occupations. In addition, evidence that herbicides are carcinogens in humans is weak [L4, L19].

Ozone and nitrogen oxides: It has been suggested that ozone and/or nitrogen oxides created when high voltage lines arc (corona discharge) might be responsible for increased cancer or other health problems (see for example Goheen et al [L43]). This is also an unlikely explanation for a connection of power-frequency magnetic fields and cancer. While ozone might be a cellular genotoxin, there is no evidence that it causes cancer in humans, and only ambiguous evidence that it causes lung cancer in rats [L44, L45]. There is essentially no evidence that the nitrogen oxides are carcinogens. Since corona discharges are caused by electric fields, not magnetic fields, this would also imply that cancer (or other health problems) would be associated with the electric fields rather than the magnetic fields; and as discussed elsewhere (Q16G, Q19L), the evidence for health effects (weak as it is) points to the magnetic not the electric fields as a cause. Finally, this potential confounder would apply only to high-voltage lines and would not explain reports of excess cancer along distribution systems or in most electrical occupations.

Traffic density: Transmission lines frequently run along busy roads, and the "high current configurations" associated with excess childhood leukemia in some of the US studies [C1, C6, C12] are associated with busy roads [C40]. It has been suggested that power lines might be a surrogate for exposure to cancer-causing substances in traffic exhaust. This may be a serious confounder of the residential exposure studies, since traffic exhaust contains known carcinogens, and traffic density has been shown to correlate with childhood leukemia incidence [E3, C40].

Socioeconomic class: Socioeconomic class may be an issue in both the residential and occupational studies, as socioeconomic class is clearly associated with cancer risk, and "exposed" and "unexposed" groups in many studies are of different

socioeconomic classes [C14, C40]. This is of particular concern in the US residential exposure studies that are based on "wire codes", since the types of wire codes that are correlated with childhood cancer are found predominantly in older, poorer neighborhoods, and/or in neighborhoods with a high proportion of rental housing [C19, C25, C40].

Ionizing radiation from corona: It has been suggested on the Internet and in transmission line hearings that corona discharges produce ionizing radiation, and that this could explain the association between power lines and cancer. Corona discharges produces heat, light (in form of small sparks), audible noise, radio interferences and a very small amount of ozone. There is no evidence that these discharges produce ionizing radiation, and strong physical arguments to suggest that they could not. Several investigators [F12, F15, F21] have measured ionizing radiation levels around high-voltage powerlines and have shown that they are not elevated. For a detailed analysis of the physical reasons why transmission lien corona will not produce ionizing radiation see Silva et al [F31].

An infectious basis for leukemia: see Q21F.

Contact currents or contact voltages: A "contact current" occurs when a person touches two conductive objects that are at different voltages. Several authors (e.g., Brain et al. [A17], Kavet and Zaffenella [F29], Kavet et al [F32]) have argued that contact currents would be higher in residences with high power-frequency magnetic fields, and that these contact currents could be high enough to cause biological effects. The plausibility of this argument is unknown because there are no relevant laboratory studies of contact currents and either cancer or genotoxicity or epigenetic activity; and there is no epidemiological evidence that contact currents are associated with childhood leukemia.

In a 2005 article, Chiu and Stuchly [F34] argue that while external fields above 290 V/m or 10 microT would be required to induce an electric field in bone of a magnitude high enough to make biological effects plausible, imperceptible contact currents could induced such fields in bone.

21C) Could the epidemiologic studies of power-frequency fields and cancer be biased by the methods used to select control groups?

An inherent problem with many epidemiologic studies is the difficulty of obtaining a "control" group that is identical to the "exposed" group for all characteristics related to the disease except the exposure being assessed. This is very difficult to do for diseases such as leukemia and brain cancer where the risk factors are poorly known. An additional complication is that usually people must consent to be included in the control arm of a study, and participation in studies is known to depend on factors (such as socioeconomic class, race and occupation) that are linked to differences in cancer rates. See Jones et al [C19] and Gurney et al [C25] for example of how selection bias could affect a power line study.

21D) Could analysis of the epidemiologic studies of power-frequency fields and cancer be skewed by publication bias?

It is known that positive studies are more likely to be published than negative studies. This can severely bias meta-analysis studies such as those discussed in Q13 and Q15. Such publication bias will increase apparent risks. This may be a bigger problem for the occupational studies than the residential ones.

Several specific examples of publication bias are known in the studies of electrical occupations and cancer. In their review, Coleman and Beral [B1] report the results of a Canadian study that found a relative risk of 2.4 for leukemia in electrical workers. The 1992 British NRPB review [B3] found that further followup of the Canadian workers showed a deficiency of leukemia (a relative risk of 0.6), but that this followup study has never been published. This is an anecdotal report; but publication bias, by its very nature, is usually anecdotal.

It is also a clear problem for laboratory studies -- it is much easier (and much more rewarding) to publish studies that report effects than studies that report no effects. An example of this can be seen in work by Cain and colleagues. In a 1993 they published a report [G25] that 60-Hz fields were a co-promoter in a cell transformation system. But in 1993 and 1994 the same authors reported at meetings that they could not replicate the co-promotion, and that some subsequent experiments even showed a decrease in transformation when 60-Hz magnetic fields were present. However, the report of failure to replicate is not published, so that only the positive report is currently in the peer-reviewed literature.

Closely related to publication bias is "reporting bias", which refers to situations where multiple studies are done but only some are reported, and to situations where abstracts and/or press reports emphasize unrepresentative subsets of the actual study. The "Swedish" studies [C18, C21] provide an example of both types of reporting bias. The original unpublished report used a number of different definitions of "exposure", and studied both children and adults. Of all the comparisons, the strongest associations were found for childhood leukemia and calculated fields. The first published English language version omitted the adult data, and the abstract emphasized the groups, exposure definitions and cancer types for which the associations were the strongest; the press

reports were based largely on that abstract. The later publication of the adult portion of the study [C18], which shows no relationship between exposure and cancer incidence in adults has received virtually no press coverage. The result is that a handful of positive associations were emphasized from a much larger group of overwhelmingly non-significant associations.

A 1996 report on breast cancer and occupational exposure [D23] provides another example of reporting bias. The study found a "modest" but non-significant increase in breast cancer in jobs with "high potential exposure". The publication itself is quite cautious, but the prepublication press release read "Occupational exposure to magnetic fields increases risk of breast cancer", and omitted all cautions.

21E) Could analysis of the epidemiologic studies of power-frequency fields and cancer be biased by multiple-comparison artifacts?

Epidemiologic studies often include multiple exposure metrics and multiple types of cancer, so that the investigator can potentially compare many different subgroups. Each such comparison (by commonly accepted statistical criteria) has a 5% probability of yielding a "statistically significant" difference, even if there were no real differences. Between multiple exposure metrics, multiple cut-points, multiple cancer sites, and subgroup analysis, a study may contain 50 or more calculations of relative risk, each individually analyzed for significance at 5%. A high incidence of "false positive" associations would be expected from such a study.

An illustrative example is the study by Feychting and Ahlbom [C18, C21], which looked at 12 cancer types (4 in children and 8 in adults), and 3 different exposure metrics (measured fields, calculated historic fields, and distances from lines). Within each exposure metric were further sub-definitions, such as different cut-points for separating unexposed from exposed. Solely because of the multiple cancer types and exposure metrics, 228 relative risks were calculated, with values ranging from 0.0 (no cancer in exposed groups) to 5.5 (more cancer in exposed groups). Each relative risk was separately analyzed to calculate 95% confidence intervals. Eleven of the 228 relative risk's had lower confidence intervals of 1.0 or above (a crude indication of statistical significance); but even if there were no relationship between power lines and cancer, 5% (or 11.5) of the 288 relative risks would been expected to be "significant" by this standard. Similarly, if there were no relationship between power lines and cancer, some "significantly" decreased rates of cancer would be expected, and such examples can be found in the study.

As a result, we are left not knowing whether the "significant correlation" of childhood leukemia with calculated historic fields is an indicator of a real association, or whether it is a piece of statistical noise. The inability of this type of epidemiologic study to prove "statistical significance" is explicitly acknowledged by Feychting and Ahlbom [C26], who point out that they do not even use the term "statistically significant" in their papers. The authors' caveat has been largely ignored by the mass media, and even by many scientific reviews of this field.

The existence of multiple comparisons, combined with post-hoc (after the fact) selection of cut-points and exposure metrics, is also a severe problem for meta-analysis, where it will cause false positives.

The multiple comparison issues is a particular problem for "hypothesis-generating" studies of the type that have dominated the epidemiology of power-frequency fields. Because of the large number of variables, it is almost impossible for such studies to show true "statistical significance". What such studies can do is generate ideas that can be tested in subsequent "hypothesis-testing" studies. The hallmarks of such "hypothesis-testing" is a small set of hypotheses (usually only one) that are stated in advance, and an experimental design that avoids the multiple comparison issue by limiting the comparisons to just those that could disprove the hypothesis. Such hypothesis-testing epidemiology have been rare in studies of power-frequency fields.

The multiple comparison problem is not unique to this type of epidemiology. It is also a pervasive problem in clinical trials, and issues such as multiple endpoints, multiple cut-points, subgroup analysis, and selection of results for summaries have been extensively discussed in the biomedical literature [L7, L8]. Two things are very clear:

1. Ignoring multiple comparison issues can lead to a dramatic increase in reports that something is statistically significant when it is, in fact noise.
2. Statistical techniques exist for correcting such multiple comparison problems, but it is better to avoid the problems by using proper experimental designs.

21F) Does the evidence that childhood leukemia has an infectious basis mean that the weak association sometimes seen between power-frequency fields and childhood leukemia is an artifact?

Interpretation of the childhood leukemia studies is greatly complicated by evidence that a high rate of "population mixing" (also called "high population mobility") is a risk factor for childhood leukemia and lymphoma [L21, L22]. The explanation for the association (called the Kinlen [L10] hypothesis) is that: "childhood leukemia might result from a rare response to a common but unidentified infection and the increased risks would occur when populations were mixed that increased the level of contacts

between infected and susceptible individuals." [L21]

The complication for the power line studies, is that it has been a common observation that the "cases" are more residentially mobile than the "controls" [C19, C45, C46], and that people living in high wire-code homes are more residentially mobile than people living in low wire-code homes [C19]. This means that the weak associations seen in some childhood cancer studies could be due to differences in residential mobility and have nothing to do with power-frequency fields.

In an editorial accompanying the Draper et al study ([C74] and see Q19N) Dickinson wrote [L46]:

> "Many external factors have been reported as associated with an increased risk of childhood leukaemia. Some may be causal, but some may merely be correlated with the actual cause. Other apparent associations may be due to chance or bias... Analysis of high quality data from population based registries in many different countries shows that the spatial and temporal distribution of acute lymphoblastic leukaemia is consistent with the possibility that an unusual pattern of exposure to infection increases the risk..."

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22) What is the strongest *evidence for* a connection between power-frequency fields and cancer?

The best evidence for a connection between cancer and power-frequency fields is probably:

- The four epidemiologic studies that show a correlation between childhood leukemia and proximity to high-current wiring (see Q14) [C1, C6, C12, C18], plus the meta-analysis of the Scandinavian studies [B4].
  - *Caution:* The 1997-1999 studies discussed in Q19H through Q19K have seriously eroded the validity of this argument.
- The pooled analyses (meta-analysis) [C54, C57] of multiple studies of power line fields which report that for measured or estimated magnetic fields, there is an increased incidence of childhood leukemia in the children in the highest exposure group.
  - *Caution:* In other areas of medicine, meta-analyses of multiple small studies has often yielded invalid results, particularly when the studies being analyzed are of highly variable design and quality.
  - *Caution:* In a 2004 followup [C72], the senior author of one of these meta-analyses reported that if all the uncertainties are taken into account the association was no longer statistically significant.
- The suggestion of a dose-response relationship (see Q20C) in some of the childhood leukemia studies [B6, C54].
- The subset of the epidemiologic studies (see Q19B) that appear to show a correlation between work in electrical occupations and cancer, particularly leukemia [D1, D3, D4, D9, B9, D28, D44, D50] and brain cancer [D10, B9, D46, D44, D47, D50].
- The lab studies that show that power-frequency fields do produce bioeffects (see Q18A).
  - *Caution:* Many of these effects have no known relationship to cancer, or have never been replicated, or have failed attempts at replication (see Q18A), or occur only for exposures far above those actually encountered in residential and occupational settings.
- The reports [G52, G116, G100] that power-frequency fields can cause DNA strand-breaks in brain cells of rodents.
  - *Caution:* See cautionary notes in Q16B.
- The laboratory studies (see Q16E) that provide evidence that power-frequency magnetic fields can promote chemically-induced breast cancer [G14, G23, G43, G79, G117].
  - *Caution:* See cautionary notes in Q16E.
- The studies reporting that intense fields can enhance tumor [G23, G34, G43] and cell [G7, G36, G39, H61, H59, G105, G110] growth rates (see Q17A).
  - *Caution:* These studies should be interpreted with great caution, as many other similar studies have not found such effects (see Q17A).
- The studies reporting that fields can cause [G30, H18] or influence [G25] neoplastic cell transformation (see Q16D).
  - *Caution:* These cell transformation studies have failed numerous confirmation attempts (see Q16D).

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23) What is the strongest *evidence against* a connection between power-frequency fields and cancer?

The best evidence that there is not a connection between cancer and power-frequency fields is probably:

- Hill criteria analysis of the entire body of epidemiologic and laboratory studies, which shows that the evidence for a causal relationship is weak to non-existent (Q20).
- The epidemiological associations are weak (Q20A) and inconsistent (Q20B), and generally fail to show any exposure-response relationship (Q20C).
- The more recent epidemiological studies have failed to find any significant evidence for an association between power lines and childhood brain cancer or childhood leukemia (Q19A, Q19H through Q19K).

- Long-term exposure of animals to power-frequency fields does not cause cancer (Q16B).
- Laboratory studies of genotoxicity have been overwhelmingly negative (Q16A thru Q16D).
- Most laboratory studies of epigenetic activity have been negative, and the few positive studies have used fields far more intense than those to which people are actually exposed (Q16D thru Q16F).
- The biophysical analyses that indicates that "any biological effects of weak (less than 5 microT) ELF fields on the cellular level must be found outside of the scope of conventional physics"(Q18B).
- Multiple comparison problems call into question the statistical significance of all of the "positive" epidemiologic studies (Q21E).
- The consistent rejection of the idea that there is convincing data to support a causal relationship between exposure to power-frequency fields and cancer by essentially all scientific panels that have examined this issue over the past decade [e.g., A1, A3, A6, A7, A8, A10, A14, A20].
    - *Caution:*An exception is the report from the State of California "EMF Program" [A15] that is discussed in Q27K.
- The argument that a connection between cancer and power lines is unlikely because childhood and adult leukemia rates have been stable over a period of time when per capita power consumption has risen dramatically. Swanson [F16] has analyzed power use in the UK between 1949 and 1989 and has calculated that average residential exposures have risen by a factor of nearly 5.
- The "power line - cancer controversy" has many of the hallmarks of "pathological science" [L16].

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24) What studies are needed to resolve the cancer-EMF issue?

Most scientists who are familiar with the literature consider that the issue has either already been resolved, or that it cannot be resolved (see Q27).

In the epidemiologic area, more of the same types of studies are unlikely to resolve anything. Studies showing exposure-response relationship between measured fields and cancer incidence rates would clearly affect thinking, as would studies identifying confounders in the residential and occupational studies.

In the laboratory, more genotoxicity and promotion studies may not be very useful. Further studies of some of the known bioeffects would be useful, but only if they identified mechanisms or established the conditions under which the effects occur (e.g., thresholds, dose-response relationships, frequency-dependence, optimal wave-forms).

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25) Is there any evidence that power-frequency fields cause any effects on human health, such as miscarriages, birth defects, Alzheimer's disease, multiple sclerosis, suicide or sleep disorders?

While this FAQ sheet, and most public concern, has centered around the possibility of a cancer risk, there have also been suggestions that there might be a connection between exposure to non-ionizing electromagnetic sources and a variety of other human health problems.

Miscarriages, birth defects and adverse pregnancy outcomes

Concern about miscarriages and birth defects has focused as much on video display terminals (computer monitors) as on power lines. The recent (post-1997) epidemiologic [J1, J4, J7, J8, J12, J18, J20] and laboratory [J1, J2, J4, J10, J11, J13, J17, J19, J21] studies provide little support for a connection between non-ionizing electromagnetic exposure and birth defects. Robert [J5], Brent [J4] and Shaw [J12] have reviewed this field in detail.

For a discussion of parental exposure to power-frequency fields and the risk of cancer in their subsequent children, see Q19M.

An exception to the lack of association of miscarriages and exposure to power-frequency fields is a study [J15, J16] which reported that high peak power-frequency exposures (and high rates of changes in exposure) were associated with an increased risk of miscarriages in humans. Interestingly the time-averaged average exposures and wire codes were not associated with increased miscarriages in this study. The sources of these peak exposures were not identified. The sources would certainly have included electrical appliances (which can create high peak fields, but have little influence on average fields); but power lines were almost certainly not a common source (as they tend to increase average exposures without much effect on peak exposures).

Other recent adverse pregnancy outcome studies include:

- 1999-2000: Ryan et al [J3] reported that exposure of mice to 2, 2000 or 10,000 microT power-frequency fields for multiple generations had no effect on fertility or birth defects. Later the same group [J6] reported that adding harmonics to the exposure also produced no reproductive toxicity.
- 2001: Al-Akhras et al [J9] reported that exposure of rats to 25 microT fields caused male and female infertility. But in 2002, the same group [J13] reported that exposure of mice to a 25 microT 50-Hz field for 90 days prior to mating had no

adverse effects on fertility or reproduction.

Alzheimer's disease and other neurological disorders

A 1996 study [E8] reported that dressmakers, seamstresses and tailors had excess rates of Alzheimer's disease; and that these groups were exposed to power-frequency fields from sewing machines. That 1996 study found no excess Alzheimer's disease in any other "electrical occupations". In 2003 there were three additional reports [D63 , D64 , D66] that Alzheimer's disease was associated with exposure to power-frequency fields. Two other studies found no excess rates of Alzheimer's disease in electrical utility workers or in other occupations with exposure to power-frequency fields [D32, D38]. In 2004, Qiu et al [E40] reported that long-term occupational exposure to power-frequency fields was associated with Alzheimer's disease and dementia in men, but not in women.

In 2003, Håkansson et al [D64] reported that an increased incidence of amyotrophic lateral sclerosis (ALS) was associated with estimated occupational exposure to power-frequency magnetic fields; but Feychting et al [D64] did not find an increase in ALS in a similar study.

Cardiac effects

In 1998, Sastre et al [E25] reported that exposure of human volunteers to power-frequency magnetic fields caused changes in heart rate. In a 1999 study that was stimulated by this hypothesis, Savitz et al [D36] reported that occupational exposure to power-frequency fields was associated with an increased incidence of certain types of heart disease. In related studies, Sait et al [E11] reported that exposure of human volunteers to a 15 microT power-frequency field caused a small decrease in heart rate. However, in 2000, Graham, Sastre and colleagues [L28, L29] reported that they could not replicate their own 1998 study [E25], even at higher field strengths.

Other recent cardiac function studies include:

- 2002: two large studies of electrical utility workers found no evidence that exposure to power-frequency fields was associated with cardiac arrhythmia or mortality [E26, E27].
- 2003: Kurokawa et al [E33] reported the absence of effects on heart rate in human volunteers exposed to 50-1000 Hz magnetic fields at 20-100 microT for 2 min-12 hr.
- 2003: Håkansson et al [E34] reported that occupational exposure to 50-Hz magnetic fields was weakly associated with the risk of death from acute myocardial infarction, but not with death from other types of heart disease.
- Ahlbom et al [E38] reported that occupational exposure to power-frequency fields was not associated with an increased risk of myocardial infarction (heart attacks).

Other recent reports of possible human health effects

- 1999: Johansen et al [D37] found no significant association of multiple sclerosis with occupational exposure to power-frequency fields.
- 1999: Graham et al [L26] reported that exposure of human volunteers to 14 or 28 microT fields at 60-Hz fields did not cause neurophysiological effects, and that there was no evidence that the volunteers could sense the field.
- 1999: Graham and Cook [L27] reported that exposure of human volunteers to a 28 microT field at 60-Hz fields caused sleep disturbance if the exposure was intermittent, but not if it was continuous.
- 2000: van Wijngaarden et al [D41] reported an association between suicide and exposure to power-frequency fields in male electric utility workers.
- 2002: Podd et al [L37] reported that exposure to a 100 microT 50-Hz field had no significant effect on reaction times in humans, but that exposure had a delayed effect on memory.
- 2002: Mostafa et al [L39] reported that 1-2 weeks of exposure to a 200 microT field caused memory impairment in rats.
- 2002: Cook et al [L36] reviewed the behavioral and physiological effects of power-frequency fields on humans and concluded that: "the variability in results... makes it extremely difficult to draw any conclusions with regard to functional relevance for possible health risks or therapeutic benefits."
- 2004: Delhez et al [E39] reported that exposure of human volunteers (healthy young men) to 20 or 400 microT 50-Hz fields for 65 minutes had no effect on cognitive function tests (attention, memory, time perception).

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26) What are some good overview articles?

Comprehensive reviews of power-frequency fields and human health

- The 1998 report from the NIEHS "working group" [A3 and see Q27F] is comprehensive, but the organization and style of the report makes it very hard to read.

- The 1998 review by Moulder [A4] is derived directly from an early-1998 version of this FAQ document.
- The 1999 review by the NAS provides an overview of the large body of laboratory work that was done under the US EMF-RAPID program, much of which has not yet been published (but see the May 2000 special issue of Radiation Research [A9]).
- The 1999 NIEHS report to the U.S. Congress [A7] provides a compact review of power-frequency fields and human health and is available on the web at: http://www.niehs.nih.gov/oc/news/emffin.htm
- The 1999 policy statement from the Committee on Man and Radiation (COMAR) of the IEEE [A8], "Possible Health Hazards From Exposure to Power-Frequency Electric and Magnetic Fields", is available on line at: http://ewh.ieee.org/soc/embs/comar/elf.pdf
- The 2000 review by Preece et al. [A10] provides a compact review that focuses on the childhood leukemia issue.
- A 2001 summary of Japanese research on biological and health effects of power-frequency fields [A12].
- A 2002 "Q and A" book from the National Institute of Environmental Health Sciences [A16] that is on-line at: http://www.niehs.nih.gov/emfrapid/booklet/home.htm
- A short 2003 review by Ahlbom and Feychting that covers the epidemiology and laboratory studies relevant to whether environmental exposure to power-frequency magnetic fields or radiofrequency radiation could be a human health hazard [A19].

Reasonably up-to-date (1999 or later) reviews of specific areas

- McCann et al [K1] review the animal carcinogenesis studies.
- Robert [J5] and Brent [J4] review the lab and epidemiological evidence for birth defects associated with power-frequency fields.
- Moulder and Foster [A5] review cancer risk assessment issues as they apply to power-frequency *electric* (as opposed to magnetic) fields.
- Ahlbom et al [B12] review the epidemiological literature on power-frequency fields.
- Silny [L23] and Ziskin [L41] on "electromagnetic hypersensitivity".

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27) Recommendations from expert groups

A number of governmental and professional organizations have made recommendations concerning exposure to power-frequency fields.

27A) Guidelines for power-frequency field exposure of the general public

- ICNIRP [M4]
  - 50 Hz: 100 microT (1 G) and 5 kV/m
  - 60 Hz: 84 microT (0.84 G) and 4.2 kV/m
  - This document also contains guidelines for other frequencies.

See Bailey et al [M6, M7] and Sheppard et al [M8] for a detailed discussion of the standards, and of the biological basis for these standards.

27B) Guidelines for occupational exposure to power-frequency fields

- ACGIH [M3]:
  - At 60 Hz: 1,000 microT (10 G)
  - This document also contains guidelines for other frequencies.
- ICNIRP [M4] and European Union draft [M9]:
  - 50 Hz: 500 microT (5 G) and 10 kV/m
  - 60 Hz: 417 microT (4.17 G) and 8.33 kV/m
  - This document also contains guidelines for other frequencies.

See Bailey et al [M6, M7] and Sheppard et al [M8] for a detailed discussion of the standards, and of the biological basis for these standards.

27C) Special exposure guidelines for people with cardiac pacemakers

Pacemaker function can be affected by power-frequency fields. Fields strong enough to interfere with pacemaker function clearly could exist in some occupational settings [L5, L6], and might even exist in some non-occupational settings [L6]. The sensitivity of cardiac pacemakers and the severity of the effects are very dependent on design and model [L5, L6, L48]. This is probably also a

situation where the electric field is at least as important as the magnetic field.

ICNIRP [M4] calculated that interference could be caused by power-frequency fields as low as 15 microT, but states that there is "only a small probability" of malfunction below 100-200 microT. NRPB-UK [M2] states that "interference is unlikely to occur" below 20 microT. ACGIH [M3] has a formal occupational limit for pacemaker wearers of 100 microT. A theoretical study done in 2002 calculated that pacemaker interference could occur at fields as low as 40 microT [L38]. Based on the above sources it would appear that pacemaker interference from a power line magnetic field would be unlikely (see Q10).

However, two studies of pacemakers reports that power-frequency electric fields as low as 5000-6000 V/m could cause interference with some models [L32]; and another implies that interference might be possible for electric fields as low as 1500 V/m [L5]. Electric fields as high 1,500 V/m would not be encountered in the vast majority of residence or in the vicinity of distribution lines, but this level could be exceeded directly under a high-voltage transmission line (see Q10).

In a 2005 study [L48], tests were performed on 245 recipients of permanent pacemakers using a dedicated exposure system that generated a 50-Hz frequency with maximum 100 microT flux density, and with the electrical field kept at 0.10 V/m.
According to the authors:
"A switch to the asynchronous mode was recorded in three patients with devices programmed in the unipolar sensing configuration. A sustained mode switch was followed by symptomatic pacing inhibition in one patient. No effect on devices programmed in bipolar sensing was observed, except for a single interaction with a specific capture monitoring algorithm."
They conclude:
"The overall incidence of interaction by a magnetic field was low in patients tested with a wide variety of conventionally programmed pacemaker models. A magnetic field pulsed at power frequency can cause a mode switch and pacing inhibition in patients with devices programmed in the unipolar sensing configuration. The risk of interference appears negligible in patients with bipolar sensing programming."

Pacemaker users who work or live in environments where there is equipment capable of causing significant electromagnetic interference should bring this to the attention of the physician who implanted the pacemaker. Pacemaker users would also be advised to exercise some caution when in the close vicinity of high voltage transmission lines, particularly lines with voltages of 230 kV and above. The same words of caution are probably applicable to implanted defibrillators, and might be applicable to other implanted biomedical devices.

27D) Did a US government agency recommend strict limits on occupational and residential exposure to power-frequency fields in 1995?

The July/August 1995 issue of *Microwave News* contained extensive quotes from what was said to be a draft report of a committee of the **National Commission on Radiation Protection (NCRP)**. The excerpt(s) appear to have been written in early 1993. According to the article, the NCRP report recommended strict standards for occupational and residential exposure to power-frequency electric and magnetic fields. The *Microwave News* report was subsequently picked up by *Science* and the *New Scientist* and then by the mass media.

An official statement by the NCRP (October 11, 1995) said that "contrary to many erroneous sources of information, the NCRP has not made recommendations on ELF EMF" and notes that "considering the extensive nature of the review process, it is impossible to predict when the NCRP may have a report on the subject of ELF and it is not possible to know the extent or recommendations that might be made".

The 2001 Annual Report of the NCRP referred to this report as still being in subcommittee SC89-3 with a "draft report being prepared for Council review" and that "The Board of Directors put the work of this Committee on hold at its December 2001 meeting". The 2004 Annual report makes no mention of this subcommittee, and the Strategic Plan for 2005-2007 makes no mention of activities is this area. It should be noted that the author of this FAQ is a member of NCRP, but was not a member of SC89-3.

27E) The 1996 and 1999 report from the U.S. National Research Council

In 1991 the US Congress asked the **National Academy of Sciences** to review the literature on the possible health risks of residential exposure to power-frequency electric and magnetic fields. In response the **National Research Council**, the research arm of the National Academy of Sciences, set up a committee of epidemiologists, biologists, chemists, and physicists who were experts in cancer, reproductive toxicology and neurobiological effects. Some members had spent their careers studying the effects of electric and magnetic fields, some where new to the field. The Committee issued its report in November of 1996 [A1]. The following are direct quotes from the executive summary.

- **Conclusions of the Committee**

    - "Based on a comprehensive evaluation of published studies relating to the effects of power frequency electric and magnetic fields on cells, tissues, and organisms (including humans), the conclusion of the committee is that the current body of evidence does not show that exposure to these fields presents a human-health hazard."
    - "No conclusive and consistent evidence shows that exposures to residential electric and magnetic fields produce cancer, adverse neurobehavioral effects, or reproductive and developmental effects."
    - "At exposure levels well above those normally encountered in residences, electric and magnetic fields can produce biologic effects...but these effects do not provide a consistent picture of a relationship between the biologic effects of these fields and health hazards."
- **Epidemiology**
    - "The driving force for continuing the study of the biologic effects of electric and magnetic fields has been the persistent epidemiologic reports of an association between a hypothetical estimate of electric- and magnetic-field exposure called the wire-code classification (see Q14) and the incidence of childhood leukemia."
    - "No association between the incidence of childhood leukemia and magnetic-field exposure has been found in epidemiologic studies that estimated exposure by measuring present-day average magnetic fields."
    - " [The] epidemiologic evidence does not support possible associations of magnetic fields with adult cancers, pregnancy outcome, neurobehavioral disorders, and childhood cancers other than leukemia."
- **Exposure Assessment**
    - "Magnetic fields of the magnitude found in residences induce currents within the human body that are generally much smaller than the currents induced naturally from the function of nerves and muscles."
    - "Because the mechanisms through which electric and magnetic fields might produce adverse health effects are obscure, the characteristics of the electric or magnetic fields that need to be measured for testing the linkage of these fields to disease are unclear."
- **Cellular and Molecular Effects**
    - "Magnetic-field exposures at 50-60 Hz delivered at field strengths similar to those measured for typical residential exposure (0.01 - 1 microT) do not produce any significant in vitro effects that have been replicated in independent studies."
    - "The overall conclusion, based on the evaluation of these studies, is that exposures to electric and magnetic fields at 50-60 Hz induce changes in cultured cells only at field strengths that exceed typical residential field strengths by factors of 1,000 to 100,000."
- **Animal and Tissue Effects**
    - "There is no convincing evidence that exposure to 60-Hz electric and magnetic fields causes cancer in animals."
    - "There is no evidence of any adverse effects on reproduction or development in animals, particularly mammals, from exposure to power-frequency 50- or 60-Hz electric and magnetic fields."
    - "There is convincing evidence of behavioral responses to electric and magnetic fields that are considerably larger than those encountered in the residential environment; however, adverse neurobehavioral effects of even strong fields have not been demonstrated."

In 1999, the National Academy of Sciences commented further on the subject, when they were asked to review research conducted by NIEHS under the Energy Policy Act of 1992 (the program called **"EMF-RAPID"**) [A6, A9]. In this report, the National Academy of Sciences concluded [A6]:

- "The NIEHS biologic research program made two important conclusions that reduce somewhat the concern about whether the use of electric power might have adverse health effects...
    - The first contribution was the effort to replicate previous reports of biological effects... All the attempted replications in the EMF-RAPID program have had negative or equivocal results...
    - The second important contribution was the completion of several investigations of the relationship between magnetic field exposure and cancer through controlled laboratory experiments in animals. Nearly all the animals studies relevant to the [power-frequency field]-cancer question had negative results, even at field levels that were orders of magnitude greater than levels typical of human exposure."
- "The EMF-RAPID biologic research contributed little evidence to support the hypothesis that a link exists between [power-frequency fields] and cancer...
    - The results of in vivo studies do not support a [power-frequency field] effect on cancer initiation, promotion or progression...
    - Evidence of any robust and replicated effects on the development of cancer is lacking."
- "The results of the EMF-RAPID program do not support the contention that the use of electricity poses a major unrecognized public-health danger".
- "The committee recommends that no further special research program focused on possible health effects of power-frequency magnetic fields be funded."

27F) The 1998 report from the U.S. National Institute of Environmental Health Sciences (NIEHS)

In 1997-1998, the US NIEHS organized a series of scientific meetings to evaluate "the potential human health effects from exposure to extremely low frequency electric and magnetic fields". The reports generated at those meetings were to be used to assist NIEHS in preparing a report to the U.S. Congress (see Q27G).

The final of the series of meetings organized by NIEHS (called the "working group") evaluated the evidence for effects on human health under the rules of the **International Agency for Research on Cancer (IARC)**. The actual report from the "working group" was released on 30-July-1998 [A3], and is available at:
http://www.niehs.nih.gov/emfrapid/html/WGReport/PDF_Page.html

The "working group" unanimously concluded that the power-frequency fields were not an IARC class 1 or class 2A agent; that is, that they were not a "known human carcinogen" or a "probable human carcinogen" (see Table below). The majority of the "working group" concluded that power-frequency fields should be classified as IARC class 2B; that is that they were a "possible human carcinogen". Other agents similarly classified by the IARC as "possible human carcinogens" include coffee, automobile exhaust, gasoline and pickled vegetables. A substantial minority of the "working group" concluded that the evidence was not even sufficient to place power-frequency fields in IARC class 2B.

According to the report of the "working group", the classification in IARC class 2B was based on "limited epidemiological evidence" that residential exposure to power-frequency fields was associated with childhood leukemia. "Limited epidemiological evidence", in the IARC scheme means: "A positive association has been observed between exposure... and cancer for which a causal interpretation is considered credible, but chance, bias or confounding could not be ruled out with reasonable confidence."

The "working group" concluded that the epidemiological and experimental evidence was "inadequate" (see Table below) to suggest that exposure to power-frequency fields was a "possible" cause of any type of cancer other than leukemia. The "working group" also concluded that the epidemiological and experimental evidence was "inadequate" (see Table below) to suggest that exposure to power-frequency fields was a "possible" cause of adverse human health effects other than cancer.

Some have interpreted the conclusions of the "working group" as a contradiction to what was said in 1996 by the National Academy of Sciences (NAS) panel (see Q27E) and in 1999 by the NIEHS in their report to Congress (see Q27G). In fact, all three reports agree that no causal association has been established between cancer and exposure to power-frequency fields. In 1999, the National Academy of Sciences commented on the "working group report" [A6]. They concluded:

> "When the working group report is considered in more detail, the dramatic contrast between the Research Council committee report [A1] and the NIEHS report [A3] -- "no effect" versus "probable carcinogen" -- is reduced; and when the differences between the two evaluation processes that were used are taken into account, the difference in conclusions is understandable. The current committee concludes, however, that the conclusions of the 1997 Research Council committee report more accurately convey the health implications of the underlying research to the public."

By "possible human carcinogen", the "working group" explicitly meant IARC class 2B. As shown in the Table below, classification in class 2B requires only weak epidemiological evidence of an association. No laboratory confirmation or biological/biophysical plausibility is required to place something in class 2B. In fact, once there is any epidemiological evidence of an association, "possible human carcinogen", may be the lowest designation allowed by the IARC scheme.

International Agency for Research on Cancer (IARC) Classification of Human Carcinogens

Group	Supporting data required for classification in group (see next table for definitions of terms)	Examples	Number so classified (as of Jul-2004)
Group 1: The agent *is carcinogenic* to humans.	Sufficient epidemiological evidence	Alcoholic beverages, Asbestos, Benzene, Radon, X-rays, Sun light, Tobacco, Secondhand smoke	95
Group 2A: The agent is *probably carcinogenic* to humans.	Limited or inadequate epidemiological evidence PLUS sufficient animal evidence	Creosote, Diesel exhaust, Formaldehyde, PCBs, Sun lamps	66
Group 2B: The agent is *possibly carcinogenic* to humans.	Limited epidemiological evidence PLUS limited or inadequate animal evidence	Automobile exhaust, Chloroform, Coffee, Ceramic & glass fibers, Gasoline, Pickled vegetables	241
Group 3: The agent is *unclassifiable as to carcinogenicity* in humans.	Inadequate epidemiological evidence PLUS inadequate or limited animal evidence OR Does not fall into other groups	Caffeine, Coal dust, Fluorescent lights, Diesel fuel, Electric fields, Mercury, Saccharin, Tea, Static magnetic fields	497
Group 4: The agent is *probably not carcinogenic* to humans.	Lack of carcinogenicity in **both** humans and animals OR Inadequate epidemiological evidence **plus** lack of carcinogenicity in animals	Caprolactam	1

Definitions used by the IARC in the Classification of Human Carcinogens

Phrase	Epidemiology	Animal carcinogenicity
Sufficient evidence	A causal relationship has been established	A causal relationship has been established in two species or in two independent studies
Limited evidence	An association is observed for which a causal association is credible, but non-causal interpretations cannot be ruled out	Animal carcinogenicity is observed; but only in a single study, or only benign tumors or tumors with high spontaneous rates are seen
Inadequate evidence	Studies are of insufficient quality or consistency to determine whether an association exists OR No human data	Studies are of insufficient quality or consistency to allow a conclusion OR No animal data
Lack of carcinogenicity	Multiple negative and consistent studies, with a full range of exposures, that show no evidence of association with any type of cancer.	Negative and consistent studies in two or more species, with a full range of exposures, that show no evidence of carcinogenesis.

27G) The 1999 and 2002 reports from the U.S. National Institute of Environmental Health Sciences (NIEHS)

In 1999, the **US NIEHS** issued a report to the U.S. Congress on "Health Effects from Exposure to Power-Line Electric and Magnetic Fields" [A7]. The NIEHS report to Congress [A7] differs from the "working group" report [A3 and Q27F] in several respects:

- The report to Congress gives more weight to animal, cellular and biophysical studies than did the "working group" report.
- The report to Congress does not focus on the IARC criteria and language that dominated the "working group" report.
- The report to Congress is much shorter than the "working group" report, and uses language that should be far easier for most people to understand.

The report is available at: http://www.niehs.nih.gov/emfrapid/html/EMF_DIR_RPT/Report_18f.htm

From the Executive Summary:

> "The scientific evidence suggesting that [power-frequency electromagnetic field] 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. While

the support from individual studies is weak, the epidemiological studies demonstrate, for some methods of measuring exposure, a fairly consistent pattern of a small, increased risk with increasing exposure that is somewhat weaker for chronic lymphocytic leukemia than for childhood leukemia. In contrast, the mechanistic studies and the animal toxicology literature fail to demonstrate any consistent pattern across studies although sporadic findings of biological effects (including increased cancers in animals) have been reported. No indication of increased leukemias in experimental animals has been observed..."

"Epidemiological studies have serious limitations in their ability to demonstrate a cause and effect relationship whereas laboratory studies, by design, can clearly show that cause and effect are possible. 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 exposure 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 [epidemiological] association is actually due to [power-frequency electromagnetic fields], but it cannot completely discount the epidemiological findings."

"The NIEHS concludes that [power-frequency electromagnetic field] exposure cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard. In our opinion, this finding is insufficient to warrant aggressive regulatory concern. However, because virtually everyone in the United States uses electricity and therefore is routinely exposed to [power-frequency electromagnetic fields], passive regulatory action is warranted such as a continued emphasis on educating both the public and the regulated community on means aimed at reducing exposures."

From the Conclusions and Recommendations of the NIEHS report to Congress:

"As part of the EMF-RAPID Program's assessment of [power-frequency electromagnetic field]-related health effects, an international panel of 30 scientists met in June 1998 to review and evaluate the weight of the scientific evidence [see Q27F]. Using criteria developed by [IARC]... a majority of the members of this Working Group (19/28 voting members) concluded that exposure to power-line frequency [electromagnetic fields] is a "possible" human carcinogen."

"The NIEHS agrees that the associations reported for childhood leukemia and adult chronic lymphocytic leukemia cannot be dismissed easily as random or negative findings. The lack of positive findings in animals or in mechanistic studies weakens the belief that this association is actually due to [power-frequency electromagnetic fields], but cannot completely discount the finding. The NIEHS also agrees with the conclusion that no other cancers or non-cancer health outcomes provide sufficient evidence of a risk to warrant concern..."

"It is our opinion that based on evidence to date, [power-frequency electromagnetic field] exposure would not be listed in the "Report on Carcinogens" as an agent "reasonably anticipated to be a human carcinogen." This is based on the limited epidemiological evidence and the findings from the EMF-RAPID Program that did not indicate an effect of [power-frequency electromagnetic field] exposure in experimental animals or a mechanistic basis for carcinogenicity."

With regard to possible regulatory action, the NIEHS report to Congress states:

"The NIEHS suggests that the level and strength of evidence supporting [power-frequency electromagnetic field] exposure as a human health hazard are insufficient to warrant aggressive regulatory actions; thus, we do not recommend actions such as stringent standards on electric appliances and a national program to bury all transmission and distribution lines."

In 2002, NIEHS released a "Question and Answer" booklet that was aimed at a more general audience [A16]; this booklet is on-line at: http://www.niehs.nih.gov/emfrapid/booklet/home.htm. This booklet states:

"The overall scientific evidence for human health risk from [exposure to power-frequency fields] is weak. No consistent pattern of biological effects from exposure has emerged from laboratory studies with animals or with cells. However, epidemiological studies... had shown a fairly consistent pattern that associated potential [exposure to power-frequency fields] with a small increased risk of leukemia in children and chronic lymphocytic leukemia in adults... For both childhood and adult leukemias interpretation of the epidemiological findings has been difficult due to the absence of supporting laboratory evidence or a scientific explanation linking exposure with leukemia."

27H) The 2004 report from the U.K.

In 2004, the **U.K. NRPB** issued a report on power-frequency fields and cancer [A20]. The report "reviews the scientific evidence relating to possible adverse effects of exposure to electromagnetic fields...[and] provides the basis of NRPB advice on quantitative restrictions on exposure and other measures to avoid adverse effects."

A major change in the thinking of the NRPB is the recommendation that restrictions on exposure to power-frequency fields in the UK should be based in the ICNIRP guidelines [M4] rather than on their own. This eliminates some differences in the exposure guidelines between the UK and most of the rest of Europe.

- **With respect to cellular studies the report concluded that:**
  - There is no convincing evidence to suggest that [power-frequency magnetic] fields are directly genotoxic... They are therefore unlikely to initiate carcinogenesis.
  - Some cellular studies report possible enhancement of genetic changes caused by known genotoxic agents... Many of these positive effects involve [power-frequency magnetic] fields greater than 100 microT.
  - The results from different studies are often contradictory and there is an almost total failure of independent replication of positive results. Those results that report a positive effect tend to show only small changes, the biological consequences of which are not clear.
- **With respect to animal carcinogenesis studies the report concluded that:**
  - A large number of well-conducted, good quality studies have not shown any field dependent effects using a range of tumor models, although the possibility that exposure [to power-frequency magnetic fields] may affect chemically induced mammary tumors cannot be dismissed.
  - The results of animal studies do not suggest that [power-frequency magnetic] fields can cause cancer or affect its development.
- **With respect to melatonin studies the report concluded that:**
  - Laboratory studies with volunteers do not suggest that melatonin rhythms are affected by acute night-time exposure to [power-frequency] magnetic fields.
  - The possibility that changes in melatonin physiology may occur in sensitive subgroups, and perhaps following prolonged exposure cannot be ruled out.
- **With respect to epidemiological studies, the report concluded that:**
  - The epidemiological evidence indicates that exposure to power-frequency magnetic fields above 0.4 microT is associated with a small absolute raised risk of leukaemia in children... However, the epidemiological evidence is not strong enough to justify a firm conclusion that [power-frequency magnetic] fields cause leukemia in children. There is little evidence to suggest... that cancer risks of other types, in children and adults, might arise from exposure to [power-frequency magnetic] fields.
  - The findings from studies of health outcomes other than cancer have generally been inconsistent or difficult to interpret.
  - The results of epidemiological studies, taken individually or as collectively reviewed by expert groups, cannot be used as a basis for derivation of quantitative restrictions on exposure to [power-frequency magnetic] fields.

Note: The U.K. National Radiological Protection Board (NRPB) is now the **Radiation Protection Division of the U.K. Health Protection Agency**.

27J) The 2002 report from the International Agency for Research on Cancer (IARC)

In 2001, **IARC** announced that it would place power-frequency magnetic fields in Class 2B, as a "possible carcinogen". Power-frequency electric fields and static electric and magnetic fields were placed in Class 3 as "unclassifiable". See the Table in Q27F for precise way in which IARC defines these terms. The full IARC report [A14] was released in 2002 as: Static and Extremely Low-frequency (ELF) Electric and Magnetic Fields.

IARC's conclusions are essentially identical to those reached in 1998 by the NIEHS "working group" (see Q27F). This is not surprising as the two groups used essentially the same epidemiological criteria and looking at essentially the same set of epidemiology studies. The major way in which the IARC conclusions differ from those of the 1998 NIEHS "working group" is that IARC considered childhood leukemia to be the only type of cancer for which power-frequency magnetic fields met the criteria for Class 2B, while the working group suggested that adult leukemia also met the criteria for Class 2B.

About childhood cancer, the IARC report [A14] concludes:

> "Since the first report suggesting an association between residential ELF electric and magnetic fields and childhood leukaemia was published in 1979, dozens of increasingly sophisticated studies have examined this association. In addition, there have been numerous comprehensive reviews, meta-analyses, and two recent pooled analyses... The two [pooled analysis] studies are closely consistent. In contrast to these results for ELF magnetic fields, evidence that electric fields are associated with childhood leukaemia is inadequate for evaluation."

"No consistent relationship has been seen in studies of childhood brain tumours or cancers at other sites and residential ELF electric and magnetic fields. However, these studies have generally been smaller and of lower quality."

"The association between childhood leukaemia and high levels of magnetic fields is unlikely to be due to chance, but it may be affected by bias. In particular, selection bias may account for part of the association... It cannot be excluded that a combination of selection bias, some degree of confounding and chance could explain the results. If the observed relationship were causal, the exposure-associated risk could also be greater than what is reported."

"Numerous studies of the relationship between electrical appliance use and various childhood cancers have been published. In general, these studies provide no discernible pattern of increased risks associated with increased duration and frequency of use of appliances..."

" "Studies on parental occupational exposure to ELF electric and magnetic fields in the preconception period or during gestation are methodologically weak and the results are not consistent."

About adult cancer and residential exposure, the IARC report [A 14] concludes:

"While a number of studies are available, reliable data on adult cancer and residential exposure to ELF electric and magnetic fields, including the use of appliances, are sparse and methodologically limited... Although there have been a considerable number of reports, a consistent association between residential exposure and adult leukaemia and brain cancer has not been established. For breast cancer and other cancers, the existing data are not adequate to test for an association with exposure to electric or magnetic fields."

About adult cancer and occupational exposure, the IARC report [A 14] concludes:

"Studies conducted in the 1980s and early 1990s pointed to a possible increased risk of leukaemia, brain tumours and male breast cancer in jobs with presumed exposure to ELF electric and magnetic fields above average levels. The interpretation of these studies was difficult mainly due to methodological limitations and lack of appropriate exposure measurements. Also, a bias towards publication of positive findings could not be excluded."

"Several large studies conducted in the 1990s of both leukaemia and brain cancer made use of improved methods... Some of these studies reported increased cancer risk for intermediate or high magnetic field exposure categories. 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 tumour. Evidence for cancers at other sites was not adequate for evaluation."

"Although the assessment of exposure to electric fields is difficult, these fields have been measured occasionally... [and] no consistent association of electric field strengths with any particular malignancy was noted."

About reproductive effects, the IARC report [A 14] concludes:

"Taken as a whole, the results of human studies do not establish an association of adverse reproductive outcomes with exposure to ELF electric and magnetic fields... Experiments with many different mammalian and non-mammalian experimental models consistently indicate lack of adverse effects on reproduction and development from exposure to... strong ELF electric (up to 150 kV/m) fields.... Prenatal exposure to ELF magnetic fields generally does not result in adverse effects on reproduction and development in mammals. When effects are observed, they usually consist of minor developmental anomalies"

In their overall evaluation, the IARC report [A 14] concludes:

- There is *limited evidence* in humans for the carcinogenicity of extremely low-frequency magnetic fields in relation to childhood leukaemia.
- There is *inadequate evidence* in humans for the carcinogenicity of extremely low-frequency magnetic fields in relation to all other cancers.
- There is *inadequate evidence* in humans for the carcinogenicity of static electric or magnetic fields and extremely low-frequency electric fields.
- There is *inadequate evidence* in experimental animals for the carcinogenicity of extremely low-frequency magnetic fields.
- No data relevant to the carcinogenicity of static electric or magnetic fields and extremely low-frequency electric fields in experimental animals were available.
- Extremely low-frequency magnetic fields are *possibly carcinogenic* to humans (*Group 2B*).

- Static electric and magnetic fields and extremely low-frequency electric fields are *not classifiable* as to their carcinogenicity to humans (*Group 3*).

See the Table in Q27F for precise way in which IARC defines the terms in the above summary.

27K) The 2002 report from the State of California

"On behalf of the California Public Utilities Commission, three scientists who work for the California Department of Health Services (DHS) were asked to review the studies about possible health problems from electric and magnetic fields (EMFs) from power lines, wiring in buildings, some jobs, and appliances..." [A15]. Their 2002 report is online at: http://www.dhs.ca.gov/ehib/emf/RiskEvaluation/riskeval.html

The three DHS scientists concluded:

- To one degree or another, all three of the DHS scientists are inclined to believe that EMFs can cause some degree of increased risk of childhood leukemia, adult brain cancer, Lou Gehrig's Disease [ALS], and miscarriage.
- They strongly believe that EMFs do not increase the risk of birth defects, or low birth weight.
- They strongly believe that EMFs are not universal carcinogens, since there are a number of cancer types that are not associated with EMF exposure.
- To one degree or another they are inclined to believe that EMFs do not cause an increased risk of breast cancer, heart disease, Alzheimer's Disease, depression, or symptoms attributed by some to a sensitivity to EMFs. However,
- All three scientists had judgments that were "close to the dividing line between believing and not believing" that EMFs cause some degree of increased risk of suicide...
- For adult leukemia, two of the scientists are "close to the dividing line between believing or not believing" and one was "prone to believe" that EMFs cause some degree of increased risk.

As to why their conclusions differed from those of other recent reviews, they wrote:

> "the DHS scientists are more inclined to believe that EMF exposure increased the risk of the above health problems than the majority of the members of scientific committees convened to evaluate the scientific literature by [the US NIEHS (see Q27K), IARC (see Q27J) and the UK NRPB (see Q27H)]... There are several reasons for these differences. The three DHS scientists thought there were reasons why animal and test tube experiments might have failed to pick up a mechanism or a health problem; hence, the absence of much support from such animal and test tube studies did not reduce their confidence much or lead them to strongly distrust epidemiological evidence from statistical studies in human populations. They therefore had more faith in the quality of the epidemiological studies in human populations and hence gave more credence to them."

How the California report defines "EMF":

> "A variety of electrical phenomena are present in the vicinity of power lines, in-home wiring, plumbing and electrical appliances. These include EMFs with a variety of frequencies and orientations, stray currents from grounded plumbing, and air pollution particles charged by electric fields [see Q32]. The epidemiological studies primarily implicate the magnetic fields or something closely correlated with them. Some researchers think that associated high- or low-frequency stray contact currents or charged air pollution particles are the true explanation rather than magnetic fields. The actions one would take to eliminate fields are not always the same as one would take to eliminate the currents or the charged particles... This additional uncertainty about what aspect of the mixture might need to be mitigated will thus provide a challenge to policy makers..."

The California report identifies the following gaps in the research:

> "Determining whether stray contact currents or charged air pollution particles are really common enough to explain the epidemiology would be highly policy relevant. Certain suggestive test tube and animal studies await replication. Epidemiology of common conditions that could be studied prospectively, like miscarriage and sudden cardiac death, would be policy relevant and could give a better understanding of what aspect of the EMF mixture might be biologically active."

The California report was reviewed by an internal **Electric and Magnetic Field Scientific Advisory Panel (SAP)**. In their final review of the report the panel wrote:

> "The panel all agreed that the conclusions were logically supported within the range of reasonable scientific discourse... But there was consensus among the SAP members that different evaluators with the same or different professional backgrounds may use the DHS guidelines and arrive at different numerical confidence estimates,

> perhaps substantially different... All three evaluators were primarily epidemiologists... Based on a sample of only three evaluators sharing a similar professional background, the conclusions drawn by these evaluators might not generalize to those from other professions... A minority of SAP members... were not sufficiently persuaded by the extensive discussions in the document on issues of biophysics, mechanistic research, and animal pathology to arrive at the same conclusions as the three DHS evaluators. These members believe that if they were to carry out their own extensive review using the same assessment guidelines, they might come to somewhat different conclusions and arrive at lower estimates of risks from [exposure to power-frequency fields]. In raising this issue these panel members considered the following factors:
> - [power-frequency fields] have very low energy;
> - Biological effects of exposure have not been demonstrated in animal models;
> - Consistent dose-response relations have not been demonstrated between [exposure] and several health outcomes;
> - These SAP members give more weight to negative studies than did the DHS reviewers;
> - Given the lack of a biological mechanism, these SAP members gave more credence to the possible effects of "confounders" than did the DHS reviewers.

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28) What effect do power lines have on property values?

There is very little hard data on this issue. There have been "comparable property" studies, but any studies done prior to 2000 (when Ahlbom et al [C54] was published) might be irrelevant. Anecdotal evidence suggests that the presence of obvious transmission lines or substations can adversely affect property values if there has been recent local publicity about health or property value concerns. If buyers start requesting magnetic field measurements, it is difficult to predict what would happen, since while measurements are relatively easy to do (Q29), they are essentially impossible to interpret (see Q14).

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29) What equipment do you need to measure power-frequency magnetic fields?

Power-frequency fields are measured with a calibrated gauss meter. The meters used by environmental health professionals are too expensive for "home" use. A unit suitable for home use should meet the following criteria:

1. a reasonable degree of accuracy and precision (plus/minus 20% seems reasonable);
2. true rms detection, otherwise readings might be exaggerated if the wave form is non-sinusoidal;
3. a tailored frequency response, because if the unit is too broad-band, higher frequency fields from VDTs, TVs, etc. may confound the measurements;
4. the correct response to overload; if the unit is subjected to a very strong field, it should peg, not just give random readings;
5. a strong electric field should not affect the magnetic field measurement.

Meters meeting these requirements are expensive, and inexpensive meters may be unreliable.

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30) How are power-frequency magnetic fields measured?

Measurements must be done with a calibrated gauss meter (Q29) in multiple locations over a substantial period of time, because there are large variations in fields over space and time. Fortunately, the magnetic field is far easier to measure than the electric field. This is because the presence of conductive objects (including the measurer's body) distorts the electric field and makes meaningful measurements difficult. Not so for the magnetic field.

It is important for the person who is making the evaluation to understand the difference between an emission and exposure. This may seem obvious, but many people, including some very smart physical scientists, stick an instrument right up to the source and compare that number with an exposure standard.

In the case of power distribution line and transformer fields, the magnetic fields may vary considerably over time, as they are proportional to the current in the system. A reasonable survey needs to be done over time, with anticipated and actual electricity usage factored in.

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31) Do the issues discussed in this FAQ sheet apply to electromagnetic fields other than power-frequency fields?

This FAQ sheet concerns itself primarily with sinusoidal fields at frequencies of 50 or 60 Hz. However, certain general issues are relevant to some other types of electromagnetic sources.

31A) Low-frequency fields other than sinusoidal power-frequency fields

The basic principles and data discussed in the FAQ sheet are generally applicable to electromagnetic sources with frequencies between 1 Hz and 30,000 Hz (30 kHz). The major issue encountered when dealing with low-frequency sources other than power-frequency is that the currents induced by time-varying magnetic fields depend on frequency and wave-form, as well as field intensity. As the frequency increases, so do the induced currents (and **the hazard potential is assumed to increase with increased induced current**). Thus safety guidelines change with frequency [M3].

The biological effects of frequencies higher than power-frequency but lower than radio-frequency radiation (300 Hz to 10 MHz) were reviewed in 2002 by Litvak, Foster and Repacholi [A13].

Estimating the currents induced by non-sinusoidal ELF wave forms is more complex, because the magnitude of the induced current depends on the rate at which the magnetic field changes. Thus a square wave of the same frequency and amplitude of a sinusoidal wave will induced a much greater current.

31B) Static electric and magnetic fields?

Static electric and magnetic fields, and ELF fields with frequencies below 1 Hz are covered in a companion FAQ sheet called "**Static Electromagnetic Fields and Cancer FAQs**" (http://www.mcw.edu/gcrc/cop/static-fields-cancer-FAQ/toc.html). For standards and regulations concerning occupational and environmental exposure to static fields see the ICNIRP guidelines [M5].

31C) Radiofrequency and microwave energy

Above 30 kHz, one moves into the radiofrequency (**RF**) and microwave (**MW**) range, and biophysical and biological issues arise [M1, M4] that are not within the scope of this FAQ sheet. First, as the wavelength gets shorter, there is non-ionizing radiation as well as electric and magnetic fields to consider. Second, as the frequency rises into the MHz range, heating due to induced electric currents may no longer be negligible.

Some of the general issues involved with radiofrequency and microwave radiation exposure are covered in Q2, Q3 and Q7. For standards and regulations concerning occupational and environmental exposure to radiofrequency and microwave radiation sources see the ICNIRP guidelines [M1].

For on-line resources on radiofrequency and microwave radiation and human health issues, see:
"FAQs about Mobile Phone Base Antennas and Human Health"
(http://www.mcw.edu/gcrc/cop/cell-phone-health-FAQ/toc.html#24).

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32) The idea that exposure to radon and other chemical carcinogens is increased by the presence of high-strength electric fields

Henshaw, Fews and colleagues [H14, H40, H41, L40] have speculated that the radioactive decay products of radon [H14], and other potentially-carcinogenic airborne particles [H40], might be attracted to strong power-frequency electric field sources, and that there could be enhanced exposure to such carcinogenic agents near high-voltage power lines. They have gone on to theorize that this could provide a mechanism for an association between power lines and childhood leukemia. The authors have so far presented no evidence that this increased pollutant exposure actually occurs; and have offered no plausible mechanism whereby any such increase, if it occurred, would lead to an increase in childhood leukemia.

The basic observation of increased deposition of radon daughter containing aerosols on very strong electric (not magnetic) field sources is plausible [H42]. However, there are major theoretical problems with the Henshaw/Fews hypotheses which indicate that the postulated mechanisms are extremely unlikely to produce adverse human health effects under real-world exposure conditions [H17, H28, H42, L31, H48].

There are particular problems with the suggestion that the Henshaw/Fews hypotheses could explain the alleged connection between powerlines and childhood leukemia:

- Residences along powerlines do not appear to have elevated electric fields [C6, C12], and it is elevated electric (rather than magnetic) fields that the Henshaw/Fews thesis requires.
- The residential epidemiological studies that have looked at both electric and magnetic fields have found that the association (where there is any) is for the magnetic, not the electric field [C6, C12].
- Elevated radon exposure is not associated with childhood leukemia [L20, L25].
- Martinson et al [F12], using solid-state dosimeters, have shown that ionizing radiation levels are not elevated around high-voltage powerlines; and Burgess et al [F15] reported similar results.
- Miles and Algar [F21] and McLaughlin and Gath [L30] also measured radon daughters under high voltage power lines and

found that the concentration was not elevated.

In a letter to the journal in which Henshaw published his original hypothesis, Jeffers [H28] commented:

> "Although the phenomena demonstrated by Henshaw et al are interesting... their own data show that DC fields are far more effective in producing [radon-containing] aerosol plate-out than AC fields. The DC fields that occur naturally and the intensity of man-made AC field strengths are well documented and lead to the view that, even for people who are occupationally exposed to high average AC fields, the additional plate-out [of radon-containing aerosols] is unlikely to exceed a few per cent..."

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33) Are some people sensitive to (allergic to) the presence of power-frequency fields?

A syndrome, now called "sensitivity of electricity" or "electrosensitivity" first appeared in Norway in the early 1980's among users of VDTs [L12, L23, L41]; and in Sweden "the problem [had] grown to epidemic proportions" by the mid-90's [L12]. By 1999, there were reports of the syndrome from many parts of the world [L23]. Initial reports were largely of a transient skin reaction, but in more recent years the syndrome has included central nervous system, respiratory, cardiovascular and digestive symptoms [L12, L23]. In double-blind studies published to date, patients with self-reported "sensitivity of electricity" have been unable to consistently sense whether a masked source was on or off [L12, L17,L47]; and no difference in the physiological response to power-frequency magnetic fields have been shown between persons claiming "electromagnetic hypersensitivity" and normal volunteers [L33, L34, L35].

In a 1999 review, Silny [L23] observes that:

1. The phenomena of "electrical hypersensitivity" cannot be explained by any known mechanisms, as the threshold for known interactions are at least 50 times higher than actual exposures levels.
2. The prevalence of the syndrome varies by a factor of 1000 or more between countries that have comparable exposure situations (for example, over 1000 cases per million people in Sweden versus less that 2 cases per million people in Italy, France and Britain).
3. The pattern of symptoms varies from country to country (for example, in Sweden most subjects report only skin symptoms, whereas in Denmark a wide range of symptoms are reported).
4. The types of exposures alleged to cause the syndrome varies from country to country (for example, in Sweden and Finland the syndrome is associated largely with work on video display terminals, whereas in Germany the syndrome is associated with power-frequency sources and radio/TV transmission towers).

In a 2005 paper, Rubin et al [L47] reviewed studies that has been done to assess whether people who report hypersensitivity to weak electromagnetic fields are better at detecting these fields under blind or double-blind conditions than nonhypersensitive individuals, and to test whether they respond to the presence of electromagnetic fields with increased symptom reporting. They were able to identify 31 studies involving 725 "electromagnetically hypersensitive" participants. They concluded:

> "Twenty-four of these [31 studies] found no evidence to support the existence of a biophysical hypersensitivity, whereas 7 reported some supporting evidence. For 2 of these 7, the same research groups subsequently tried and failed to replicate their findings. In 3 more, the positive results appear to be statistical artifacts. The final 2 studies gave mutually incompatible results. Our metaanalyses found no evidence of an improved ability to detect [electromagnetic fields] in 'hypersensitive' participants..."
>
> "The symptoms described by 'electromagnetic hypersensitivity' sufferers can be severe and are sometimes disabling. However, it has proved difficult to show under blind conditions that exposure to [electromagnetic fields] can trigger these symptoms. This suggests that 'electromagnetic hypersensitivity' is unrelated to the presence of [electromagnetic fields], although more research into this phenomenon is required."

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34) Is there a health hazard from living near a power line?

No absolute answers can be provided, but certain general conclusions can be drawn from the existing science:

- There is a broad consensus in the scientific community that no causal association has been established between residential or occupational exposure to power-frequency fields, and human health hazards (including cancer).
- There is a broad consensus that exposure to these fields has not been, and **cannot be proven to be absolutely safe**.
- There is also a broad consensus that if there is a human health hazard, it is either very small or restricted to small subgroups; that is, that the possibility of a large and general hazard has been ruled out.

Regardless of the science, the public controversy remains. This is seen in the continuing litigation over cancers that are alleged to have been caused by exposure to power-frequency fields, and by the public opposition that meets almost all attempts to site or upgrade power lines. The public concern is sustained by uneven reporting on this issue by the mass media, by the inability of scientists to guarantee that no risk exists, and by statements from scientists and government officials that more research is needed. This public concern is further encouraged by lay-oriented books that allege that there has been a conspiracy to conceal the health risks of power-frequency fields [L11].

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35) Who wrote this FAQ?

This FAQ document originated in the early 1990's as a USENET FAQ in sci.med.physics. The USENET FAQ was maintained by Dr. John Moulder, Professor of Radiation Oncology, Radiology and Pharmacology/Toxicology at the Medical College of Wisconsin. Dr. Moulder has taught, lectured and written on the biological effects of non-ionizing radiation and electromagnetic fields since the late 1970's.

The USENET FAQ was converted to html in 1997 by Bob Mueller and Dennis Taylor of the General Clinical Research Center at the Medical College of Wisconsin. The FAQ was expanded and updated to serve as a teaching aid at the Medical College of Wisconsin. The web server and web management was provided by the General Clinical Research Center at the Medical College of Wisconsin. The development and maintenance of this document was not supported by any person, agency, group or corporation outside the Medical College of Wisconsin.

In August 2005, Dr. Moulder became Director of the NIH-funded Medical College of Wisconsin Center for Medical Countermeasures Against Radiological Terrorism. This new job does not leave him the time required to keep these FAQs up-to-date. When the FAQs had become more than two years out-of-date they were discontinued. There is no version more up-to-date that this PDF version.

Parts of this FAQ were derived from the following peer-reviewed publications:

- JE Moulder and KR Foster: Biological effects of power-frequency fields as they relate to carcinogenesis. Proc Soc Exp Med Biol 209:309-324, 1995.
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- JE Moulder KR Foster: Is there a link between exposure to power-frequency electric fields and cancer? IEEE Eng Med Biol 18(2):109-116, 1999.
- JE Moulder: The Electric and Magnetic Fields Research and Public Information Dissemination (EMF-RAPID) Program. Radiat Res 153:613-616, 2000.
- JE Moulder: The controversy over powerlines and cancer, III Jornadas sobre Líneas Eléctricas y Medio Ambiente, Red Eléctrica de España, Madrid, 2000, pp. 159-168.

Dr. Moulder maintained similar "FAQ" documents on "Mobile (Cell) Phone Base Antennas and Human Health" and "Static EM Fields and Cancer".

Public controversy about electricity and health will continue
until:
future research shows conclusively that the fields are hazardous,
or
until the public learns that science cannot guarantee absolutely safety,
or
until the public and media gets bored by the subject.

Neither of the first two outcomes are particularly likely,
but the third may happen.

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