Appendix H – Electric and Magnetic Fields (PSC Overview)

EMF – Electric & Magnetic Fields

January 2008

What is EMF?

Electricity produces two types of fields; an electric field and a magnetic field. These fields are also called electromagnetic fields or EMF. Since the late 1970s, concern has primarily focused on the magnetic field, so today when people talk about EMF they generally are referring only to the magnetic field.

The EMF produced when we use electricity is part of the electromagnetic spectrum. This spectrum includes all forms of electromagnetic energy. Electromagnetic energy occurs naturally or can be created by electric devices. The electromagnetic spectrum includes cosmic rays, gamma rays, x-rays, sunlight, microwaves, radio waves, heat, and the magnetic fields created by electric currents (see Figure 1).

Although gamma rays, microwaves, and magnetic fields created by electric current are part of the electromagnetic spectrum, they are very different from one another. The ionizing radiation from gamma rays can break molecular bonds. This means that gamma rays and other forms of ionizing radiation can break apart DNA. Exposure to this kind of radiation can lead to cancer.

At lower levels of the electromagnetic spectrum, the amount of energy decreases. Microwaves do not have enough energy to break molecular bonds, although direct exposure to high levels of microwave radiation can cause significant heating.

Power line magnetic fields are in the Extremely Low Frequency (ELF) range of the electromagnetic spectrum. The energy in these magnetic fields is very small. EMF from appliances and power lines does not have enough energy to break molecular bonds.

Cells can respond to exposure to these low energy fields. These responses, or biological effects, tend to be indirect. It has not been shown that these indirect effects cause health problems.

How electricity produces magnetic fields

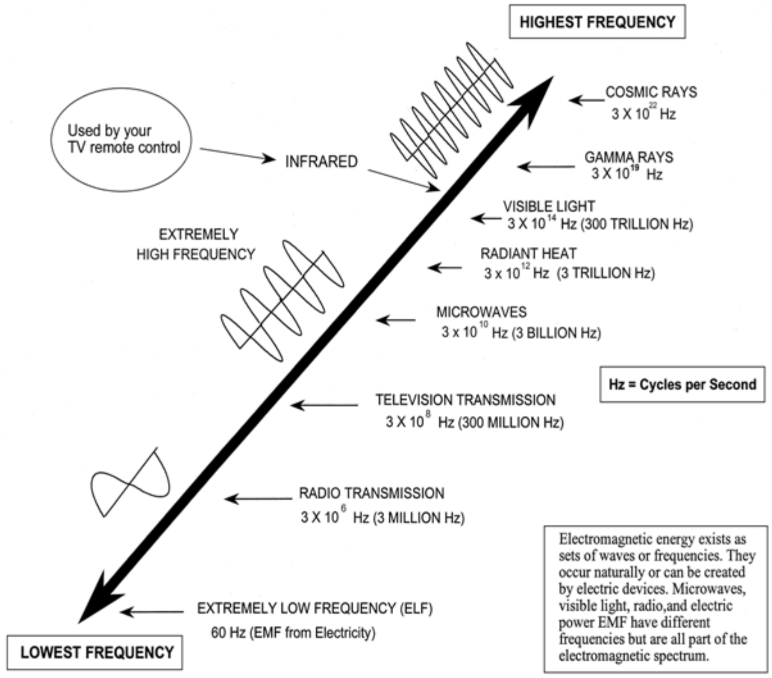
Magnetic fields are created by charges (electrons) moving in a conductor, such as a wire. The number of electrons moving through a conductor at any given time is called the current (measured in amperes). As the current increases, so does the magnetic field. The magnetic field decreases as the distance from the source increases.

Electric fields

Electric fields are found wherever there is electricity. Electric fields are created by the presence of electric charges and are measured in volts per meter (V/m). An electric field is associated with any device or wire that is connected to a source of electricity, even when a current is not flowing. A magnetic field, on the other hand, is created only when there is a current.

Electric fields are easily shielded by common objects such as trees, fences, and walls. Scientific studies have not found any association between exposure to electric fields and human disease.

Figure 1 The Electromagnetic Spectrum



Power line voltage and magnetic fields

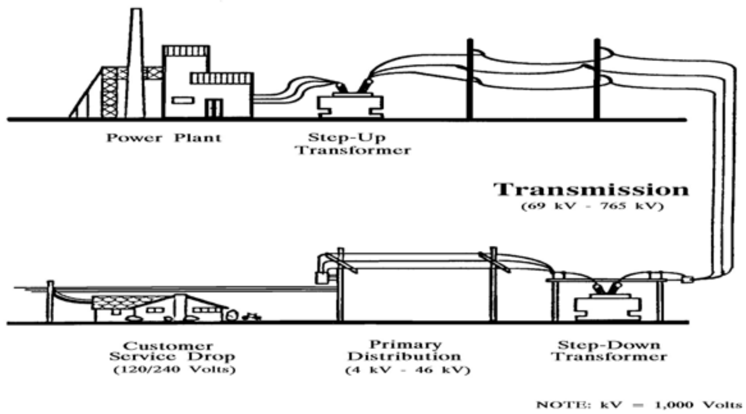
The size of the magnetic field cannot be predicted from the voltage. It is not uncommon for a 69 kV (69,000 volt) line to have a higher magnetic field than a 115 kV (115,000 volt) line. This is because the current flowing in the line, not the voltage, creates the magnetic field. The size of the magnetic field around a line is proportional to the current. This means that the magnetic field level increases as the current in the line increases. Very high voltage lines (345 kV) can carry high current and as a result produce relatively high magnetic fields.

The size of the magnetic fields from electric distribution lines

Electric distribution lines bring electricity to your home, school, and office. Figure 2 shows how distribution lines fit into the electrical system. Primary distribution lines have different voltages depending on the need. Common voltages for primary distribution are 4 kV, 12.5 kV, and 24.9 kV. Power lines with voltages of 69 kV or more are generally considered transmission lines, not distribution lines. Service lines serve your home and provide the 240/120 volts that our appliances require. Transformers, the round canisters near the top of the poles or the green metal boxes on the ground, take high voltage from the primary distribution line and transform it to low voltage for use in your home.

The size of the magnetic field coming off a distribution line depends on the amount of current flowing on that line. Primary distribution lines can produce fields similar to the larger transmission lines.

Figure 2 Simplified electrical system



Other sources of EMF

Any device that uses electric current has a magnetic field. Electric appliances such as radios, refrigerators, microwaves, electric ovens, computers, TVs, and hair dryers produce magnetic fields. The wiring that runs through floors, walls, and ceilings is also a source of magnetic fields when electricity is used (see Table 1).

Levels of EMF in a home

Every home is different. Because EMF changes with the current, generally, magnetic fields increase in your home as you use more electricity. They may be higher in areas of your home where electrical use is concentrated.

A nationwide study, conducted in the 1990s, found that higher magnetic field levels are generally found in:

- Urban versus rural areas.
- Duplexes or apartments versus single-family homes.
- Old homes versus new homes.
- Houses with grounding to a metallic waterline that is connected to the city main.
- Houses with knob-and-tube wiring.
- Houses with two-prong versus three-prong outlets.
- Houses with air conditioning.
- Small residences versus large residences.
- High-density versus low-density residential areas.

Table 1 Magnetic Fields from Common Appliances

Magnetic Field Strength (Milligauss - mG)		
Appliances*	At 10 - 12 Inches	At Working Distance (19 - 22 Inches)
Microwave	17 - 236	5 - 28
Electric range	1.8 - 2.9	0.4 - 10
Refrigerator	1.3 - 15.7	0.6 - 11.4
Color TV	3.5 - 18.6	0.9 - 8.2
Fluorescent light	1.2 - 56.7	0.3 - 15
Ceiling fan	0.3 - 49.5	0.0 - 6
Power Tools	At 1 - 4 Inches	At Working Distance (12 - 20 Inches)
Cordless drill	8	5 - 8
Table saw	760 (at motor)	12
Plunge router	300	30
Power Lines**	At Center Line	At 40 Feet
46 kV (138 amps)	9.6	3.7
69 kV (167 amps)	23	7
115 kV (90 amps)	15	5.5
138 kV (300 amps)	39	17
345 kV (628 amps)	95.8	56.4

Sources:
Appliances - Survey of Residential Magnetic Field Sources, Electric Power Research Institute (EPRI), September 1993.
Power tools - Actual measurements by author.
Power lines - Data comes from actual transmission construction cases.

* For appliances, EMF measurements will vary between make and model.
** For power lines, many variables affect EMF strength: the amount of current, distance from the wires, and the line configuration (how wires are placed in relation to one another). Current flow depends on how much electricity is being used by customers on that line. Use will vary with time of day, time of year, and kind of line. For example, a 138 kV line is generally capable of carrying a maximum of 1,566 amps but normal current flow is much lower. The example in the table is for an existing 138 kV line where 300 amps is the normal current flow.

Measuring EMF

The Gauss (G) is the common unit of measure for magnetic fields. Magnetic fields are measured with a gauss meter. These meters have a small wire coil inside them that produces a voltage when exposed to a magnetic field. Many of these meters are simple to use and provide a digital readout in milligauss (mG). The fields encountered in everyday life are measured in milligauss. A milligauss is one-thousandth of a gauss. The Tesla, another unit of measure for magnetic fields, is often used in scientific studies. One Tesla is equal to 10,000 gauss. Because the fields we are concerned about are small, scientists often report their field measurements in microteslas (µT). A microtesla is one-millionth of a Tesla and is equal to 10 mG.

Epidemiology

The concern about exposure to power frequency EMF has developed because a number of epidemiological studies have found a weak statistical association between exposure to power-frequency magnetic fields and human health effects. Other epidemiological studies, however, have shown no such association. Because of this inconsistency in the findings of epidemiological research, this issue has been controversial for some time. It is important to know something about the science of epidemiology and statistical analysis in order to understand what the study results mean and why there is controversy.

Epidemiology is the study of patterns of disease. Epidemiologists attempt to discover statistical associations between the occurrence of disease in a population and exposure to an infectious or non-infectious agent. Bacteria is an example of an infectious agent. Examples of non-infectious agents could include pesticides, cigarette smoke, or EMF.

Epidemiological studies are field studies. Unlike laboratory research where investigators have total control over study conditions, epidemiologists must observe the world as it is, and must draw inferences from information observed or collected about a study population's life, habits, and exposure to disease agents. Because of this limitation, epidemiological studies suffer from a number of inherent weaknesses. These weaknesses include bias, misclassification, confounding, and statistical variation.[1] Epidemiologists must take such factors into consideration when designing a study and analyzing the results. For example, we know that in-utero exposure to ionizing radiation (e.g. x-rays) is a risk factor for childhood leukemia. Scientists studying human disease and exposure to EMF must identify and acknowledge the presence of known risk factors in any study population. Unfortunately, it is not uncommon for published studies to suffer from and be criticized for weaknesses in study design or failure to account for confounding factors. Another problem that arises in studies on EMF is that it is not possible to compare exposed populations to unexposed populations. In studies on cigarette smoking for example, people either smoke cigarettes or they do not. But in EMF research everyone is exposed to power frequency magnetic fields. So scientists must find a way to measure EMF exposure and separate populations in terms of low and high exposure. This is not a simple task. As described in the section, "Other Sources of EMF", people are exposed to a wide variety of EMF sources and some of those fields can be very high.

The results of epidemiological studies are usually presented either as a relative risk (RR) or an odds ratio (OR). Relative risk is a comparison of the rates of disease between populations. It is calculated by dividing the risk of an exposed person getting a disease by the risk of an unexposed person getting the same disease. An OR compares the odds of exposure rather than rates of exposure. ORs are calculated by dividing the odds of exposure among cases by the odds of exposure among controls. Interpreting an OR is the same as interpreting the RR. An RR/OR of 1.0 means no difference between exposed and unexposed populations. An RR/OR less than one

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[1] Types of bias include **selection bias** (where not everyone eligible to be in a study can be selected as a subject or when those selected are different, in a systematic way, from those excluded from the study) and **recall bias** (this occurs in some types of studies where health evaluations rely on each individual's recall of illness or physiological distress). **Misclassification** occurs when either a test subject's illness is misidentified or exposure to an agent or risk factor is misclassified. **Confounding** is a term that refers to the potential that the disease is actually being caused by an agent or risk factor other than the one being studied. **Statistical variation** refers to chance fluctuations from the expected outcome. For example, if one were to flip a coin 10,000 times one would expect to get nearly 5,000 heads and 5,000 tails. But if one were to flip a coin just ten times one would not expect to get five tails and five heads. Nor would one expect to get ten occurrences of the same outcome (all heads). The statistical variation from the ideal (a perfect 50/50 split) will occur, especially when the number of trials is small. In the same way statistical variation must be considered in epidemiological studies especially when the number of cases is small.

means the exposed population is at a lower risk than the unexposed population while a RR greater than one indicates an increased risk. An RR/OR of 1.5 would suggest the exposed population is 50 percent more likely to contract a disease than the unexposed population. Conversely, an RR/OR of 0.7 would mean the exposed group is 30 percent less likely to develop the disease than the unexposed.

When evaluating epidemiological research, it is important to be able to judge the strength of the results. In other words, do the statistical associations resulting from the study indicate a strong and clear measure of risk? An RR of 5 or more is generally considered strong. (For example, studies comparing smokers to non-smokers showed RRs of 10 to 30 for lung cancer in smokers.) An RR of less than 3 is usually considered weak. Relative risk values of 1.5 or less are generally considered too weak to support any meaningful conclusions.

Because the results of a study are statistical estimates, researchers must present a range over which they are confident the estimate is reliable and the result is less likely to be caused by a random statistical variation. (See footnote 1.) This is usually expressed as a 95 percent confidence interval. For example, a reported RR of 1.2 with a 95 percent confidence interval of 0.7 – 1.9 (reported as RR 1.2 (0.7-1.9)) means that the researcher is 95 percent confident that the true value for the RR is between 0.7 and 1.9. In this case the result would not be statistically significant because the 95 percent confidence interval includes a value less than one. Sample size is a key factor in the reliability of a study's results. Assuming a study is well designed and carefully conducted, the larger the sample, the more reliable are the results.

Cause and effect relationships

Because epidemiological studies result in statistical associations rather than direct evidence of cause and effect, other scientific work must be conducted before scientists can determine that statistical associations from epidemiological studies actually reflect a cause and effect relationship. Usually when epidemiological studies show a consistent and strong association to a risk factor, scientists will develop a plausible theory for how such an exposure might cause disease. This is called a biological mechanism. Then laboratory studies are conducted to test the biological mechanism. In addition, exposure studies on animals need to be conducted under controlled conditions to determine if exposure to the agent does indeed result in disease. In the case of EMF, because a number of epidemiological studies identified an association with leukemia, laboratory studies on mice exposed to EMF would need to be conducted to show if exposure to EMF does cause disease.

By combining epidemiological, biological mechanism, and animal studies scientists are able to piece together how a risk factor or agent might cause disease and how serious exposure might be to human health. The certainty that a cause and effect relationship exists is increased when all three types of studies show positive results.

Epidemiological studies

The health effects of exposure to power frequency EMF have been intensively studied for over 25 years. Much of the EMF research, especially in the early years, has focused on epidemiology. In general, these studies can be separated into two major categories: studies focusing on residential exposure and those focusing on occupational exposure.

At the root of the controversy surrounding this issue is the variability of the results. One would expect that with a serious health threat the studies would show a consistent and strong positive association with human health effects. For EMF this has not been the case. While some studies have shown an association, others have not. Overwhelmingly, those studies showing positive associations with human disease have not shown a strong association. In addition, studies with positive results have not always shown an association with the same disease or exposure measurement.

Residential exposure

Early Research

The first epidemiological study to suggest an association between EMF exposure and human health was published in 1979.[2] The Wertheimer/Leeper study looked at birth and death certificates in Denver and related exposure to EMF by using a surrogate instead of actual field measurements. The surrogate measure used is called a "wire code" which classifies power lines in terms of physical size. The physical size of a power line was assumed to be related to the amount of current flowing on the line. It would then follow that large power lines will tend to have higher magnetic fields than smaller power lines. The homes where cases and controls lived were then classified in terms of proximity to high and low current line configurations. This study found an association between high current line configurations and childhood leukemia and reported an Odds Ratio (OR) of 2.35 for leukemia and an OR of 2.22 for all cancers. In 1980, another study, conducted in Rhode Island, was published.[3] This study was similar in design to the Wertheimer/Leeper study. This study found no association between wire codes and leukemia (OR=1.09). Two studies conducted in England in the mid 1980s also found no association between leukemia and other cancers and exposure to power lines.[4] However, a study conducted in Sweden and published in 1986 showed an association between central nervous system cancers (brain cancer) and electric power facilities but no association with leukemia.[5] In 1988, Savitz *et. al.* published a study that again looked at cancer and power lines in Denver.[6] This study was the largest up to that time and was designed to eliminate some of the weaknesses found in Wertheimer and Leeper's 1979 study. This study characterized the residential magnetic field environment by using both wire coding and actual measurement of fields in residences. This study again showed a positive association between childhood leukemia (OR=1.54) and total cancers (OR=1.53) based on a difference between low current and high current power line configurations. These findings, while positive, are generally considered weak associations because the OR values are well below 3.0. The study found no association between measured magnetic fields and cancer.

In order to have confidence that an exposure agent is actually linked to human disease, scientists look for strong and consistent associations from the epidemiological research. In the case of EMF, the associations, while positive, are not very strong (values for OR or RR are almost

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2 Wertheimer, N. W., E. Leeper. 1979. Electric Wiring Configurations and Childhood Cancer. Am. J. Epidem. 109: 273-284.

3 JP Fulton *et al.*, 1980. Electrical wiring configurations and childhood leukemia in Rhode Island. Am. J. Epidem. 111:292-296.

4 McDowall, M.E., 1986. Mortality of Persons Resident in the Vicinity of Electrical Transmission Facilities. Br. J. Cancer 53:271-279. Myers, A., *et. al.* 1985. Overhead Power Lines and Childhood Cancer. Technical Report, Proceedings of the International Conference on Electric and Magnetic Fields in Medicine and Biology.

5 Tomenius, L., 1986. 50Hz Electromagnetic Environment and the Incidence of Childhood Tumors in Stockholm County. Biolectromagnetics 7:191-207.

6 Savitz, D. A., *et. al.* 1988. Case-control Study of Childhood Cancer and Exposure to 60-Hz Magnetic Fields. Am. J. Epidem. 128(1):21-38.

always below 3). Secondly, study outcomes are not consistent between studies, with some studies showing weak associations and others showing no association at all. In the case of cigarette smoking, for example, the vast majority of epidemiological studies showed a strong positive association between cigarette smoking and lung, neck, and throat cancer.

Swedish Study — 26 years of data, small population

In addition to looking for consistency between studies, scientists are also interested in consistency of results within studies. An example of conflicting results within a study can be shown by examining research published in 1993 from Sweden.[7] The Swedish study covered approximately 26 years. The researchers used two different measures of EMF exposure. One of the concerns about this study is that the researchers obtained different results depending on which exposure measurement they used. Since EMF measurements were not actually taken over the 26-year period reviewed by the study, the researchers estimated past EMF exposure by calculating the average EMF from power lines. They called this substitute for actual exposure measurements "historical calculated fields." The other estimates of exposure they used were actual measured magnetic fields recorded during the study.

The study found no relationship between historical calculated fields and central nervous system cancers (brain tumors), lymphoma, or for all childhood cancers combined (including leukemia). They did find "for leukemia in children and exposure defined from historical calculated fields, …elevated estimated relative risks, which increase with level of exposure." The RR was estimated at 2.7 and 3.8 depending on the magnetic field cut point used.

However, when they looked at measured magnetic fields, the Swedish scientists found something different. The researchers found no increased risk for leukemia or for all childhood cancers combined but did find an increase in estimated relative risk for central nervous system tumors. For this relationship, however, the increased risk only exists for an intermediate exposure level. Higher or lower levels showed no relationship.

Measured fields did not show any link to leukemia but calculated historical fields did. Actual measurements showed an increased risk for central nervous system tumors but calculated historical fields did not. Another interesting finding was that the increased risk for leukemia only held for single-family homes. It did not hold for apartment buildings.

One concern about the study is the very small number of actual leukemia cases. This study included almost 500,000 people (a little more than 127,000 children) over a period of 26 years. There were a total of 38 childhood leukemia cases for the entire study. Twenty-seven cases occurred in the lowest exposure category and served as the standard to which all other cases were compared. The remaining 11 cases, which lead to the positive findings, were found in two higher exposure groups. While the study design helps limit the effect of small sample sizes, the statistics are still based on very small numbers. This tends to make the results less reliable.

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[7] Feychting, M.; & Ahlbom, A. 1993. Magnetic Fields and Cancer in Children Residing Near Swedish High-Voltage Power Lines. Am. J. of Epidemiology 7: 467-481.

Danish and Finnish Studies — Little leukemia risk

The results from two other epidemiological studies were also released in 1993. These studies, one conducted in Denmark[8] and the other conducted in Finland,[9] were published in the October 1993 edition of the British Medical Journal.

In the Danish study, researchers reported that their results were not fully compatible with the Swedish study. The Danes did not find an increased risk for leukemia but did find some evidence of an effect on a combination of cancers, including central nervous system cancers and lymphoma. However, this finding was at a much higher magnetic field level than identified in the Swedish study. The association between EMF exposure and cancer was very weak because of the small number of actual cases and was considered statistically unstable.

The Danish researchers concluded that, if there is a risk to exposure to magnetic fields, it must be very small. They also pointed out that the incidence rate of leukemia over the last 45 years has changed very little, while electrical consumption in Denmark has increased 30-fold. If EMF causes leukemia, you would expect to see an increase in leukemia that follows the increased use of electricity, but this has not happened.

In the Finnish study, researchers found no increased risk of leukemia, central nervous system cancer, or lymphoma. They also found no increased risk when they combined all cancer types. They concluded that residential magnetic fields from transmission lines do not constitute a major public health problem regarding childhood cancer.

Canadian Studies — previous studies reexamined

Two Canadian studies published in 1999 also show significant inconsistencies between studies. Green, *et. al*. looked at childhood leukemia and EMF exposure in Ontario Canada.[10] Green's study showed an association between contemporary measured fields outside residences and childhood leukemia (RR=3.5). However, there was no association with childhood leukemia for contemporary fields inside residences (RR=1.1). In addition, when using wire codes (as with Wertheimer and Leeper, and Savitz) there was no association with cancer. This study also found a positive association when comparing fields measured with personal monitors and childhood leukemia (RR=2.4). At the same time McBride conducted a much larger study in Ontario.[11] This study found no association with childhood leukemia for personal monitors, contemporary measured fields inside residences, historic magnetic fields or wire codes.

British Journal of Cancer — 2000

In September 2000 a pooled analysis of EMF studies was published in the British Journal of Cancer. The study pooled earlier research conducted in Europe, North America, and New Zealand. This study reported a weak association (RR = 2) between exposure to power frequency magnetic fields greater than 4 mG and childhood leukemia. While the results showed a weak

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[8] Olsen, J.H.; Nielsen, A.; & Schulgen, G. 1993. Residence Near High Voltage Facilities and Risk of Cancer in Children. British Medical Journal 307: 891-895.

[9] Verkasalo, P.K., *et al.* 1993. Risk of Cancer in Finnish Children Living Close to Power Lines. British Medical Journal, 307:895-899.

[10] Green. L. M., A. B. Miller *et. al.* 1999. A Case-Control Study of Childhood Leukemia in Southern Ontario, Canada, and Exposure to Magnetic Fields in Residences. Int. J. Cancer 82:161-170.
Green. L. M., A. B. Miller *et. al.* 1999. Childhood Leukemia and Personal Monitoring of Residential Exposures to Electric and Magnetic Fields in Ontario, Canada. Cancer Causes Control 10:233-243.

[11] McBride, M.L., R.P. Gallagher, *et al.* 1999. Power-frequency Electric and Magnetic Fields and Risk of Childhood Leukemia in Canada. Amer. J. Epidem. 149:831-842.

positive association, the authors were careful to point out that selection bias, confounding, and a very small number of leukemia cases in high exposure groups (0.8 percent) could have accounted for some of the elevated risk. They also stated that numerous animal and laboratory studies have failed to show any association between cancer and exposure to EMF.

2005 Draper Study

In 2005 a British study of childhood leukemia and birth addresses within 600 meters of high voltage power lines was published.[12] This study used 9,700 matched case-control pairs for leukemia. Exposure was based on the shortest distance from a power line in the year of birth. This study reported a slight increase in childhood leukemia within 600 meters of a high-voltage transmission line. However, the increase in risk extended out to distances where the magnetic field from the power lines would have been overwhelmed or replaced by ambient magnetic field levels. The authors state in the study:

"Our increased risk seems to extend to at least 200 m, and at that distance typical calculated fields from power lines are <0.1 micro T (<1 mG) and of the <0.01 micro T (<0.1 mG) – 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."

2006 Kabuto study

A Japanese study on childhood leukemia and proximity to power lines was published in 2006.[13] This study used exposure assessments and distance from power lines in its evaluation. A pooled analysis of data was used. One limitation of this study was a relatively low response rate. Of the 781 leukemia cases identified, only 40% responded to the request for inclusion in the study. A small increase in risk was detected for leukemia at exposures over 4 mG. However, the importance of this study was limited by the small sample size and a relatively high level of statistical uncertainty.

Continued search for the cause of childhood leukemia

Childhood leukemia is a relatively rare disease and its causes are not well understood despite decades of study. Because scientists studying EMF exposure have found only inconsistent and at best weak associations between exposure and leukemia it is likely that some unidentified confounding factor or factors may be affecting study results. In 1997, a paper published in the Lancet proposed the hypothesis that a malfunction in a person's immune response may, for some individuals, lead to leukemia[14]. This malfunction is thought to be related to the rate of early childhood infection. The hypothesis suggests that some children whose immune systems are not sufficiently challenged in early childhood may be predisposed to develop leukemia. To test this hypothesis epidemiological researchers began to look at ways of measuring the rate of early infection in children. Attendance in a day-care facility is one surrogate measure of early childhood infection. Children who begin attending day-care at an early age are exposed to more

[12] Draper, G *et. al.* 2005. Childhood Cancer in relation to Distance from High Voltage Power Lines in England and Wales: a case-control study. BMJ:1290-1293.

[13] Kabuto *et. al.* 2006. Childhood leukemia and magnetic fields in Japan case-control study of childhood leukemia and residential power-frequency magnetic fields in Japan. Int. J. Cancer. 119(3):643-650.

[14] Greaves, M. F. 1997, Aetiology of Acute Leukemia. Lancet 349:344-349.

pathogens than children who remain in the home and so their as yet untested immune systems are challenged and strengthened. Likewise, the amount of time a child is breast-fed would also be related to the health of the child's immune system. If the hypothesis is correct, one would expect a negative correlation between day-care attendance and the occurrence of leukemia. In other words, attendance at a day-care facility and breast-feeding might impart some protection against leukemia.

Some epidemiological studies have shown just such a relationship. A study conducted in France found an inverse relationship between childhood leukemia and early common infections, day-care attendance, and prolonged breast-feeding.[15] Other studies have also suggested some support for the challenged immune system hypothesis.[16, 17]

Some recent studies (2007-2008) have reported a genetic component that appears to be involved in the development of childhood leukemia. Some researchers suspect that the process which leads to childhood leukemia begins during pregnancy with the fusion of two genes into a mutant hybrid. This genetic change can lead to the creation of pre-cancerous stem cells. Those stem cells can develop into malignant stem cells that can lead to the development of cancer. However, not everyone with this genetic mutation will develop leukemia. This important new discovery may significantly increase our understanding of the causes of childhood leukemia and provide new strategies for treatment.

Occupational studies

Epidemiological studies of occupational exposure to EMF suffer from the same general weaknesses affecting residential studies. As a group, the studies show inconsistent results and weak correlations. Early occupational studies reported a higher incidence of some cancers in some electrical occupations. However, many of these studies only used job titles to classify study subjects. No attempt was made to measure exposure to EMF.[18] Since 1994, there have been approximately 17 studies investigating occupational exposure to EMF and cancer. These later studies have also been hampered by an inability to accurately determine historic exposure. Studies generally look at cancer incidence over two or more decades. The actual long-term exposure to EMF for the cases in the study is unknown. As a surrogate for historic exposure many of these studies used short-term (measured exposure during one shift) contemporary EMF measurements for each job classification studied.

Occupational EMF studies have not been consistent in their findings. For example, Sahl *et. al.* studying EMF and cancer in utility workers in the United States, found no association between electrical occupations and the incidence of leukemia, brain cancer, and lymphoma.[19] On the other hand, Theriault *et. al.* studied utility workers from three different utilities in Canada and

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[15] Perrillat, F *et. al.* 2002. Day-care, early common infections and childhood acute leukemia: a multicentre French Case-control study. British Journal of Cancer 86:1064-1069.

[16] Murray, L *et. al.* 2002. Association of early life factors and acute lymphoblastic leukemia in childhood:historical cohort study. British Journal of Cancer 86:356-361.

[17] Schuz, J. *et. al.* 1999. Association of childhood leukemia with factors related to the immune system. British Journal of Cancer 80:585-590.

[18] Milham, S. 1982. Mortality From Leukemia in Workers Exposed to Electrical And Magnetic Fields (letter). New Eng. J. Med. 307:249.
Wright, W.E., *et al.* 1982. Leukemia in Workers Exposed to Electrical and Magnetic Fields (letter). Lancet 8308 (2):1160-1161.

[19] Sahl, J. D. *et. al.* 1993. Cohort and Nested Case-Control Studies of Hematopoietic Cancers and Brain Cancer Among Electric Utility Workers. Epidemiology 4:104-114.

France.[20] The results showed a weak association between presumed exposure and two types of leukemia with OR values ranging from 2.25 – 3.15. The researchers did report a statistically significant association for acute nonlymphoid leukemia (OR=3.15) but not for chronic lymphoid leukemia. The OR for brain cancers was also weak (1.95) and was not statistically significant. The authors concluded: "Despite the attempts made in this study to achieve adequate power, definitive evidence of an association between exposure to magnetic fields and leukemia and brain cancer has not been obtained." In another study, Savitz *et. al*. found a very weak association for total mortality and overall cancer mortality with an RR of 1.2 for the group with the highest estimated exposure. Leukemia mortality was not linked with estimated exposure. Brain cancer mortality was elevated, with an RR of 2.6 for the highest exposure category.

In an attempt to make sense of conflicting results from the studies described above, Kheifets *et. al.* conducted a comparative analysis of the three studies (Sahl *et. al*. 1993, Theriault *et. al*. 1994, and Savitz & Loomis. 1995).[21] These studies looked at exposure for workers from a total of nine electric utilities. A combined analysis of the data resulted in an RR of 1.12 for brain cancer and 1.09 for leukemia. The researchers concluded these studies showed only a weak association between magnetic fields and both brain cancer and leukemia.

Biological mechanism

As stated earlier, epidemiological studies, by themselves, cannot be used to prove a cause and effect relationship between exposure and human disease. In addition to epidemiological evidence, scientists need to propose a plausible biological mechanism. The biological mechanism explains how exposure to a suspected agent, such as EMF, might actually cause disease in the human body. Laboratory tests, usually at the cellular level, can then be conducted to test the proposed mechanism. For example, if a suspected agent is believed to cause cancer by affecting a cell's DNA then researchers will expose cells, under strictly controlled conditions, to the agent. Study results that show DNA damage will then lend support to the proposed biological mechanism. Studies of this type need to be repeated a number of times by different researchers in order for scientists to have confidence that a proposed mechanism could actually work under real world conditions.

We know that cancer can be initiated when a cell's DNA is damaged. Agents that cause damage to a cell's DNA are called genotoxins. Certain non-genotoxic substances called epigenetic agents can also contribute to the development of cancer. Epigenetic agents affect carcinogenisis indirectly, by increasing the ability of genotoxins to cause injury to cells. In a paper published in 1998, Moulder reviewed nearly 100 published studies on EMF and carcinogenicity.[22] These studies showed no repeatable evidence that power frequency fields have the potential to either cause or contribute to cancer. Studies showing some evidence of carcinogenic activity evaluated levels of EMF much higher than those associated with power lines.

Power-frequency EMFs are low energy fields. They do not have enough energy to break chemical bonds or to cause mutation in DNA. Power frequency EMF of the type found near

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[20] Thériault, G. *et. al.* 1994. Cancer Risks Associated with Occupational Exposure to Magnetic Fields among Utility Workers in Ontario and Quebec, Canada and France: 1970-1989. Amer. J. Epidem. 139:550-572.

[21] Kheifets, L. I. *et. al.* 1999. Comparative Analyses of the Studies of Magnetic Fields and Cancer in Electric Utility Workers: Studies from France, Canada, and the United States. Occup. Environ. Med. 56:567-574.

[22] Moulder, J. E. 1998. Power-frequency Fields and Cancer. Crit. Rev. Biomed. Eng. 26:1-116.

transmission lines can induce currents in the body, but these currents are much smaller than the typical electric currents present in the body from biological activity.[23]

Some theories on biological mechanisms suggest that a “resonance mechanism” could overcome biophysical constraints and make cells or organisms sensitive to power frequency EMF. However, scientists reviewing such theories have argued that such a mechanism is highly unlikely.[24] A study in 1987 suggested that “ion cyclotron resonance” could affect a cell’s calcium ion uptake and that this might, to some extent, explain the epidemiological associations. Liboff *et. al.* found that exposure to power frequency EMF caused changes in calcium ion uptake of cells.[25] Subsequent studies, however, failed to replicate this effect.[26]

Another theory for a biological mechanism involves the production of the hormone melatonin. It has been hypothesized that exposure to power-frequency EMF might suppress melatonin production and that melatonin might actually have cancer preventative properties.[27] However, three studies on humans found that exposure to both continuous and intermittent fields at levels of 10 mG and 200 mG had no effect on nighttime melatonin production.[28]

Although a number of possible biological mechanisms have been proposed, to date no plausible biological mechanism has been discovered that could explain how exposure to low- energy, power-frequency EMF might cause human disease.

Cosmic radiation, radon, and power lines

In the 1990s two theories were published proposing mechanisms that might explain how exposure to electric power lines might lead to human disease. These theories are based on the idea that power line electric or magnetic fields might focus or attract naturally occurring radiation in quantities large enough to lead to human health effects. If this were true, it might explain the slight increase in risk of childhood leukemia that has been reported in some epidemiological studies.

Cosmic Radiation

In 1992, Anthony Hopwood, an amateur astronomer, published an article in Electronics World and Wireless World entitled Natural Radiation Focused by Power Lines.[29] Using a homemade radiation detector, Mr. Hopwood took radiation count measurements under and near an 11 kV

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[23] Adair, R. K. 1991. Constraints on Biological Effects of Weak Extremely-low-frequency Electromagnetic Fields, Phys Rev A 43:1039-1048.

Valberg. P.A. *et al.* 1997. Can Low-level 50/60-Hz Electric and Magnetic Fields Cause Biological Effects. Rad. Res. 148:2-21.

[24] Adair, R. K. 1992. Criticism of Lednev’s Mechanism for the Influence of Weak Magnetic Fields on Biological Systems. Bioelectromag 13:231-235.

[25] Liboff, A.R., *et. al.* 1987. Ca^{2+}-45 Cyclotron Resonance in Human Lymphocytes. J. Bioelectricity 6(1):13-22.

[26] Parkinson, W. C. and C.T. Hanks. 1989. Experiments on the interaction of Electromagnetic Fields with Mammalian Systems. Biol Bull 176(S): 170:178.

[27] Stevens, R. G. *et. al.* 1992. Electric Power, Pineal Function, and the Risk of Breast Cancer. FASEB J. 6:853-860.

[28] Graham, C. *et al.* 1996. Nocturnal Melatonin Levels in Human Volunteers Exposed to Intermittent 60 Hz Magnetic Fields. Bioelectromag 17:263-273.
Selmaoui, B. *et al.* 1996. Acute exposure to 50 Hz Magnetic Field does not affect Hematologic or Immunologic Functions in Healthy Young Men: A circadian study. Bioelectromag 17:364-372.
Graham, C. *et al.* 1997. Human Melatonin during Continuous Magnetic Field Exposure. Bioelectromag 18:166-171.

[29] Hopwood, A. 1992. Natural radiation focused by power lines: New evidence. Electronics World + Wireless World. 92:912-915.

power line. He reported that the counts varied as he moved away from the line. He recorded a minimum count immediately under the line. The count reached a maximum a few meters away from the centerline but then continued to decrease as he moved further away from the line. Hopwood hypothesized that the power lines somehow "focused" cosmic rays at a certain distance from the line. Exposure to these higher concentrations of cosmic rays might lead to health effects.

Shortly after Hopwood published his theory, England's National Radiological Protection Board (NRPB) conducted a study to test his hypothesis. Researchers for the NRPB attempted to reproduce Hopwood's experiment using more sophisticated measuring devices. They took radiation counts at the same 11 kV line tested by Hopwood and at a 440 kV line. They could not duplicate Hopwood's results and found no significant differences in radiation measurements under or away from the line.[30]

In 1997 and again in 2000, researchers reported additional attempts to duplicate Hopwood's findings. In both these studies, the researchers concluded that there is little support for Hopwood's theory that power lines could focus cosmic radiation in such concentrations as to threaten human health. Vistnes *et. al.* measured cosmic radiation under and around a 300 kV and a 420 kV power line. They found small variations in dose rates with distance from the power lines. However, no symmetrical pattern was observed. These researchers concluded that their study did not support the idea that power lines could "focus" cosmic radiation.[31] Skedsmo and Vistnes concluded in their study that Hopwood's hypothesis "… is neither supported by any experimental observations performed after the original finding, nor by our theoretical analyses. While in theory a small effect of electromagnetic fields on the trajectories of cosmic particles can be demonstrated, our simulations show that the effect is far too small to be of any possible health significance."[32]

Radon

Radon is an odorless, naturally occurring radioactive gas that comes from the soil. Radon and its radioactive decay products are found in easily measurable concentrations in all outdoor air and in higher concentrations indoors. Studies of tens of thousands of miners exposed to high concentrations of radon and its decay products show that they cause lung cancer. However, these studies found no significant increase in other forms of cancer due to exposure to radon and it decay products.[33] The risk of lung cancer from exposure to radon and radon decay products depends on their concentration in air and the length of time a person is exposed to the radon source.[34]

In 1996 and again in 1999, D. L. Henshaw *et al*. published papers suggesting that the electric fields created by large electric transmission lines could significantly increase the concentration and deposition of radon decay products in the vicinity of power lines. Inhaling the increased

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[30] Burgess. P., and M. Clark. 1994. Cosmic radiation and power lines. Radiol. Protec. Bull. 131:17-19.

[31] Vistnes, A. I., Strand, T., and Thommesen, G. 1997. Focusing of cosmic radiation by power lines? J. Radiol. Prot. 17(3):185-193.

[32] Skedsmo. A., and A. I. Vistnes. 2000. Deflection of cosmic radiation near power lines – a theoretical approach. Health Phys. 78(6):679-686.

[33] National Research Council. 1999. Health Effects of Exposure to Radon – BEIR VI.

[34] For more information on radon go to www.slh.wisc.edu/radiochem/results.html or contact the Wisconsin State Laboratory of Hygiene – Environmental Health Division – Radiochemistry Unit.

concentrations of radon decay products might increase the risk of cancer. This theory is sometimes referred to as the Henshaw hypothesis.

However, other measurement studies have not been able to show that power lines can significantly increase local concentrations of radon. Miles and Algar measured radon decay product concentrations in high and low electric fields created by a high-voltage (400kV) power line. Their results found no significant difference in outdoor radon decay product concentrations between locations with high and low electric fields.[35]

In another study McLaughlin and Gath studied the behavior of airborne radon daughters in the vicinity of a 400 kV power line. They took measurements with the power line on and off. They found that the fields produced by the power line did not concentrate radon decay products under or near the power line. Their study also provided no support for the Henshaw hypothesis.[36]

The Wisconsin Department of Health and Family Services - Radiation Protection Section acknowledges that if radon and radon decay product concentrations increased near power lines, there might be a small increase in the risk of lung cancer for people spending a large amount of time under or very near those lines. However, the increased risk is insignificant compared to the risk from indoor radon levels. Outdoor radon concentrations are about a quarter of average indoor levels. People spend very small amounts of time in a single location outdoors. Studies have shown that on average, people spend 70 percent of their time in their homes. So the increases found by Henshaw do not represent a significant increase in people's total radon exposure.[37]

If the insignificant increases in radon and decay product concentrations suggested by Henshaw were responsible for significant increases in the incidence of leukemia or any other cancer, we certainly would see a more significant incidence of those cancers resulting from radon in homes. There also would have been significant increases in those cancers in the miner studies. In addition, subsequent scientific studies have not confirmed the results of Henshaw's research.

Based on the scientific research to date, and consistent with the assessments of major authoritative groups, the Wisconsin Department of Health and Family Services - Radiation Protection Section believes there is no compelling evidence indicating that power lines increase the risk of any kind of cancer by concentrating radon and radon decay products in their vicinity.

Whole animal studies

Whole animal studies involve subjecting study animals to EMF under strictly controlled conditions. When epidemiological studies suggest associations between exposure agents and disease, whole animal studies are used to determine whether or not exposure does indeed lead to disease. Until recently few studies on animal carcinogenesis and EMF have been conducted.

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[35] Miles, J. C. H., and R. A. Algar. 1997. Measurements of radon decay product concentrations under power lines. Radiation Prot. Dosimetry. 74(3):193-194.

[36] McLaughlin, J. P. and G. Gath. 1999. Radon progeny activities in the vicinity of high voltage power lines. Radiation Prot. Dosimetry. 82(4):257-266.

[37] Wisconsin Department of Health and Family Services, Radiation Protection Unit, P.O. Box 309, Madison, WI 53701-0309; (608) 267-4795.

In 1997 a study conducted by Yasui *et. al*. exposed male and female rats to 50 Hz fields at levels of 5 and 50 Gauss.[38] No effect was found on overall cancer rates or rates of leukemia, lymphoma, brain cancer, and breast cancer. Another 1997 study conducted by Mandeville *et. al*. exposed female rats for two years to 60Hz fields at intensities of 20 mG, 200 mG, 2 Gauss, and 20 Gauss.[39] No effect on survival, or leukemia or solid tumor incidence was found. In 1998, Harris *et. al*. exposed lymphoma-prone mice to 50 Hz fields at 10 mG, 1 Gauss, and 10 Gauss.[40] This study found no effect on lymphoma incidence. The U. S. National Toxicology Program supported studies by McCormick[41] and Boorman *et. al*.[42] These studies showed that mice and rats exposed to power-frequency EMF had no increase in mortality or cancer incidence. Exposure to intermittent (one hour on and one hour off) fields at 60 Hz and 10 Gauss had no effect on overall cancer, leukemia, brain cancer, lymphoma, or breast cancer. A recent study also looked at the impact of EMF exposure on rats with leukemia.[43] This study exposed leukemic rats to 50 Hz fields at 1 Gauss until the test subjects died. Exposure to EMF had no effect on the progression of leukemia.

Overall, whole animal exposure studies conducted to date have not shown evidence that long-term exposure to EMF causes cancer and found no link to leukemia, brain cancer, and breast cancer.

REVIEWS AND RECOMENDATIONS

National Research Council EMF Research Review

In 1991, the U.S. Congress requested the National Academy of Sciences to review the literature on the health effects from exposure to EMF. The National Research Council (NRC) was given the task of conducting the review. A 16-member committee composed of scientists and other experts reviewed more than 500 studies spanning 17 years of research. The studies covered a wide range of subject areas including cellular and molecular effects, epidemiology, and animal and tissue effects. Based on this comprehensive evaluation, the committee issued a 314-page report in October 1996.[44] This report concluded that the current body of scientific evidence does not show that exposure to EMF presents a human health hazard. No conclusive or consistent evidence has shown that exposure to residential EMF produces cancer, neurobehavioral problems, or reproductive and development effects. The NRC review did not cover occupational exposure studies.

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[38] Yasui, M. *et. al.* 1997. Carcinogenicity Test of 50 Hz Sinusoidal Magnetic Field in Rats. Bioelectromag 18:531-540.90.

[39] Mandeville, R. *et. al.* 1997. Evaluation of the Potential Carcinogenicity of 60 Hz Linear Sinusoidal Continuous Wave Magnetic Fields in Fischer F344 rats, FASEB J 11:1127-1136.

[40] Harris, A. W. *et. al.* 1998. A Test of Lymphoma Induction by Long-Term Exposure of Eμ-Pim1 Transgenic Mice to 50-Hz Magnetic Fields. Rad. Res. 149:300-307.

[41] McCormick, D.L., G. A. Boorman *et. al.* 1999.Chronic Toxicity/Oncogenicity Evaluation of 60 Hz (power frequency) Magnetic Fields in B6C3F1 Mice. Toxicol. Pathol. 27:279-285.

[42] Boorman, G.A., D.L. McCormick *et. al.* 1999. Chronic Toxicity/Oncogenicity Evaluation of 60 Hz (power frequency) Magnetic Fields in F344/N rats. Toxicol. Pathol. 27:267-278.

[43] Devevey, L., C. Patinot. *et. al.* 2000. Absence of the Effects of 50Hz Magnetic Fields on the Progression of Acute Myeloid Leukaemia in Rats. Int. J. Radiat. Biol. 76:853-862.

[44] National Research Council Committee on the Possible Effects of Electromagnetic Fields on Biological Systems. (1996). Possible Health Effects of Exposure to Residential Electric and Magnetic Fields. National Academy Press 314 pp. (800-624-6242).

EMF research and public information dissemination program

In 1992, the National Energy Policy Act established a federal scientific and engineering research program to study EMF. This program is called the EMF Research and Public Information Dissemination (RAPID) Program. The National Institute of Environmental Health Sciences (NIEHS) is charged with evaluating the human health effects of exposure to EMF. In June 1998, a scientific working group, established to advise the NIEHS, issued a report recommending that EMF be classified as a Class 2B possible carcinogen using a classification system developed by the International Agency for Research on Cancer (IARC).[45] This is not a determination of carcinogenicity. In the IARC classification system, a substance must be placed in Class 2B if there is inadequate epidemiological evidence and insufficient animal data supporting carcinogenicity. The report states in its conclusion:

"The NIEHS believes that the probability that ELF-EMF exposure is truly a health hazard is currently small. The weak epidemiological associations provide only marginal, scientific support that exposure to this agent is causing any degree of harm. The NIEHS concludes that ELF-EMF 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."

The NIEHS continues to study and evaluate EMF, but the scientific support for a serious health risk is very small, even after two decades of research.

National radiation protection board report—2001

In early March of 2001, England's National Radiological Protection Board (NRPB) issued a report on power frequency magnetic fields.[46] The report is a comprehensive review of epidemiological and experimental studies on exposure to power frequency magnetic fields and human disease. The report concluded that at a cellular level, there is no clear evidence of power frequency EMF affecting biological processes. Animal studies of carcinogenesis also provide no support for power frequency EMF causing cancer. This includes studies of leukemia, lymphoma, brain cancers, and tumors in general. Studies of impacts on melatonin showed no changes in the timing and production of melatonin in human test subjects. In addition, the report stated that there was no evidence of any EMF link to breast cancer or to negative effects on the immune system.

The NRPB report also reviewed epidemiological studies and concluded that there is no evidence linking EMF to cancers in general or leukemia in adults. In its conclusion the report states: "In the absence of clear evidence of a carcinogenic effect in adults, or of a plausible explanation from experiments on animals or isolated cells, the epidemiological evidence is currently not strong enough to justify a firm conclusion that such fields cause leukemia in children." While the NRPB advisory group recognized that the scientific evidence associating exposure to power frequency EMF and health effects is very weak it also suggested that there remains a possibility of a small risk of leukemia in children under the age of 15. As a result, the NRPB recommended the continued study of exposure to children.

[45] NIEHS Report on Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields. 1999. National Institute of Environmental Health Sciences-National Institutes of Health. NIH publication No. 99-4493. 67 pp.

[46] Doll, R. National Radiological Protection Board. 2001.ELF Electromagnetic Fields and the Risk of Cancer. Doc NRPB: 12 (1).

Summary

Many scientists believe the potential for health risks for exposure to EMF is very small. This is supported, in part, by weak epidemiological evidence and the lack of a plausible biological mechanism that explains how exposure to EMF could cause disease. The magnetic fields produced by electricity are weak and do not have enough energy to break chemical bonds or to cause mutations in DNA. Without a mechanism, scientists have no idea what kind of exposure, if any, might be harmful. In addition, whole animal studies investigating long-term exposure to power-frequency EMF have shown no connection between exposure and cancer of any kind.

While scientific consensus appears to be forming, there are still some unanswered questions about EMF exposure and human health. The Commission will continue to consider EMF in its power line siting decisions. But the Commission must balance the likelihood of health effects from exposure to power line EMF with issues of need, cost, and environmental impact. The PSC will base its EMF policy on a continuing review of scientific research.

2002 Report from the State of California

In response to a California Public Utilities Commission request, three scientists from the California Department of Health Services reviewed the studies related to possible health problems from exposure to EMF created by power lines, wiring in homes and businesses, and appliances.[47] This panel's conclusions differed from the conclusions of other review panels (NIEHS, IARC, and the NRPB) by expressing a greater belief that exposure to EMF may lead to some degree of increased risk for certain diseases. The report's major conclusions are:

- 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, 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.

The reviewers were asked to express in numbers their individual professional judgments that the range of added personal risks suggested by the epidemiological studies were "real." They did this as a numerical "degree of certainty" on a scale of 0 to 100. For two of the reviewing scientists the degree of certainty for some of their conclusions was quite large, indicating a weakness in their positive conclusions.

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[47] Kheifets L; Shimkhada R: 2005. Childhood *leukemia* and EMF: review of the epidemiologic evidence**.** Bioelectromagnetics, Vol. Suppl. 7, pp. pp. S5-S11.

An internal Electric and Magnetic Field Scientific Advisory Panel (SAP) reviewed the final California report. This review 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."

While the California report should not be discounted, its weaknesses must be acknowledged in the light of the conclusions reached by other review panels.

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

In 2002 The IARC released its report on EMF (Static and Extremely Low-frequency (ELF) Electric and Magnetic Fields). The IARC reviewed the available scientific evidence to date and reached largely the same conclusions found in the NIEHS review of magnetic fields. This report did not find reliable and consistent evidence to implicate exposure to EMF with increased risk for adult cancers or reproductive effects. However, the study also concluded that:

> "The association between childhood leukemia 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."

The IARC did classify low frequency EMF as a Class 2B carcinogen because of the lingering concern regarding childhood leukemia. Agents listed in Class 2B are considered possible carcinogens as opposed to Class 1 – definitely a carcinogen, and Class 2A – a probable carcinogen. For agents in Class 2B there is limited epidemiological evidence plus limited or inadequate evidence from animal tests. Class 2B agents include automobile exhaust, coffee, and pickled vegetables.

2007 World Health Organization (WHO) – Environmental Health Criteria (EHC) Monograph 238 – Extremely Low Frequency Fields (0-100 kHz)

The WHO monograph on extremely low frequency (ELF) electric and magnetic fields reviewed the scientific literature on exposure to ELF fields and the potential for human health impacts. The report evaluated biophysical mechanisms, neurobehavior, potential effects on the neuroendocrine system, neurodegenerative disorders, cardiovascular disorders, the immune system, reproduction and development, and cancer.

Biophysical Mechanisms
The report reviewed scientific work on explaining the biological mechanism by which exposure to ELF fields might cause human health impacts. The biological mechanisms reviewed in this report included direct biophysical interactions with fields. These included: breaking of chemical bonds, effects on charged particles, and narrow bandwidth or the "resonance" mechanism. The scientific evidence did not find plausible support for these mechanisms. (See page 12 for a discussion on biological mechanisms). In addition, other possible mechanisms such as neural response, radical pair, and effects on magnetite in the brain were found to be implausible.

Possible Health Effects:
The review found that scientific evidence did not support a link between ELF magnetic fields and health effects resulting in impacts to neurobehavior (hypersensitivity, depression, and insomnia), the endocrine system, neurodegenerative disease (ALS and Alzheimer's), cardiovascular disorders, human reproduction, or the immune system. In general, studies exploring these areas of human health were inconclusive, inconsistent, or showed no support at all for health impacts.

Cancer and Childhood Leukemia:
For cancer studies, the WHO review incorporated the IARC 2002 conclusions (See above). In addition, the WHO reviewed studies conducted since the IARC released its scientific review in 2002. In terms of adult cancers, the review concluded that a consistent association between exposure to power frequency magnetic fields and adult leukemia or brain cancer has not been established.

Since the IARC review, two major epidemiological studies on childhood leukemia have been published: the Draper and Kabuto studies. (See page 9) These studies were added to the WHO epidemiological review.

The WHO review concluded that studies on the effects of ELF magnetic fields on cells have shown no evidence of genotoxicity. In addition, studies on cell proliferation, calcium signaling, intercellular communication, heat shock protein expression, and malignant transformation have not yielded positive results linking ELF exposure to changes in cellular function.

Overall, in terms of effects on the occurrence of cancer including childhood leukemia, the WHO report did not find any overwhelming evidence that would change the conclusions of the IARC 2002 report. While some concern remains, the continued lack of support from whole animal studies and a continued inability to explain the mechanism by which disease may be caused by low level ELF exposure continues to temper the final scientific judgment. The report's final conclusion on health risk for childhood leukemia states:

> "Consistent epidemiological evidence suggests that chronic low-intensity ELF magnetic field exposure is associated with an increased risk of childhood leukemia. However, the evidence for a causal relationship is limited, therefore exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted."

Pacemakers and Defibrillators—Electromagnetic Interference

Implantable medical devices are becoming increasingly common. Two such devices, pacemakers and implantable cardioverter defibrillators (ICDs), have been associated with problems arising from interference caused by magnetic and electric fields. This type of interference is often termed electromagnetic interference or EMI. EMI can cause inappropriate triggering of a device or inhibit the device from responding appropriately. Sources of EMI have been documented by medical personnel and include radio-controlled model cars, slot machines, car engines, digital cellular phones, anti-theft security systems, certain procedures conducted in a hospital environment including radiation therapy, and high-voltage electrical systems and devices.[48] It has been estimated that up to 20 percent of all firings of ICDs are inappropriate, but only a very small percentage of those are caused by external electromagnetic interference.[49]

Modern implantable devices are very sophisticated and are capable of a wide variety of tasks and functions.

Pacemakers and ICDs perform different tasks within the body. Pacemakers are designed to provide the heart with the appropriate electrical signal needed to stimulate regular contractions. Pacemakers are programmable and can function in a number of different modes. Commonly, pacemakers exposed to electromagnetic interference of sufficient size and frequency will revert to what is called an asynchronous mode pacing.[50] Once the interference is removed, the pacemaker returns to its normal operating parameters. Asynchronous mode is not life threatening and will not harm a patient. However, a serious situation might occur if external electromagnetic interference is large enough to "trick" the pacemaker circuitry into interpreting the interference as normal heart behavior but is not large enough to trigger asynchronous mode. In that case, the pacemaker would be inhibited from firing and would not respond appropriately to a slow heart rate or cardiac insufficiency. This could result in a serious health threat.[51]

Defibrillators or ICDs detect when ventricular fibrillation occurs and will then administer a shock to the heart to reestablish a normal heart rhythm. In certain circumstances it is possible for EMI to mimic electrical signals that the ICD interprets as fibrillation. In this case the ICD can inappropriately deliver a shock to the heart. This type of response has been reported in a case of prolonged exposure to fields generated by an antitheft device in the doorway of a store.

A number of researchers, primarily in England, have studied the behavior of implantable cardiac devices exposed to 50 Hz high-voltage electrical systems. The researchers found that exposure to electric fields can induce currents in the body that can interfere with the proper operation of pacemakers and ICDs. The results from these studies can be somewhat confusing because responses to electric fields will vary depending on the manufacturer and model of the devices studied. In addition, the physical attributes of study subjects, the degree of grounding, and their

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48 Harthorne, J. W., P. Barach., *et. al*. 1999. Implantable Defibrillators, Pacemakers, and Electronic Antitheft Devices. N. Eng. J. Med. 340:1117-1119.

49 Op cit. Harthorne *et. al*.

50 The earliest pacemakers (1960s and 1970s) functioned asynchronously. This means that the pacemaker provided a regular, fixed-rate electrical signal to the heart. This is inefficient in terms of battery life and is not physiologically normal. Modern pacemakers operate in physiological mode where the pacemaker senses the natural electrical activity of the heart and supplies support only when needed. Modern pacemakers operate in asynchronous mode only as a default.

51 Sastre, A. 1997. Susceptibility of Implanted Pacemakers and Defibrillators to interference by Power-Frequency Electric and Magnetic Fields. EPRI TR-108893.

location (i.e. their physical orientation in space with respect to the electric field) all have an impact on the amount of body current induced and how the implanted device responds.

The first study of power-frequency EMI and implantable cardiac devices was published in 1983 by Butrous *et. al*.[52] This study examined 35 patients with pacemakers. The pacemakers included 16 different models from 6 manufacturers. The patients were exposed to electric fields in the air that varied from 1 kV/m to 20 kV/m.[53] These fields induced body currents of between 10 and 337 microamperes (μA).[54] The study showed a clear linear relationship between electric field intensity and body currents. The researchers identified four device responses to the EMI: (1) normal sensing and pacing in some units; (2) reversion to the fixed (asynchronous) rate in other units; (3) slow and irregular pacing in several units; (4) mixed behavior over a specific range of field strengths in which slow and irregular pacing preceded reversion to asynchronous or fixed rate pacing.

Reversion to asynchronous pacing occurred in 18 test subjects. This condition is generally not life threatening; the physiologic responses of patients ranged from no noticeable difference in physical well-being to a sense of discomfort or dizziness. In this study, seven of the 18 patients experiencing reversion to asynchronous pacing reported being aware of competitive pacing and described the sensation as very uncomfortable. One patient experienced dizziness. In addition, some studies have indicated that there is a small possibility that reversion to asynchronous pacing could lead to dangerous arrhythmias.[55,56]

In the Butrous study, pacemaker responses depended on the magnitude and distribution of induced body current relative to the pacemaker as well as field strength. The threshold at which an implantable device responded to an external EMI varied for each unit depending on the make and model of the device and the patient height, build, and posture (physical orientation with respect to the electric field). The results showed a wide range of responses. For example, each of the units from one manufacturer reverted to asynchronous mode at widely different body currents (37, 46, 55, and 70μA). Electric fields in the range of 2-5 kV/m can cause body currents of this magnitude.[57]

In 1988, Kaye *et. al.* studied 28 patients with pacemakers and temporary transvenous electrodes.[58] This study induced body currents into patients in order to simulate exposure to electric fields. The minimum current producing inappropriate pacing varied widely among different pacemakers ranging from 27-246 μA. Using the linear relationship between body currents and electric fields demonstrated by Butrous *et. al.* in their 1983 study, it can be inferred that the most sensitive pacemaker studied by Kaye could have malfunctioned when exposed to a 50 Hz electric field of 1.5-2.0 kV/M. The least sensitive pacemakers would not have shown

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[52] Butrous, G.S., J.C. Male., *et. al.* 1983. The Effect of Power Frequency High Intensity Electric Fields on Implanted Cardiac Pacemakers. Pacing & Clinical Electrophysiology. 6:1282-1292.

[53] 1kV/m = 1,000 Volts/meter

[54] A microampere = one millionth of an ampere.

[55] Tavel, M.E. and Fisch. C. 1964. Repetitive Ventricular Arrhythmia Resulting from Artificial Internal Pacemaker. Circulation, 30:493.

[56] Bilitch, M., Cosby, R.S., and Caferky, E.A.:1967. Ventricular fibrillation and Competitive Pacing. N. Eng. J. Med. 276:598.

[57] Bilitch, M., Cosby, R.S., and Caferky, E.A.:1967. Ventricular fibrillation and Competitive Pacing. N. Eng. J. Med. 276:598.

[58] Kaye, G.C., Butrous, G.S., *et. al.* 1988. The effect of 50 Hz External Electric Interference on Implanted Cardiac Pacemakers. Pacing & Clinical Electrophysiology. 117:999-1008.

inappropriate behavior until electric fields reached nearly 20 kV/m.[59] In this study three Medtronic pacemakers did not exhibit inappropriate behavior and were unaffected by body currents up to 600 μA.

Astridge *et. al*. exposed 22 patients with implanted dual pacemakers to body currents. Patients were selected with programmable pacemakers with interchangeable lead configurations. In all, pacemakers from four manufacturers (five different models) were studied. Because the pacemakers all had interchangeable lead configurations, the researchers were able to study differences in pacemaker behavior between monopolar and bipolar configurations. With the exception of one manufacturer (Medtronic), all pacemakers eventually malfunctioned when exposed to 50 Hz current. Dual chamber pacemakers with a monopolar lead configuration were considerably more sensitive to induced 50 Hz body currents. Inappropriate operation for dual chamber pacemakers, configured with the atrial lead monopolar, occurred for body currents ranging from 10-80μA (electric fields in the range of 1.5-4 kV/m could, under proper conditions, induce similar body currents). For pacemakers with the ventricular lead monopolar, the onset of inappropriate behavior occurred over a range of from 40-120 μA of induced body current (3-12 kV/m).[60]

Toivonen *et. al*. studied the behavior of pacemakers for 15 patients using 12 different models of pacemakers from four manufacturers.[61] This study exposed patients to 50 Hz, 110 kV and 400 kV high-voltage power lines. As with other studies the results varied considerably among type and model. Results showed that for pacemakers programmed to a normal sensitivity (monopolar mode) the earliest evidence of pacing abnormalities occurred for one pacemaker in areas with electric fields ranging from 1.2 to 1.7 kV/m (near the 110 kV power line). Five pacemakers showed signs of inhibition and six signs of premature pacing when exposed to areas with electric fields in the 7 to 8 kV/m range (near the 400 kV power line). Considerable variability was found among pacemaker models. Some pacemakers maintained normal function even in 8 kV/m fields.

The effects of exposure to high-voltage power systems will vary between individual and make and model of pacemaker or ICD. Electric fields appear to be the most likely source of interference. Magnetic field levels that may cause problems with pacemakers and ICDs are generally very large. Technical data from Medtronic (a major manufacturer of pacemakers and ICDs) recommend a threshold of 1 gauss for modulated magnetic fields. This threshold level is 5 to 10 times greater than the magnetic fields likely to be produced by a high voltage power line. Electric fields, however, may be more problematic. Medtronic recommends a "two to three foot distance from the pacemaker to high voltage lines for every 10,000 volts."[62] Electric fields below 6 kV/m will not interfere with Medtronic ICDs.

Power lines are only one of a number of potential EMI sources that people are exposed to in their daily lives. Some examples of common sources of EMI include cellular phones, the ignition system of internal combustion engines (cars, lawnmowers, and chainsaws), slot machines, and antitheft devices found in many retail stores. All pacemaker and ICD patients are informed of

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59 Op. cit. Sastre. 1997

60 Astridge, P.S., Kaye, G.C., *et. al.* 1993. The Response of Implanted Dual Chamber pacemakers to 50Hz Extraneous Electric Interference. Pacing & Clinical Electrophysiology. 16:1966-74.

61 Toivonen, L. Valjus, J.. *et. al.* 1991. The Influence of Elevated 50Hz Electric and Magnetic Fields on Implanted Cardiac Pacemakers: the Role of the Lead Configuration and Programming Sensitivity. Pacing & Clinical Electrophysiology. 14:2114-2122.

62 High Power Voltage and Pacemakers. 1996. Medtronic Pacing Technical Services.

the potential problems associated with exposure to EMI and must adjust their behavior accordingly. Moving away from a source is a standard response to the effects of exposure to EMI. Electric fields are also relatively easy to shield. Buildings, cars, or the enclosed cab of a truck or tractor should provide ample shielding from external electric fields.

Reducing EMF Levels from Power Lines

Low-EMF pole design

A common method to reduce EMF is to bring the lines (conductors) closer together. This reduces the magnetic fields created by each of the three conductors because the fields interfere with one another. The overall effect is to reduce the total EMF coming from the line. There are practical limits to how close together conductors can be placed. Conductors must be far enough apart so that arcing cannot occur and so that utility employees can safely work around them.

The benefit of using a structure design that reduces EMF will diminish as you move away from the power line. Generally, EMF levels for most modern transmission pole designs are nearly the same at a distance of between 150 to 200 feet.

Magnetic fields can also be reduced with a double-circuit pole. A double-circuit pole has two circuits on one structure. When a double circuit is built, the magnetic fields from each of the phase conductors will interact with one another. This often results in a reduction in magnetic fields over what would be experienced with just one transmission line in place. In addition, double-circuit poles are often taller and therefore raise the wires farther overhead.

Disadvantages of low-EMF poles

The closer the conductors are to one another, the shorter the distance between poles. This means that a power line using low-EMF poles will tend to have more poles per mile. Increasing the number of poles increases the cost of the line. It may also increase environmental impacts. For example, using more poles may make farming more difficult.

Why don't the utilities use low-EMF poles for all their projects?

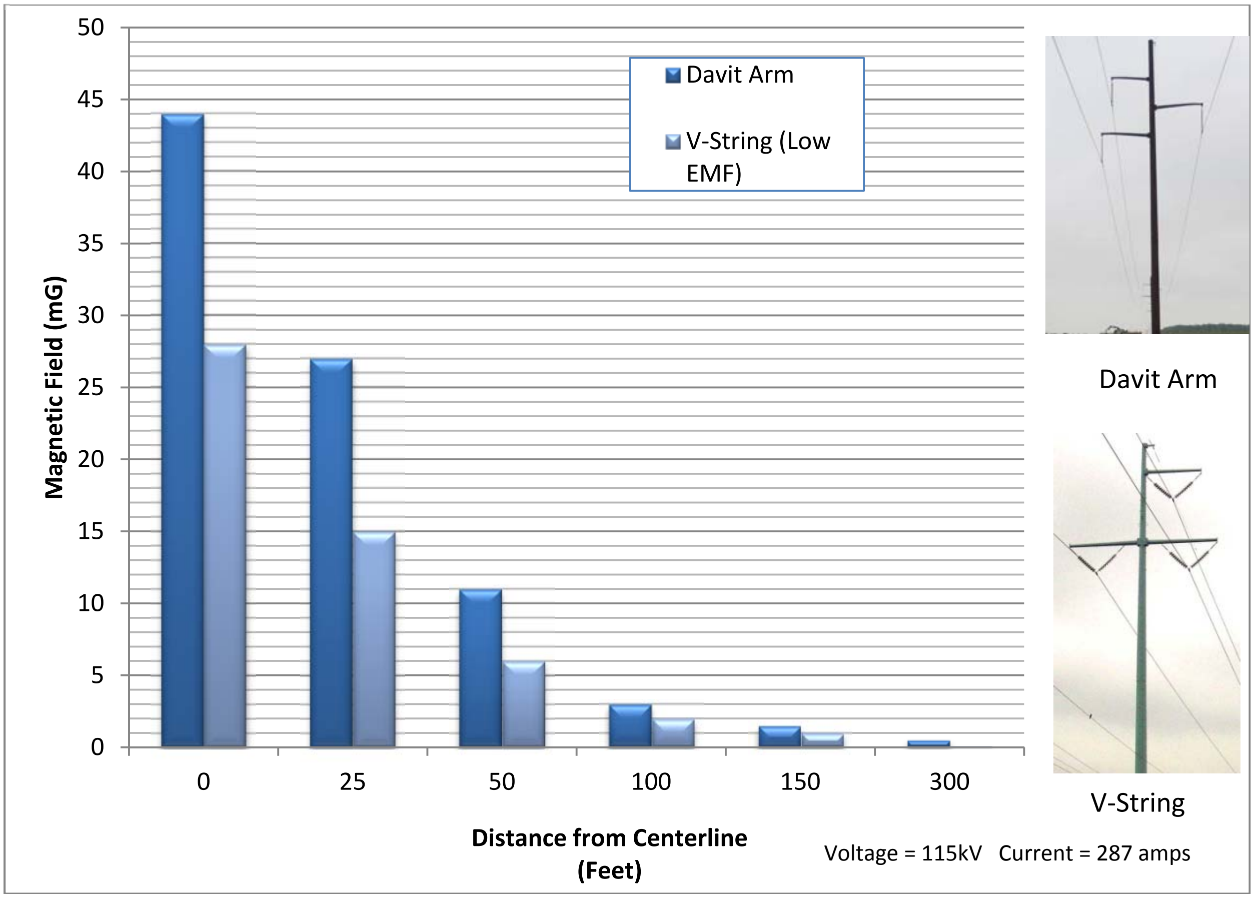
- Using all low-EMF poles usually increases the total cost of the project because there are more poles per mile.
- Other types of construction may be necessary to reduce environmental impacts. For example, poles capable of supporting the conductors over larger spans can be used to cross rivers, small wetlands, or farm fields.

Figure 3 compares magnetic fields between a low-EMF pole (V-string design) and a higher EMF pole (Davit Arm design). At 150 feet, the magnetic fields are very nearly the same for each structure. In this example, it would seem reasonable to use low-EMF poles when the line is within 150 feet of a residence, school, or hospital. However, the extra cost would not be justified if the line were further than 150 feet from these buildings because it would not reduce exposure to the inhabitants.

Underground lines decrease magnetic fields

Analysis shows that underground power lines, especially on transmission systems, reduce magnetic fields. Underground lines bring the conductors closer together than is possible with an overhead line. While the magnetic field directly over an underground transmission line can be very high, the closeness of the conductors increases the cancellation effect. This means that the magnetic fields from an underground line will diminish much more rapidly with distance from the line. A study conducted by the State of Rhode Island indicated that at a distance of as little as 25 feet, an underground transmission line can reduce EMF by more than 99 percent when compared to overhead lines.

Figure 3 EMF for two types of transmission structures



Today, some high voltage transmission lines in heavily developed urban areas are built underground. This is because adequate clearances may not be possible for overhead lines on congested city streets. Typically, lines are buried 3.5 to 4 feet deep.

Some problems with underground transmission lines:

- They are more expensive. Because there are many project specific variables that affect the cost of any transmission line, the relative difference in cost between overhead and underground construction can vary. In most cases, however, underground construction costs range between four and ten times more than equivalent overhead construction costs. Occasionally unusual circumstances, (i.e., an underground crossing of a major river with a high capacity line), could drive costs higher than ten times overhead construction.

- While outages are rare, they are difficult and time-consuming to repair, possibly resulting in longer power outages.
- They can cause serious environmental problems, depending on their location. (Buried cables require digging trenches which disturbs the soil. Oil-filled cables present the danger of fluid leaks that can result in soil and water contamination.)

Commission Activity

Orders to the Wisconsin utilities

Since 1989, the Commission has periodically reviewed the science on EMF and has held hearings (as part of its Advance Plan process)[63] to consider the topic of EMF and human health effects. The most recent hearings on EMF were held in July 1998. As a result of these hearings, the Commission has ordered Wisconsin utilities to:

- Contribute to the national EMF research effort.
- Provide information to the public on EMF, perform EMF measurements for customers upon request, and develop (with Commission staff guidance) a uniform EMF measurement protocol.
- Evaluate and include information on how magnetic fields differ for alternative power line configurations in construction applications.
- Consider the number of persons exposed to EMF along proposed transmission line routes and the intensity and duration of exposure.
- Submit a list of homes, workplaces, hospitals, nursing homes, day-care centers, and schools near proposed and alternate transmission line routes.

Certification requirements for construction projects

Magnetic field estimates for proposed utility projects

A utility must provide information on EMF when it applies to the Commission for permission to build a transmission line. Each application must include estimates of the magnetic field created by the proposed new line. Utility engineers calculate the EMF for any given voltage, pole design, and current flow based on criteria established by Commission staff.

The Commission requires utilities to provide information about the types of buildings along any route: residences, hospitals, nursing homes, day-care centers, schools, and workplaces. In its application, a utility must report the number and type of buildings within 300 feet of a proposed centerline. EMF fields also calculated out to a minimum of 300 feet. In situations where a proposed line would replace an existing line or be built as a double circuit with an existing line, the utility is also required to provide estimates of the magnetic fields that are being produced by the existing facility. During the review process, Commission staff calculates the changes in EMF levels likely to occur as a result of the new line. Estimates are created for a new line using the expected loads (current flow) at the time the line would go into service and for estimated loads ten years in the future.

[63] Change to Wis. Stat. 196.41 passed by the Legislature in 1997 eliminated the Advance Plan process.

Commission staff checks the utility's calculations of the estimated magnetic fields and then analyzes each route for potential exposure to magnetic fields. This information is then provided to the public and considered in route selection decisions made by the Commission. When selecting transmission line routes, the Commission seeks to balance environmental and social impacts with need, performance, and cost.

The Public Service Commission of Wisconsin is an independent state agency that oversees more than 1,100 Wisconsin public utilities that provide natural gas, electricity, heat, steam, water and telecommunication services.

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