Electromagnetic Fields (EMFs) and Childhood Leukemia

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History

The history of electricity dates back to Thales von Milet who discovers static electricity of amber in about 600 BC. Then later in the 1600s physicist William Gilbert hypothesized about the magnetic properties of the earth. In 1729 Benjamin Franklin discovers the electrical nature of lightning. Then as centuries passed, more and more scientists learned more about the properties of electricity, and inventors harnessed those properties into useful products such as light bulbs, home appliances, telephones, televisions, etc. Nowadays electricity is ubiquitous and with the increase in electricity use, there need to be power lines to support all the current and voltage going to power people's homes and businesses.

In United States in the 1960s, new high voltage electric power transmission lines emerged. The high voltage transmission systems consisted of copper, aluminum, or steel wires, suspended from towers of steel or wood by porcelain insulators. In certain areas where many large power lines create a safety hazard, the power lines are constructed underground to distribute the electricity. The modern electric power system consists of six main components: 1) the power station, 2) a set of transformers to raise the generated power to the high voltages used on the transmission lines, 3) the transmission lines, 4) the substations at which the power is stepped down to the voltage on the distribution lines, 5) the distribution lines, and 6) the transformers that lower the distribution voltage to the level used by the consumer's equipment (Encarta article http://encarta.msn.com/encyclopedia_761566999/Electric_Power_Systems.html).

Exposure to electromagnetic fields (EMFs) has become an issue for public health officials over the years. In the 1960s new high voltage electric power transmission lines emerged. Originally there were some aesthetic and potential decreases in property values concerns over the construction of these new power lines in certain areas. There was also concern from environmental activist groups because the new power lines would destroy the land where they were built. Among all these concerns was the first study published about the link between proximity to high current power lines and higher incidences of childhood leukemia. (Wertheimer et al., 1979) From the time of that study on, there has been concern over the possible health hazards of EMFs emitted from these high voltage power lines, especially with the potential link between power lines and cancer.

Mechanism

Electrical power is a very important component to our society today. We use it everyday to light our homes, the power our computers, to turn on our televisions, etc. In our technology-advanced society, however, there has been some concern that exposure to electromagnetic fields (EMF) that stems from electrical power may increase the chances for childhood cancer.

Many epidemiological studies over the years have shown contradictory evidence both for the link between EMFs and leukemia and against. Because of the conflicting results from various studies, no mechanism has been established. There have been some speculation and hypotheses with some initial results, but no independent replication of positive results have been published extensively on any particular mechanism. This has been the main problem behind elucidating the mechanism. Two of the possibilities are discussed here: free-radical recombination by magnetic fields (Lacy-Hulbert et al., 1998), and more recently DNA damage (genotoxicity) (Crumpton and Collins, 2004).

Free radicals are generated as intermediates in metabolism and may attack lipids, proteins, or DNA. Therefore, if somehow the production of these free-radicals was increased, there could theoretically also be an increase in chemical damage to DNA. When radical ions combine, the product may be in an excited state and fluorescence may be observed. More commonly, however, the overall yield is changed and measured (Brocklehurst, 2002). Usually radicals are generated in the triplet state where the electron spins are parallel. The triplets must move to the singlet state before reacting. The interconversion from triplet to singlet is affected by local magnetic fields through a hyperfine interaction (Brocklehurst, 2002). According to Lacy-Hulbert et al., a static magnetic field may removed the degeneracies of the triplet state and cause separation of the triplet states so that the electron interchange is prevented. This keeps up to two thirds of the radicals from reacting, thus these radicals leave the vicinity of the reactions to affect components of biological systems.

Some experiments have been conducted to test this theory, but none of the produced statistically significant or reproducible results. One study showed that 0.1 mT fields at 60 Hz on phorbol ester-induced respiratory burst in rat neutrophil preparations showed 10% greater fluorescence than control unexposed cells. However, the 10% increase was within the ± 20% of the standard deviation range (Roy et al., 1995). The variability of these results do not fully support this potential mechanism. This effect has been shown with relatively high field strengths (>1 mT), and it remains to be demonstrated that this effect is seen at lower field strengths (Harkins and Grissom, 1995; Eveson et al., 2000). Since most of the residential exposures are on the order of magnitude of < 100 μT, studies with higher exposures are not as relevant to the majority of residential exposures. Since no clear-cut and independently replicated results have been established so far for low EMFs, this may not be the actual mechanism behind EMF associated leukemia.

Another recent study conducted by Ivancsits et al. in 2003 showed that intermittent extremely low electromagnetic fields cause DNA damage in a dose dependent way. Previous findings with human lymphocytes by Cohen et al. in 1986 and Cardossi et al. in 1992 had shown no statistically significant correlation between low level 60-Hz electromagnetic fields and chromosome breakage. Ivancsits's group, however showed that intermittent EMF exposure, as opposed to constant exposure to EMFs, showed increases in double strand breaks in DNA. Perhaps applying a constant EMF probably induced adaptive mechanisms that would protect DNA damage, whereas an intermittent EMF may interfere with these protective mechanisms, thereby leading to DNA damage (Ivancsits et al., 2002).

Cause-effect relationship between EMFs and childhood leukemia

Public concern regarding possible health risks from residential exposures to low-strength, low-frequency electric and magnetic fields produced by power lines generated considerable debate among scientists and public officials. Over the past 25 years, a myriad of epidemiological and laboratory studies have been conducted to establish whether causality exists.

Observational epidemiology, on the other hand, has a number of strengths and weaknesses. Because exposures are observed rather than controlled, accurate determination of the exposure is more challenging due to difficulties in assigning random exposures to the population. However, epidemiology has an advantage in addressing humans in their natural environment. In addition, environmental exposure conditions that are difficult to duplicate precisely in the laboratory can be studied directly for many years through epidemiology. Given the strengths and weaknesses of epidemiology relative to other approaches, consistent information from various approaches is desirable to enhance confidence that inferences are valid.

To determine the relationship between EMFs and leukemia, if any, we reviewed high-quality epidemiological studies and meta-analyses that discuss the potential association, potential sources of random and systematic errors, and possible confounding factors.

Exposure Assessment

Residential exposure to EMF is assessed by several different methods: (1) Wire codes; (2) Distance between power lines and residences; (3) calculated historical magnetic field levels; (4) residential area measurements; and (5) personal magnetic field measurements. (Ahlbom, 2001)

Wire codes estimate field level from visual inspection of the characteristic features. The following properties are taken into account and put into an algorithm for assigning the wire code: size of wires, closeness to the origin of electric current, and load that the wire is designed for, i.e. the type of distribution. The first coding classification, developed by Wertheimer and Leeper (Wertheimer & Leeper, 1979) is dichotomous: high (HCC) or low current configuration (LCC). A refined scheme include the following categories: very high current configuration (VHCC), ordinary high current configuration (OHCC), ordinary low current configuration(OLCC), very low current configuration(VLCC) and underground power lines (UG). Distance between power lines and residences is used in some of the earlier European studies that evaluated EMF levels based on the distance from homes to electric generating or transmission equipment, including high-voltage power lines, overhead power lines, substations, transformers, electric railroads, or subways(Coleman, 1989; Myers et al, 1990; Tynes et al., 1997; Verkasalo et al., 1993) Calculated historical magnetic field levels was used in the Nordic studies. Long-term power line load data and specifications for power lines and associated structures obtained from various registries were used to calculate the exact magnetic field strength. Residential area measurements are spot measurements with a dosimeter used to determine the magnetic field in each residence over a short term, with the assumption that this is representative of the overall long-term exposure. 24-hr or longer area magnetic field measurements are sometimes used instead to obtain a more representative average. Personal magnetic field measurements are a direct measure of personal exposure obtained by a personal dosimeter carried around by the child for a day, taking into account exposure from all po§sible sources. However its invasiveness prevented this assessment method from being used widely, resulting in low study power.

Sources of Error

Random error

The power of a statistical test is important in its interpretation to reduce random error. However, in studies of EMF exposure and childhood leukemia, the power was generally low because the populations studied were small. Since leukemia is a rare disease, it naturally limits the population size. Because few people are also exposed to high levels of EMFs, it further limits study power.

Exposure misclassification

Exposure misclassification is a pervasive concern in epidemiologic studies on the effects of exposure to electric and magnetic fields. There is currently no ideal way of assessing EMF exposure. Misclassification could result from the use of residential exposure only; greater magnetic fields than those produced by typical residential wiring may be produced by large facilities outside the house that are unaccounted for.

A second major limitation is that the estimates are made from wire codes, calculated magnetic fields, and field measurements. Many studies crudely estimate exposure by examining proximity of the house to the electrical facility. Some highly variable parameters such as net and ground currents as well as transient jumps in current have no observable marker. Studies have demonstrated the inconsistency in field levels measured in homes with similar wiring codes (Zafanella, 1993). Exposure to appliances and sources outside the house were rarely considered. (Wartenberg, 2001)

The third limitation of the exposure assessments is the lack of consistent data on size and characteristics of estimation errors. Wire coding introduces crude errors that are very difficult to quantify. One might expect spot measurements, which quantify fields from all sources as opposed to one source, to be a better estimator of overall exposure. There are also discrepancies in the estimated EMF because short measurement times may not be representative of overall exposure.

The fourth limitation of the exposure assessments is bias in measurement. Measurements in the center of the room and in times of low power give measurement of fields from exterior sources, biasing the estimate.

The fifth limitation is that since everyone is exposed to EMFs to a certain degree, it is difficult to define a reference “no exposure” population – one can only compare between two populations whose exposure differ by a threshold value that may be rather arbitrary(usually 0.2, 0.3 or 0.4 uT). In addition, these category boundaries may differ from study to study, resulting in cutpoint bias, the use of a non-representative odds ratio due to the choice of exposure classification rule (Wartenberg et al., 1991)

Taking this all into account, there is really no persuasive evidence that one approach to exposure assessment is necessarily better than another. However, in order to keep our task manageable, we consider all the assessment methods used but may focus on one approach when multiple approaches are used.

Confounding Factors

The goal of control selection is to identify an unbiased sample from the population to identify a baseline of exposure. The ideas unbiased sample is often not met, introducing problems such as controls refusing to participate making random selection more difficult.

When studies used wire code assesments, there was stronger evidence for the association between EMFs and leukemia as compared to other exposure assessments. Perhaps there was some confounding effect from the wire code that accounts for these higher relative risks. To determine whether other factors contribute to the observed association, Zaffanella et al. Conducted a case specular study using existing data and new wire code evaluations.   New control homes were assigned directly across the street from case homes. The odds ratio showed the association to still be statistically significant.

Analysis of epidemiological studies

A number of studies provide relevant data on childhood leukemia, and table *** shows a summary of the major studies conducted in US or western Europe conducted in the past 3 decades. In our evaluation of individual studies, we took into account their different assessments, analytical methodologies, case and control selections, and confounders and effect modifiers, weighing the evidence accordingly. Results from formal meta-analyses and pooled analyses were also considered to reach our conclusion.

Since some of the studies include several magnetic-field measurement metrics, our target measure is defined to be a child's time-weighted average exposure up to 3 months before diagnosis. When we had several measures from a study, emphasis is put on a measure that, based on earlier work, (Kleinerman et al, 1997; Zaffanella et al, 1998; Kheifets et al, 1997), seemed likely to provide the best approximation for this target. We weigh calculated historical fields or averages of multiple measurements more than spot measurements when given the choice.(Greenland et al, 2000)

While different assessment methods for exposure from power lines have been developed, the approaches used in more recent studies are becoming increasingly sophisticated. Methods vary according to the outcome studied (one mortality study, all others incidence studies), source of data (hospital records, incidence registry, birth registry, death registry), maximum age of subjects (from 10 to 20), and exposure metric used. The studies chosen for discussion below and included in our analysis for the final conclusion were chosen because of their robust assessment methods, statistical power and quality of the analysis. The quality of the analysis we determined mainly by looking at how often the study was cited by other meta-analysis and the reason why it was excluded, if it was. Results of one study in which 0.1 uT was the highest exposure cut point (Myers et al., 1990) was not used since most other studies use a cut points of 0.2-0.4 uT. Two were excluded from this analysis because the data presentation or the analyses were incomplete (Myers et al. 1990; Lowenthal et al. 1991), and two others were excluded because children were not analyzed independently of older subjects (McDowall 1986; Schreiber et al. 1993). The strength of the evidence for each study included was also weighed according to the assessment method, statistical power, and the quality of the analysis.

Wire code classification

In the first study, by Wertheimer and Leeper, cancer mortality was examined by a case-control study for residents of greater Denver, Colorado. The unadjusted relative risk for leukemia was 3.0(95% CI 1.8-5.0). Accounting for potential confounding factors and effect modifiers (e.g. socioeconomic class, urban-suburban differences, traffic density and gender) did not change the results. Blinding of leukemia status of subject in determination of the wire code was not found to have an effect on the statistical significance of the association. Children in families of higher socioeconomic class have greater access to health care and may thus have higher rates of survival from cancer. Consequently, there may be a bias toward lower socioeconomic cases in this study.

Savitz et al. conducted a case-control study of residential exposure in Denver again in 1988. Home exposure was assessed by the wire coding scheme of Wertheimer and

Leeper(Wertheimer and Leeper, 1979) and the five-level wire code of Wertheimer and Leeper(Wertheimer and Leeper, 1982) for 90% of cases and 93% of controls and by spot measurements of EMF taken 1-9 years after diagnosis, for 36% of cases and 75% of controls. A weighted average of all measurements was computed and used s a summary exposure measure. The relative risk calculated from wire codes for all cancers among children living in homes in the high-current classification was 1.5 (95% CI 1.0-2.3). The estimated relative risks tend to increase linearly up to an almost tripling of risk in the highest exposure category(2.8; 0.9-8.4), representing a statistically significant linear trend. This association, however, was not found by spot measurements. Control selection bias may have been introduced if exposure was relative to characteristics of residential stability. The very low participation rate for spot measurements among the cases limits the validity of those results. Control selection through random-digit dialing may also bring about confounders from socioeconomic status. A strength of the study is the evaluation of a large number of potential confounding factors.

London et al. (1991) conducted a case-control study in Los Angeles county during 1980-1987, and assessed exposure in selected homes during an etiological period that they defined based on age. The relative risk for leukemia in relation to the dichotomous wire code configuration was 1.7(95% CI 1.1-2.5) and for the five category wire code scheme the relative risk was 2.2(95% CI, 1.1-4.3). A number of potential factors associated with cancer risk that were controlled for included age, gender, ethnicity, paternal use of pesticides, drugs, incense, traffic density and socioeconomic status. A limitation of this study is the uneven ascertainment of wire code information between cases and controls.

Linet et al(1997) recruited participants from a group of children with Acute Lymphoblastic Leukemia(ALL) under 15 years of age taking part in a nation-wide telephone interview study. The risk of ALL was not found to have increased among children whose main residences were in the highest wire-code category (relative risk 0.88: 0.48-1.63). The group later analyzed different components of wire coding, creating an exposure index based on distance of homes from various power sources. Neither distance nor exposure index was related to the risk of ALL.

Other studies have also used wire codes to assess exposure and found different results. Some researchers reanalyzed datasets of wire code data combined with measured residential magnetic fields to better represent exposure. Using this method, Kleinerman et al(2000) concluded no association, while Bowman & Thomas(2000) concluded a positive association. A reason for inconsistencies in the studies is the different exposure formulas used. The study of Kleinerman et al, 2000, used the same formula for all homes and utilities for all nine states. Although their paper did not report correlations with measurements, the simplicity of their index would seem to create greater exposure assessment errors (Bowman and Thomas, 2000). In contrast, Bowman and Thomas(1999) used residential magnetic field measurements from their dataset to determine the values of several parameters in their model, which is usually not done because of the increased difficulty. Overall, it seems that there is some evidence of wire codes being significantly associated with leukemia in children.

Distance between power lines and residences

This is a rather crude assessment of residential exposure used for several studies. Elevated risks of childhood leukemia(OR = 1.45, 2.0, 1.3) were found for the small fraction (0.6%) of children residing within 10m or 50 m of an overhead power line or within 25 m of a substation, respectively, in a southeast England study. (Coleman et al, 1989).

There were a number of negative results. Risk was not increased among children residing less than 51 m from high-voltage lines in Norway (Tynes et al, 1997). Risk of ALL was not increased among children residing within 40 m of transmission lines or three-phase primary distribution lines in nine Midwestern and mid-Atlantic states in the United States, nor was risk increased according to the contribution of all transmission lines and three-phase primary distribution power lines near a child's residence (Kleinerman et al, 2000). Many of these studies mentioned in the above two paragraphs suffer from low power due to the small number of cases.

Calculated historical magnetic field levels

Several Nordic studies used historical data to calculate magnetic field strengths, and although they vary somewhat in study design, they were all population based, with minimal potential for selection bias. Three of the studies found increasing leukemia risk with increasing calculated fields(Feychting &Ahlbom, 1993; Olsen et al., 1993; Verkasalo et al., 1993), and a smaller study found no effect(Tynes et al. 1992). The exposure estimates may be less subject to misclassification than those in the studies based on wire codes because they use historical data. The main limitations of all four of the studies are the small number of cases and the low prevalence of exposure. Potential confounding factors from traffic was controlled in the Swedish study and did not change the effect estimate. Adjustment for socioeconomic status was made in all except the Finnish study, with no effect on the risk estimate. The results overall support an association between EMF and childhood leukemia.

Residential measurements

In residential studies assessing exposure using spot magnetic field measurements, London et al., 1991, Michaelis et al., 1998, and Savitz et al., 1988 were all high-quality studies. The results of these studies were inconsistent, two being close to unity and the Savitz et al. study showing increased risks. However, the Savitz study is limited by the very low participation rate. The Michaelis et al. study is also limited by the small exposed group. Also, the Feychting and Ahlbom 1993 study was given less weight because the measurements were made too long after the relevant etiologic period. The strength of spot measurement studies is that neither selection bias nor confounding factors had a major impact. Nonetheless, the evidence provided by these studies does not support a significant relative risk for childhood leukemia.

Personal magnetic field measurements

Two Canadian studies used direct personal exposure measurement as the metric (Green et al., 1999; McBride et al., 1999). While Green et al. reported a significantly elevated risk, McBride et al. reported a slightly elevated risk that was not statistically significant. Because of the limited prevalence of this metric, it is impossible for firm conclusions to be drawn. Personal magnetic field measurement is limited because the measurements of exposure are only made after the diagnosis of leukemia. A moderate correlation between repeated spot measurements taken in the same residential location several years after the initial measurement has been suggested by very limited data.(Dovan et al., 1993)

Meta-Analyses

In the report by Great Britain's Advisory Group on Non-ionizing Radiation of the National Radiation Protection Board (NRPB 1992), the board found a statistically significant increased odds ratio using the wire code metric. For data based on the distance from the source of electromagnetic fields and for measured magnetic fields, the pooled odds ratios were increased, but not statistically significant. They concluded that in spite of the increased odds ratios, the small sample sizes and methodologic problems in each of the studies precluded drawing definitive conclusions.

Washburn et al. (1994) conducted a set of meta-analyses for leukemia, lymphoma, and nervous-system cancers by combining the results of 13 studies. Increased risks were found for all three diseases; those for leukemia were statistically significant. Their sensitivity analyses showed that the inclusion or exclusion of data that overlap in the two Swedish studies and the choice of exposure metric had a limited effect on the results.

Ahlbom et al. (2000) combined the results from five recent Nordic studies (Olsen et al. 1993; Verkasalo et al. 1993; Feychting and Ahlbom 1993, Tynes and Haldorsen, 1997; Michaelis et al, 1998) as well as a UK study(UKCCS, 1999), and US studies(Linet et al, 1997; Dockerty et al, 1998; Mcbride et al, 1999). (See Table 1 for summaries.) All Nordic studies used a population registry and estimates of historical exposure, and none of the North American studies relied solely on wire codes. Ahlborn et al. argued that the included studies were similar enough to one another to warrant a pooled analysis. By combining the risk ratios of those studies and assigning them weighting factors proportional to the inverse of their variances, Ahlbom and colleagues (2000) found statistically significant increased risk ratios for childhood leukemia with residential EMF exposure 0.4 uT. This is in agreement with an earlier meta-analysis(Ahlbom et al, 1993) with Nordic studies only.

A pooled study by Moulder combined data from many sources in Figure 1, including many cited in this paper. The overall relative risk calculated based on these studies showed a slight positive association that was not statistically significant. These studies represent all the methods of measuring EMFs levels equally, but gives more weight to studies according to their power.

Some argue that pooling together the results from all the studies would not only bring about problems with comparing different methodologies and standards, but also is extremely difficult to interpret because of the so-called “wire-code paradox.” The Commission on Life Sciences and National Research Council(1996) was one of the expert committees who found the “wire-code paradox.” The expert committees noted on the basis of the earlier studies that there is a stronger association between markers for EMF exposure and leukemia risk than between direct measurements and leukemia risk. The paradoxical element arose in part from the presumption that wire codes were a proxy for fields and thus should show less consistent associations if fields have an effect.

However, the pooled analysis of Ahlbom et al found no such ‘wire-code paradox’. Two North American studies with exposure data from both direct measurements and wire codes show no clear evidence of increased risk associated with residing in homes in high wire-code categories(RR for VHCC: 1.24(0.82-1.87). The measured magnetic fields were in fact low in all the wire-code categories, with the median field strength in controls in the VHCC category being 0.11 uT. The reasons for the elevated risk estimates for high wire-code categories in the earlier North American studies are unclear, although considerable potential for bias has been noted for both studies carried out in Denver (Portier and Wolfe, 1998). The Greenland et al. pooled analysis also refuted the “wire-code paradox,” stating that wire codes show less consistent associations with childhood leukemia than do magnetic fields. Examination of their data, however, shows that the relative risk for the VHCC was more statistically significant than that obtained for the highest category of exposure categorized with field measurements. This may suggest that there is in fact a wire code paradox despite their claims. Studies that combined both field measurements and wire codes showed a positive association between field strength and leukemia.

Epidemiological Conclusions

In examining the data from all the studies mentioned above, we found many contradictory results. Some studies showed positive associations between EMFs and leukemia, while many others had equivocal or negative results. In order to draw a conclusion from this, we weighted the studies based on their errors and power. In our own evaluation of individual studies, we took into account their different assessment and analytical methodologies, case and control selection, confounders and effect modifiers. We weighed all these along with the meta-analyses conducted and concluded that there is a weak positive association based on relative risk values, but the 95% confidence intervals generally included values below unity. From this conclusion, we suggest that further advancements to more accurately assess exposure are required to make any progress to determine if this weak association is in fact true.

The current types of exposure assessments makes it difficult to compare relative risk or odd ratio values across studies. In the five methods in current use, wire codes and historical magnetic field level calculations generally support the link between EMFs and leukemia. Nevertheless, distance based field calculations and spot measurements generally do not provide evidence of this association. The personal dosimeter measurement studies have not been conducted extensively enough to judge the possible implications of the method as a whole. There needs to be more work done to develop a reliable, universal metric before more time and funding is spent on this area.

After examining many individual studies and meta-analyses, we found more support for our conclusion. Biases and confounding factors, such as socioeconomic status, selection bias, and recall bias, may have influenced the results, although most studies claimed that adjusted for these factors did not significantly alter their conclusions.

Media Evaluation

Much of the media evaluation in this matter is sensationalistic. One account tells of a farmer whose barn lights that stay on, even when they are turned off due to the presence of high electromagnetic fields in the area (http://www.midtod.com/9603/voltage.phtml). The article then proceeds to use this as a jumping off point for discussing childhood cancer, even though the mechanisms behind this phenomenon and any effect EMFs may have on cells are different. EMFs are not well understood by most members of the community, and many people fear things that they can neither see nor understand. The media therefore searches for a visible link showing the presence of EMFs, instead of trying to use an accurate metric for measuring the EMFs. They also rarely include analysis of statistical data, preferring instead to focus on individual cases. While this does put a human face to the story, it does not evaluate whether the numbers are significant to show that the cancer was caused by the presence of EMFs. Also, these stories rarely include any data on fields emitted from other sources of EMFs, focusing only on the presence of power lines.

However, this media attention comes from a lot of public concern over EMFs. Because the public for the most part does not understand EMFs well and because children's health is highly valued, there is significant interest and fear about the effects of living near power lines. In an USA Today survey of readers, EMF was reported as a major environmental concern (http://www.safelevel.com/news.html). Many people are hesitant to buy houses around power lines, causing lower housing prices in those areas (Wall Street Journal, September 8 1993). All these effects lead to increased media coverage of EMFs and increased public demand for research on EMFs despite the wealth of information showing no clear evidence for a significant link between childhood leukemia and other cancers and living near power lines.

An article in the New England Journal of Medicine () discusses the impacts that the public's reactions have on research. Campion states that when childhood leukemia is being discussed, "people's reactions may be driven more by passion than by reason." The research into leukemia and power lines began with a small cluster in Denver and used crude methods and a very small sample size. However, their findings were that living near a high voltage power line doubled the risk of childhood leukemia and this new study was spread in the media as proof of a causal link between cancer and EMFs. Later studies would give conflicting results, but sensationalistic media coverage again stepped in suggesting that government cover-ups and industry pay-offs were responsible for the negative studies. Public efforts that led to congressional funding for more EMF research in the US and Sweden almost made significant changes in their laws based on a flawed study with low power.

In the article published in 1997, Campion says that over 18 years, there has been a large amount of research done without showing any conclusive links. Some studies have shown weak associations and other studies are either negative or not significant. It is now 8 years later and a total of 26 years of research efforts and funding have yet to show a strong association between EMFs and leukemia. As Campion suggests, it may be time to stop letting public fear of government, industry, and "dangerous-looking high-voltage power lines" control the allotment of resources and instead start spreading out resources and looking for other causes of childhood leukemia. (Campion E, New England Journal of Medicine; Vol 337:44-46, 1997)

Government Regulations

Most government regulations on EMF emissions do not deal with fields emitted from power lines. Emissions from power lines are generally around 0.2-1.0uT about 10 meters away from a distribution line. Exposure directly in the path of a high-voltage power line is about 10uT, but that number decreases as a function of distance and is in the range of 0.1-1.0uT at the edge of the power line path. By the time the EMF reaches the houses surrounding the power line path, the exposure level is even lower. (http://www.mcw.edu/gcrc/cop/powerlines-cancer-faq/toc.html#10) However, the regulations on fields emitted that are generally followed are those of the International Commission on Non-Ionizing Radiation Protection which sets a 100uT level for home exposure (International Commission on Non-Ionizing Radiation Protection: Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys 74:494-522, 1998.).

There is a great amount of disparity between the emitted levels of EMFs from power lines and regulations of EMFs. Carl Blackman (personal communication) proposed that this is because the regulations deal more with heating and appliances than power line emittance. Appliances have large EMF emissions at close range, starting from over 100uT immediately at the source but declining rapidly so that just a few feet away the EMFs are back below 0.1uT. However due to the inconclusive evidence suggesting a weak link between the EMFs created by power lines and childhood leukemia, this disparity between regulations and power line emittance does not appear to be a problem.

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