Update on Scientific Research Regarding Potential Health Effects of Power-Line Electric and Magnetic Fields (EMF)

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1 Introduction and Overview

This Gradient Corporation Report provides VELCO an update on published research literature regarding the science of potential impacts on human health arising from exposure to electric-utility, power-line electric and magnetic fields (EMF). For the **2006 to Aug. 2007 time period**, our Report identifies and provides short summaries of those EMF research articles having key relevance to understanding how individuals in the general public might be affected by exposure to power-line EMF.

We used a similar approach to this literature review as we did in previous annual editions of Gradient's EMF update. For example, we identified potentially relevant, peer-reviewed EMF health-effect-research articles through literature searches, and by examining EMF-specific databases. Search engines such as "PubMed" (National Library of Medicine) (http://www.ncbi.nlm.nih.gov/Literature/), Science Citation Index (http://library.dialog.com/), and CSA Illumina (http://ca2.csa.com/) were used. We also accessed reference lists available online from the World Health Organization (WHO) that are compiled as part of their International EMF Project (http://www.who.int/peh-emf/research/database/en/) and from Dr. John Moulder's (Medical College of Wisconsin) website on "What's New" (http://www.mcw.edu/gcrc/cop/powerlines-cancer-FAQ/toc.html#whatsnew). Details on the article selection process are provided in the next section, "Selection of Articles and Summary Points." A listing of all those 2006-2007 articles we identified as relevant and Abstract Summaries of the key articles can be found in the final section of this Report.

1.1 Epidemiology

As in our previous reviews, our selection of key articles placed emphasis on health effects of EMF from electric-utility power lines, and on integration of the three main lines of scientific evidence: (A) Epidemiology, (B) Animal Studies, and (C) Mechanisms of Action. Furthermore, a central focus of our literature review and summary was on power-line EMF and health endpoints related to cancer, specifically childhood leukemia. Our findings for 2006-2007 remain relatively similar to the situation reported in the previous year, 2005-2006. We list below selected, representative recent publications following the three main lines of scientific evidence. A more complete listing and summary of key publications makes up the remainder of this report.

(A) For nearly three decades, some epidemiology studies have reported weak associations between surrogate markers of power-line magnetic field exposure (such as distance from power-lines) and risk of childhood leukemia. As a result, power-line EMF was classified as a "possible" (Group 2B) carcinogen in 2002 by the International Agency for Research on Cancer (IARC). [1] Epidemiology continues to provide the strongest suggestions of health effects, however, the results among the studies remain weak and inconsistent, and poorly linked to actual EMF exposures. In addition, these statistical, correlative results have still been unable to establish causation. That is, because epidemiology is an observational science, it is difficult to apply the rigorous scientific methods that would be possible in a controlled laboratory setting on a controlled clinical trials setting. Problems continue to cloud the

[1] IARC classified power-frequency magnetic fields as "possibly carcinogenic," based on "limited" evidence from humans concerning childhood leukemia, "inadequate" evidence from humans concerning all other cancer types, and "inadequate" evidence from animals. Power-frequency electric fields were judged "not classifiable" (Group 3) on the basis of "inadequate" evidence from both humans and animals.

interpretation of the epidemiology. As the WHO recently stated in their review of Extremely Low Frequency Fields: [2]

> "*Uncertainties in the hazard assessment [of epidemiological studies] include the role that control selection bias and exposure misclassification might have on the observed relationship between magnetic fields and childhood leukaemia. In addition, virtually all of the laboratory evidence and the mechanistic evidence fail to support a relationship between low-level ELF magnetic fields and changes in biological function or disease status. Thus, on balance, the evidence is not strong enough to be considered causal, but sufficiently strong to remain a concern.*" [pg. 12, emphasis added]

Indeed, an epidemiologic study that reports "statistically significant" associations is only testing that significance against the role of random chance, but there are numerous other uncertainties that, if they were to be quantitatively included in the confidence interval (*e.g.*, confounding factors, measurement error, selection bias, misclassification), the confidence / error bars would be much broader and would likely overlap a null outcome (*i.e.*, "no association").

We identified five recent epidemiological studies since the last review that relate to EMF exposure and childhood cancer (E1-E5) and provide a summary of the epidemiological findings in the next section below:

(E1) Feizi AA, Arabi MA. 2007. Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines - a risk factor in Iran. *Asian Pac J Cancer Prev.* Jan-Mar;8(1):69-72.

(E2) Lowenthal RM, Tuck DM, Bray IC. 2007. Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study. *Intern Med J.* 37:614-9.

(E3) Mejia-Arangure JM, Fajardo-Gutierrez A, Perez-Saldivar ML, Gorodezky C, Martinez-Avalos A, Romero-Guzman L, Campo-Martinez MA, Flores-Lujano J, Salamanca-Gomez F, Velasquez-Perez L. 2007. Magnetic fields and acute leukemia in children with Down syndrome. *Epidemiology* 18:158-61.

(E4) Schüz J, Svendsen AL, Linet MS, McBride ML, Roman E, Feychting M, Kheifets L, Lightfoot T, Mezei G, Simpson J, Ahlbom A. 2007. Nighttime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis. *Am J Epidemiology* 166:263-9.

(E5) Svendsen AL, Weihkopf T, Kaatsch P, Schüz. 2007. Exposure to magnetic fields and survival after diagnosis of childhood leukemia: a German cohort study. *J Cancer Epidemiological Biomarkers Prev.* 16:1167-71.

1.2 Laboratory Animal Studies

(B) Other lines of scientific evidence continue to weigh against a causal association between power-line EMF and cancer. There are still no established laboratory bioassay or animal models relevant to human cancer risk that show biological changes related to power-line EMF exposure leading to tumors.

[2] WHO's 2007 monograph, the "Environmental Health Criteria N°238 on Extremely Low Frequency Fields" (446 pages) is available on the WHO website: http://www.who.int/peh-emf/publications/elf_ehc/en/index.html

Lifetime exposures to high levels of 60-Hz magnetic fields has been tested in many animal studies and have shown negative results for initiation or exacerbation of disease or a pre-disease condition, even in genetically modified and susceptible animals. Our review found two current animal studies related to cancer effects from EMF exposure (A1-A2) with a summary to follow.

(A1) Erdal N, Gürgül S., Çelik A. 2007. Cytogenetic effects of extremely low frequency magnetic field on Wistar rat bone marrow *Mutation Research/Genetic Toxicology and Environmental Mutagenesis* 630: 69-77

(A2) Negishi T, Imai S, Shibuya K, Nishimura I, Shigemitsu T. 2007. Lack of promotion effects of 50 Hz magnetic fields on 7,12 dimethylbenz(a)anthracene-induced malignant lymphoma/lymphatic leukemia in mice. *Bioelectromagnetics* [Epub online Aug 10]

1.3 Mechanistic and *In Vitro* Studies

(C) Research scientists continue to try to elucidate a potential mechanism that might explain the epidemiological correlations. To date, however, the extensive efforts by scientists have not identified plausible mechanisms by which public exposure to power-line EMF can cause adverse health effects. Thus, without a firm understanding of the mechanism (if any) underlying potential health effects, it remains unknown as to what, if any, aspect of EMF exposure should be controlled. We selected for review 4 mechanistic studies (M1-M4), summarized in the next section:

(M1) Cho YH, Jeon HK, Chung HW. 2007. Effects of extremely low-frequency electromagnetic fields on delayed chromosomal instability induced by bleomycin in normal human fibroblast cells. *J Toxicol Environ Health A* 70:1252-8.

(M2) Mairs RJ, Hughes K, Fitzsimmons S, Prise KM, Livingstone A, Wilson L, Baig N, Clark AM, Timpson A, Patel G, Folkard M, Angerson WJ, Boyd M. 2007. Microsatellite analysis for determination of the mutagenicity of extremely low-frequency electromagnetic fields and ionising radiation in vitro. *Mutation Res.* 626:34-41.

(M3) Villarini M, Moretti M, Scassellati-Sforzolini G, Boccioli B, Pasquini R. 2006. Effects of co-exposure to extremely low frequency (50 Hz) magnetic fields and xenobiotics determined in vitro by the alkaline comet assay. *Science of the Total Environ.* 361:208-19.

(M4) Wahab MA, Podd JV, Rapley BI, Rowland RE. 2007. Elevated sister chromatid exchange frequencies in dividing human peripheral blood lymphocytes exposed to 50 Hz magnetic fields. *Bioelectromagnetics* 28:281-8.

1.4 Summary Assessments and Guidelines

Lastly, a variety of international scientific "blue-ribbon" panels have reviewed, and continue to review, EMF health effects research. Overall, the absence of robust findings from all lines of scientific evidence, including animal and mechanistic studies that can be carefully replicated in the laboratory, causes health agencies to be cautious about the reported epidemiological links. The statistical results are suspected to be due to such factors as selection bias and unmeasured or uncontrolled confounding. Scientific guideline-setting committees do not consider the epidemiologic evidence to be adequate for guideline development. No major public-health agency has set guidelines based on distance from power-

line rights-of-way. Some agencies have provided guidelines for acceptable, continuous-exposure of the general public to power-line magnetic-field levels, and these values range from about 800 mG to 9,000 mG.

For example, a new, draft power-line EMF standard was proposed in December 2006 by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The draft document can be found at the website http://www.arpansa.gov.au/pubs/comment/dr_elfstd.pdf , and its title is: "Radiation Protection Standard: Exposure Limits for Electric & Magnetic Fields – 0 Hz to 3 kHz." The ARPANSA proposed value for acceptable "General Public" exposure to 60-Hz EMF is 4,166 V/m for the electric field, and 100 μT (100 microTesla) for the magnetic field, the latter being equal to 1,000 mG. Thus, ARPANSA's proposed 1,000 mG guideline is basically the same as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, where the general public magnetic-field guideline is 833 mG for 60-Hz EMF.

In a letter to the Editor of the journal *Risk Analysis*, O'Carroll and Henshaw (2007) summarize and comment on the health effects findings related to EMF exposure of three large review bodies — the U.S. National Institute of Environmental Sciences (NIEHS, 1999), the International Agency for Research on Cancer (IARC, 2002), and the California Health Department of Health Services Report (CDHS, 2002). The authors determined which review body assigned a 2B cancer classification ("possible causal relationship") to various diseases (childhood leukemia, adult leukemia, adult brain cancer, amyotrophic lateral sclerosis, and miscarriage). The CDHS differs from the other two agencies in that they classify all five cancers as 2B carcinogens. Furthermore, the authors were of the opinion that CDHS is justified in there assessment. They evaluated the total number of studies CDHS considered for each disease outcome, the number of positive results, and the number of statistically significant results (O'Carroll and Henshaw, 2007, Table 2), then tested whether the positive or statistically significant results would occur by chance. They found that all significant positive results are unlikely to be chance findings. It is worth noting, however, that this simplistic analysis did not account for the numerous uncertainties in these studies. Moreover, that despite the fact that results from these studies may not be due to chance alone does not imply causality. That is, there remain potentially confounding factors that could account for the associations between disease and surrogate factors for EMF exposure, and importantly, a biological mechanism is still unknown. Also for many of the disease outcomes, including childhood leukemia, the number of studies with statistically significant results was less than 30%.

Indeed, in their recent Environmental Health Criteria on Extremely Low Frequency Fields the WHO (2007) appears to agree with the findings of IARC and states that:

> "*A number of other diseases have been investigated for possible association with ELF magnetic field exposure. These include cancers in both children and adults, depression, suicide, reproductive dysfunction, developmental disorders, immunological modifications and neurological disease. The scientific evidence supporting a linkage between ELF magnetic fields and any of these diseases is much weaker than for childhood leukaemia and in some cases (for example, for cardiovascular disease or breast cancer) the evidence is sufficient to give confidence that magnetic fields do not cause the disease* ." (pg. 12, emphasis added)

Furthermore, in their "Summary and Recommendations for Further Study" WHO emphasizes

> "*the limit values in exposure guidelines [not] be reduced to some arbitrary level in the name of precaution. Such practice undermines the scientific foundation on which the limits are based and is likely to be an expensive and not necessarily effective way of providing protection* (page 12)."

WHO concludes that:

"*given both the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, and the limited impact on public health if there is a link, the benefits of exposure reduction on health are unclear. Thus, the costs of precautionary measures should be very low* (page 13)."

2 Selection of Articles and Summary Points

We reviewed the most current literature on the biological effects of non-ionizing electromagnetic waves using several computerized comprehensive databases that covered international journals literature, books, reports, monographs, government publications and meeting abstracts. We searched the literature for the years 2006 and 2007 (Jan. – Aug.) and retrieved references relevant to electric and magnetic fields exclusively from power-line (50 and 60 Hz) sources. A total of 65 article abstracts were evaluated for relevance, and key articles were identified for review. The attached spreadsheet provides the full list of references by topic area, author, and full citation. In addition abstracts of key articles are attached.

A total of 20 articles were identified as relevant to the current state of knowledge of health effects associated with exposures to extremely low frequency electromagnetic fields (ELF-EMF), with the focus on cancer effects: 3 from 2006 and 17 from 2007. Of these, 5 are epidemiological or human studies, 2 are animal studies, 4 are *in vitro* or mechanistic studies, 8 are review articles, and one is a commentary. A summary of the results is provided below.

2.1 Epidemiological/Human Studies

Four case-control studies reported associations between an elevated risk of leukemia (or lymphoproliferative/ myeloproliferative disorders) and various measures of EMF exposure (*e.g.* distance to power-lines, calculated emissions, and spot measurements). However, these studies suffer from the uncertainties common to epidemiological studies, including potential biases, small sample sizes, lack of actual personal exposure measurements, and potential confounding by socioeconomic or other factors. [3]

For example, Feizi and Arabi (2007) assessed the risk of childhood leukemia in this case-control study conducted in Iran. The authors report a statistically significant elevated risk of leukemia for children living < 500 m from high voltage power lines. Similarly, risks were elevated for children exposed to a calculated magnetic field (based on distance, voltage and average load) of > 0.45 μT (> 4.5 mG). The study however, suffered from potential selection bias and very small numbers of controls (2 in the case of children living < 500 m, and 5 for children with >0.45 μT calculated exposures).

A similar case-control study was conducted in Tasmania for patients (0-94 years old) diagnosed with lymphoproliferative (LPD) and myeloproliferative (MPD) disorders between 1972 and 1980 (Lowenthal *et al*. 2007). The study found large positive associations between LPD and MPD diagnoses and distance from power-lines, although most were not statistically significant. However, as the authors readily acknowledge, the study had several limitations, including biases in their choice of controls, lack of exposure measures, confounding by socioeconomic status or other variables, and the imprecise nature of their analysis due to the small number of available subjects.

[3] For a useful, general summary of the strengths and weaknesses of epidemiologic studies, see the New York Times article by Gary Taubes "Do We Really Know What Makes Us Healthy" of September 16, 2007 at: http://www.nytimes.com/2007/09/16/magazine/16epidemiology-t.html?em&ex=1190347200&en=27b704bf46166f31&ei=5087%0A

A third study (Schuz *et al*. 2007) pooled data from case-control studies from 4 different countries to determine if nighttime ELF EMF exposures had greater biological relevance than 24-hour or 48-hour measurements. The results from this study were consistent with previous findings, and the authors concluded that "*the results do not support the hypotheses that nighttime measurements are more appropriate; hence, the observed associations between ELF EMF and childhood leukemia still lacks a plausible explanation.*"

Lastly, Mejia-Arangure *et al*. (2007) conducted a case-control study in Mexico City to determine the effects of EMF exposure (using spot measurements) in children with Down syndrome. The authors report a positive and statistically significant effect for direct measurements of > or = 6.0 mG (0.6 μT). Selection bias may have been present in the study as cases differed from controls for some important characteristics such as socioeconomic status and family history of cancer. Also, odds ratios for magnetic field measurements between 1 and 5.99 mG (0.1 to 0.599 μT) were less than one and seemed to abruptly 'jump' to 3.7 for exposures equal or greater than 6 mG (0.6 μT), indicating some inconsistency.

In a different study, Svendsen *et al*. (2007) assessed the effects of magnetic field exposure on the survival rate of children diagnosed with leukemia, finding poorer survival rates with fairly low exposures (0.1 to 0.2 μT, based on 24-hr magnetic field measurements). However, the authors caution that the results are based on very small numbers and that the biological mechanism to support these findings is still unknown.

The meaning of these new epidemiological results will need to be evaluated as the scientific community assesses their strengths and weaknesses, however, as several of the reviews point out, numerous limitations to epidemiological studies introduce substantial uncertainty. Thus, a spurious association cannot be ruled out. Also, neither a reproducible animal bioassay system nor a plausible biological mechanism of action has been found, and the epidemiological results are not supported by scientific evidence from these other lines of evidence.

2.2 Animal Studies

Two animal studies were identified as relevant to cancer related effects of EMF. Erdal *et al*. (2007) assessed the cytogenetic effects of acute (4-hr) and long-term (45 days) to 50 Hz magnetic field (1 mT = 10,000 mG) on rat bone marrow cells. The authors report no significant chromosomal aberrations between exposed and control groups, but there was some evidence of genotoxicity (a statistically significantly higher mean micronucleus frequency) in the rats exposed to long-term magnetic fields and cytotoxicity in both the acute and long-term exposed rats. The authors note that "*On theoretical grounds, ELF MF do not have enough energy to break chemical bonds directly in DNA molecules. Genetic effects should therefore be induced by an indirect effect with ELF fields acting as a promoting or co-promoting agent rather than as an initiator*." As a positive control, the authors used a known genotoxic agent, mitomycin C, but the acute and long-term effects of EMF on bone marrow, although often statistically significant, were decidedly milder than the positive control.

In contrast to the somewhat positive findings of Erdal *et al*. (2007), Negishi *et al*. (2007) found that the cumulative proportion of mice with malignant lymphoma/lymphatic leukemia in magnetic-field exposed mice was no different from sham-exposed mice. The authors exposed mice to 50 Hz circularly polarized magnetic fields up to 350 μT (3,500 mG) for 30 weeks to look for any increases in leukemia induced by 7,12-dimethylbenz(a)anthracene. They found no increase, and importantly, the authors were able to reproduce their negative results. They concluded that their study provided no evidence to support the hypothesis that power frequency magnetic fields pose a risk for leukemia.

2.3 Mechanism + *in vitro* Studies

The 4 *in vitro* studies were conducted in different cell lines exposed to extremely low frequency magnetic fields (ELF-MF) ranging from 1 μT to 3 mT (10 mG to 30,000 mG) and showed mixed genotoxicity results. For example, Cho *et al*. found no observed effect of 60-Hz ELF-EMF (0.8 mT) on the delayed chromosomal instability induced by bleomycin in fibroblast cells, although there was some evidence of enhanced cytotoxicity. Mairs *et al*. (2007), on the other hand, used a more sensitive method of detecting DNA damage involving microsatellite sequences, and found a 3.75-fold increase in mutation induction in glioma cells after a 12 hrs exposure to 1 mT (50 Hz), compared with unexposed control. In addition, the mutagenic capacity of gamma-irradiation was found to increase with ELF-MF exposure.

In another study, the genotoxic and/or co-genotoxic activity of ELF-MF at 3 mT was assessed in human peripheral blood leukocytes (Villarini M *et al*., 2006)**.** The authors found that ELF-MF alone was unable to cause direct primary DNA damage. However, results were mixed with co-exposure to different mutagens. Co-exposure with N-methyl-N'-nitro-N- nitrosoguanidine resulted in increased DNA damage, where as co-exposure 4-nitroquinoline N-oxide actually reduced DNA damage. The authors believe that because the two chemicals have different mechanisms of genotoxicity in regard to a key enzyme, the influence of MF on this enzyme may explain the divergent results. Lastly, Wahab *et al*. (2007) found elevated sister chromatid exchange frequencies in human peripheral blood lymphocytes exposed to varying fields (sinusoidal or square, either continuous or pulsed) at field strengths of 1 μT or 1 mT for 72 h. In addition, the study was conducted twice to assess reproducibility. It is worth noting that the results from this study were not statistically significant in the first round and barely reached significance in the second round and there was some inconsistency in effects at the two doses used.

Even though some of these studies report *in vitro* EMF effects, it has been characteristic of the EMF *in vitro* research area that such effects are reported frequently, but on closer examination, turn out to be "one of a kind" results, *i.e.*, seemingly not real or repeatable. A reliable and replicable result for EMF *in vitro* effects that is agreed-upon as real by the scientific community is yet to be found.

2.4 Reviews

Several of the reviews included in the list of articles below assess the policy implications of the potential health effects of MF exposure. In general there is widespread consensus that the epidemiological evidence is too uncertain to warrant strict regulatory-limit policies and expensive implementation plans. For example, Kheifets *et al*. (2007) found that, even assuming a causal relationship between EMF exposure and leukemia, the attributable fraction would be < 10%, with point estimates ranging from < 1% to about 4%. This translates to between 100 to 2,400 leukemia cases worldwide, a fairly limited health impact. Similarly, Otto and von Mühlendahl (2007) found that the potential carcinogenic effects of EMF, if they exist, are likely to be insignificant compared to more established causes of childhood leukemia. Thus, standards or guidelines may not be warranted, particularly at the risk of compromising the obvious benefits of electric power. Schuz (2007) summarizes by stating:

> "*The contradictory results from epidemiological and experimental research may either be due to methodological limitations creating a spurious association in the epidemiological studies or to a failure of experimental research to examine mechanisms relevant in the complex origin of childhood leukemia. Taking this together, the overall evidence is not strong enough to demand a revision of the current guidelines for public protection.*"

3 Abstracts

Below are abstracts for the key articles (a complete list of references is in the attached spreadsheet). The 19 articles are identified as follows:

E1 – E5:	5 Epidemiology studies
A1 – A2	2 Laboratory animal studies
M1 – M3	3 Mechanistic or *in vitro* studies
R1 –R8	8 Reviews of mechanistic or *in vitro* studies
O1	1 Commentary

3.1 Epidemiological/Human Studies

E1: Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines - a risk factor in Iran.
Feizi AA, Arabi MA.
Asian Pac J Cancer Prev. **2007** Jan-Mar;8(1):69-72.

Abstract: Many investigators have studied the effects of Extremely Low Frequency-Magnetic Fields generated by ordinary and domestic power lines, as a risk factor in acute leukaemias of children, but there are limited information available regarding very high voltage overhead power lines. Children in developing countries sometimes live very close to such structures and we have registered several patients with acute leukaemias appearing in clusters. In the present study we have analyzed 60 consecutively diagnosed patients with acute leukaemias, and 59 matched controls in a provincial capital city in North-Western Iran. After provision of consent, a detailed form was filled in, and a visit to the present (or previous) residential areas of both groups was arranged. The locations of the very high voltage power lines (123, 230, 400 kilo volts), were noted in each area, if present, and their distances from the houses under study were detected. The expected intensities of the Magnetic Fields (B) were calculated having the mean intensity of the electrical current and other line characteristics, by means of relevant equations. Fourteen patients in the case group (23.5%) were living near the high voltage power lines in distances < or = 500 meters. (Mean B = 0.6 microTeslas, microT). In the control group at the same distance, the figure was 2 children (3.3%) (Mean B = 0.35 microT). Statistically, the likelihood of leukaemia was increased considerably in this distance (Odds ratio (OR) = 8.67, 95% Confidence Interval (CI) = 1.74-58.4, P value= 0.001). On the other hand 15 pts (25 %) in the leukaemia group were experiencing Magnetic fields above 0.45 microT in comparison to 5 in the control group (8.5%)(OR = 3.60, 95% CI = 1.11-12.39, P = 0.01). More children in developing countries like Iran live close to very high voltage lines, and they experience relatively more harmful effects from the Magnetic Fields, in comparison with children in developed countries. Residence near very high voltage overhead power lines, in distances < or = 500 meters, and Magnetic Fields >0.45 microT, should be considered a risk factor for the pathogenesis of acute leukaemias in children.

E2: Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study.
Lowenthal RM, Tuck DM, Bray IC.
Intern Med J. **2007** Sep;37(9):614-9. Epub 2007 Jun 2.

Abstract: BACKGROUND: Studies have shown an association between electromagnetic fields and childhood leukaemia. The aim of this study was to determine whether there is an increased risk of lymphoproliferative disorders (LPD) or myeloproliferative disorders (MPD) associated with residence < or =300 m from high-voltage power lines. METHODS: Case-control study of 854 patients diagnosed with LPD or MPD (including leukaemia, lymphoma and related conditions) aged 0-94 years comprising all cases diagnosed in Tasmania between 1972 and 1980. Controls were individually matched for sex and approximate age at the time of diagnosis. RESULTS: Compared with those who had always lived >300 m from a power line, those who had ever lived within 50 m had an odds ratio (OR) of 2.06 (95% confidence interval 0.87-4.91) for developing LPD or MPD (based on 768 adult case-control pairs); those who had lived between 50 and 300 m had an OR of 1.30 (0.88-1.91). Adults who had lived within 300 m of a power line during the first 15 years of life had a threefold increase in risk (OR 3.23; 1.26-8.29); those who had lived within the same distance aged 0-5 years had a fivefold increase in risk (OR 4.74; 0.98-22.9). These associations were strengthened when analyses were repeated for 201 pairs with entirely Tasmanian residential histories. CONCLUSION: Although recognizing that this study has limitations, the results raise the possibility that prolonged residence close to high-voltage power lines, especially early in life, may increase the risk of the development of MPD and LPD later.

E3: Magnetic fields and acute leukemia in children with Down syndrome.
Mejia-Arangure JM, Fajardo-Gutierrez A, Perez-Saldivar ML, Gorodezky C, Martinez-Avalos A, Romero-Guzman L, Campo-Martinez MA, Flores-Lujano J, Salamanca-Gomez F, Velasquez-Perez L.
Epidemiology. **2007** Jan;18(1):158-61.

Abstract: BACKGROUND:: We analyzed effects of exposure to magnetic fields on the expression of acute leukemia in children with Down syndrome (who have a 20-fold higher risk of leukemia). METHODS:: We performed a case-control study that included 42 children with both acute leukemia and Down syndrome as cases and 124 healthy children with Down syndrome as controls. We obtained demographic information concerning the children and took spot measurements of magnetic fields at each residence. RESULTS: The odds ratio for direct measurements of magnetic fields >/=6.00 mG was 3.7 (95% confidence interval = 1.05-13.1). CONCLUSION:: The association between magnetic fields and leukemia in children with Down syndrome suggests the possibility of a causal role for magnetic fields in the etiology of leukemia among a genetically susceptible subgroup of children.

E4: Nighttime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis.
Schüz J, Svendsen AL, Linet MS, McBride ML, Roman E, Feychting M, Kheifets L, Lightfoot T, Mezei G, Simpson J, Ahlbom A.
Am J Epidemiol. **2007** Aug 1;166(3):263-9. Epub 2007 May 7.

Abstract: It has been hypothesized that nighttime bedroom measurements of extremely low frequency electromagnetic fields (ELF EMF) may represent a more accurate reflection of exposure and have greater biologic relevance than previously used 24-/48-hour measurements. Accordingly, the authors extended a pooled analysis of case-control studies on ELF EMF exposure and risk of childhood leukemia to examine nighttime residential exposures. Data from four countries (Canada, Germany, the United Kingdom, and the United States) were included in the analysis, comprising 1,842 children diagnosed with leukemia and 3,099 controls (diagnosis dates ranged from 1988 to 1996). The odds ratios for nighttime ELF EMF exposure for categories of 0.1-<0.2 microT, 0.2-<0.4 microT, and >or=0.4 microT as compared with <0.1 microT were 1.11 (95% confidence interval (CI): 0.91, 1.36), 1.37 (95% CI: 0.99, 1.90), and 1.93 (95% CI: 1.11, 3.35), respectively. The fact that these estimates were similar to those derived using 24-/48-hour geometric mean values (odds ratios of 1.09, 1.20, and 1.98, respectively) indicates that the nighttime component cannot, on its own, account for the pattern observed. These results do not support the hypotheses that nighttime measures are more appropriate; hence, the observed association between ELF EMF and childhood leukemia still lacks a plausible explanation.

E5: Exposure to magnetic fields and survival after diagnosis of childhood leukemia: a German cohort study.
Svendsen AL, Weihkopf T, Kaatsch P, Schüz J.
Cancer Epidemiol Biomarkers Prev. **2007** Jun;16(6):1167-71.

Abstract: Inspired by a recent U.S. study showing poorer survival among children with acute lymphoblastic leukemia (ALL) exposed to magnetic fields above 0.3 microT, we examine this relationship in a German cohort of childhood leukemia cases derived from previous population-based case-control studies conducted between 1992 and 2001. A total of 595 ALL cases with 24-h magnetic field measurements are included in the analysis with a median follow-up of 9.5 years. We calculate the hazard ratios (HR) using the Cox proportional hazards model for overall survival, adjusted for age at diagnosis, calendar year of diagnosis, and gender. Elevated hazards are found for exposures between 0.1 and 0.2 microT [HR, 2.6; 95% confidence interval (95% CI), 1.3-5.2], based on 34 cases with 9 deaths as well as for exposures above 0.2 microT (HR, 1.6; 95% CI, 0.6-4.4), based on 18 cases with 4 deaths. After adjustment for prognostic risk group, the hazard for exposures above 0.2 microT increases to HR,

3.0 (95% CI, 0.9-9.8). In conclusion, this study is generally consistent with the previous finding; however, we report the excess risk at field levels lower than those in the U.S. study. In all, the evidence is still based on small numbers, and a biological mechanism to explain the findings is not known.

3.2 Animal Studies

A1: Cytogenetic effects of extremely low frequency magnetic field on Wistar rat bone marrow
Erdal N, Gürgül S., Çelik A.
Mutation Research/Genetic Toxicology and Environmental Mutagenesis **2007** June, 630 (1-2): 69-77

Abstract: In this study, the genotoxic and cytotoxic potential of extremely low frequency magnetic fields (ELF-MF) was investigated in Wistar rat tibial bone marrow cells, using the chromosomal aberration (CA) and micronucleus (MN) test systems. In addition to these test systems, we also investigated the mitotic index (MI), and the ratio of polychromatic erythrocytes (PCEs) to normochromatic erythrocytes (NCEs). Wistar rats were exposed to acute (1 day for 4 h) and long-term (4 h/day for 45 days) to a horizontal 50 Hz, 1 mT uniform magnetic field generated by a Helmholtz coil system. Mitomycin C (MMC, 2 mg/kg BW) was used as positive control. Results obtained by chromosome analysis do not show any statistically significant differences between the negative control and both acute and long-term ELF-MF exposed samples. When comparing the group mean CA of long-term exposure with the negative control and acute exposure, the group mean of the long-term exposed group was higher, but this was not statistically significant. However, the mean micronucleus frequency of the longer-term exposed group was considerably higher than the negative control and acutely exposed groups. This difference was statistically significant ($p < 0.01$). The results of the MI in bone marrow showed that the averages of both A-MF and L-MF groups significantly decreased when compared to those in the negative control ($p < 0.001$ and $p < 0.01$, respectively). No significant differences were found between the group mean MI of A-MF exposure with L-MF. We found that the average of PCEs/NCEs ratios of A-MF exposed group was significantly lower than the negative control and L-MF exposed groups ($p < 0.001$ and $p < 0.01$, respectively). In addition, the group mean of the PCEs/NCEs ratios of L-MF was significantly lower than negative control ($p < 0.01$). We also found that the MMC treated group showed higher the number of CA and the frequency of MN formation when compared to those in all other each groups (p-values of all each groups <0.01) and also MMC treated group showed lower MI and the PCEs/NCEs ratios when compared to those in all other each groups (p-values of all groups <0.01). These observations indicate the *in vivo* suspectibility of mammals to the genotoxicity potential of ELF-MF.

A2: Lack of promotion effects of 50 Hz magnetic fields on 7,12 dimethylbenz(a)anthracene-induced malignant lymphoma/lymphatic leukemia in mice.
Negishi T, Imai S, Shibuya K, Nishimura I, Shigemitsu T.
Bioelectromagnetics. **2007** Aug 10; [Epub ahead of print]

Abstract: New-born CD-1 mice were initiated with a single subcutaneous injection of 60 microg 7,12-dimethylbenz(a)anthracene (DMBA) within 24 h after birth. After weaning, the mice were randomly divided into five groups of 100, 50 males and 50 females each. One group served as a cage control. The other four groups of mice were exposed to either 0 (sham-exposed), 7, 70, or 350 microT(rms) circularly polarized 50 Hz magnetic fields (MFs) for 22 h/day, 7 days/week for 30 weeks. Animals were observed daily and the development of malignant lymphoma/lymphatic leukemia was examined histopathologically. The experiment was conducted twice. There was no observed sexual difference in the cumulative proportions of mice with malignant lymphoma/lymphatic leukemia and a 3-way analysis of deviance using the Cox regression model revealed no interactions between experiment, sex, or group. The cumulative proportions of mice with malignant lymphoma/lymphatic leukemia in the MF-exposed groups were not significantly higher than those in the sham-exposed group of each sex in individual experiments and in males and females combined in each experiment, and in all the animals from the two experiments

combined. These data provide no evidence to support the hypothesis that power frequency MFs is a significant risk factor for hematopoietic neoplasia.

3.3 Mechanism + *in vitro* Studies

M1: Effects of extremely low-frequency electromagnetic fields on delayed chromosomal instability induced by bleomycin in normal human fibroblast cells.
Cho YH, Jeon HK, Chung HW.
J Toxicol Environ Health A. **2007** Aug;70(15-16):1252-8.

Abstract: This study was carried out to examine the interaction of extremely low-frequency electromagnetic fields (ELF-EMF) on delayed chromosomal instability by bleomycin (BLM) in human fibroblast cells. A micronucleus-centromere assay using DNA probes for chromosomes 1 and 4 was performed and a 60-Hz ELF-EMF of 0.8 mT field strength was applied either alone or with BLM throughout the culture period. The frequencies of micronuclei (MN) and aneuploidy were analyzed at 28, 88, and 240 h after treatment with BLM. The coexposure of cells to BLM and ELF-EMF led to a significant increase in the frequencies of MN and aneuploidy compared to the cells treated with BLM alone. No difference was observed between field-exposed and sham-exposed control cells. The frequency of MN induced by BLM was increased at 28 h, and further analysis showed a persistent increase up to 240 h, but the new levels were not significantly different from the level at 28 h. BLM increased the frequencies of aneuploidy at 28, 88, and 240 h, and significantly higher frequency of aneuploidy was observed in the cells analyzed at 240 h compared to the cells examined at 28 h. No interaction of ELF-EMF on delayed chromosomal instability by BLM was observed. Our results suggest that ELF-EMF enhances the cytotoxicity of BLM. BLM might induce delayed chromosomal instability, but no effect of ELF-EMF was observed on the BLM-induced delayed chromosomal instability in fibroblast cells.

M2: Microsatellite analysis for determination of the mutagenicity of extremely low-frequency electromagnetic fields and ionising radiation in vitro.

Mairs RJ, Hughes K, Fitzsimmons S, Prise KM, Livingstone A, Wilson L, Baig N, Clark AM, Timpson A, Patel G, Folkard M, Angerson WJ, Boyd M.
Mutat Res. **2007** Jan 10;626(1-2):34-41. Epub 2006 Sep 20.

Abstract: Extremely low-frequency electromagnetic fields (ELF-EMF) have been reported to induce lesions in DNA and to enhance the mutagenicity of ionising radiation. However, the significance of these findings is uncertain because the determination of the carcinogenic potential of EMFs has largely been based on investigations of large chromosomal aberrations. Using a more sensitive method of detecting DNA damage involving microsatellite sequences, we observed that exposure of UVW human glioma cells to ELF-EMF alone at a field strength of 1 mT (50 Hz) for 12 h gave rise to 0.011 mutations/locus/cell. This was equivalent to a 3.75-fold increase in mutation induction compared with unexposed controls. Furthermore, ELF-EMF increased the mutagenic capacity of 0.3 and 3 Gy gamma-irradiation by factors of 2.6 and 2.75, respectively. These results suggest not only that ELF-EMF is mutagenic as a single agent but also that it can potentiate the mutagenicity of ionising radiation. Treatment with 0.3 Gy induced more than 10 times more mutations per unit dose than irradiation with 3 Gy, indicating hypermutability at low dose.

M3: Effects of co-exposure to extremely low frequency (50 Hz) magnetic fields and xenobiotics determined in vitro by the alkaline comet assay.
Villarini M, Moretti M, Scassellati-Sforzolini G, Boccioli B, Pasquini R.
Sci Total Environ. **2006** May 15;361(1-3):208-19. Epub 2005 Jun 24.

Abstract: In the present study, we used human peripheral blood leukocytes from 4 different donors, to investigate in vitro the possible genotoxic and/or co-genotoxic activity of extremely low frequency magnetic fields (ELF-MF) at 3 mT intensity. Two model mutagens were used to study the possible interaction between ELF-MF and xenobiotics: N-methyl-N'-nitro-N-nitrosoguanidine (MNNG) and 4-nitroquinoline N-oxide (4NQO). Primary DNA damage was evaluated by the alkaline single-cell microgel-electrophoresis ("comet") assay. Control cells (leukocytes not exposed to ELF-MF, nor treated with genotoxins) from the different blood donors showed a comparable level of basal DNA damage, whereas the contribution of individual susceptibility toward ELF-MF and the tested genotoxic compounds led to differences in the extent of DNA damage observed following exposure to the genotoxins, both in the presence and in the absence of an applied ELF-MF. A 3 mT ELF-MF alone was unable to cause direct primary DNA damage. In leukocytes exposed to ELF-MF and genotoxins, the extent of MNNG-induced DNA damage increased with exposure duration compared to sham-exposed cells. The opposite was observed in cells treated with 4NQO. In this case the extent of 4NQO-induced DNA damage was somewhat reduced in leukocytes exposed to ELF-MF compared to sham-exposed cells. Moreover, in cells exposed to ELF-MF an increased concentration of GSH was always observed, compared to sham-exposed cells. Since following GSH conjugation the genotoxic pattern of MNNG and 4NQO is quite different, an influence of ELF-MF on the activity of the enzyme involved in the synthesis of GSH leading to different activation/deactivation of the model mutagens used was hypothesized to explain the different trends observed in MNNG and 4NQO genotoxic activity in the presence of an applied ELF-MF. The possibility that ELF-MF might interfere with the genotoxic activity of xenobiotics has important implications, since human populations are likely to be exposed to a variety of genotoxic agents concomitantly with exposure to this type of physical agent.

M4: Elevated sister chromatid exchange frequencies in dividing human peripheral blood lymphocytes exposed to 50 Hz magnetic fields.
Wahab MA, Podd JV, Rapley BI, Rowland RE.
Bioelectromagnetics. **2007** May;28(4):281-8.

Abstract: The in vitro cytomolecular technique, sister chromatid exchange (SCE), was applied to test the clastogenic potentiality of extremely low frequency (ELF)electromagnetic fields (EMFs) on human peripheral blood lymphocytes (HPBLs). SCE frequencies were scored in dividing peripheral blood lymphocytes (PBLs) from six healthy male blood donors in two rounds of experiments, R1 and R2, to determine reproducibility. Lymphocyte cultures in the eight experiments conducted in each round were exposed to 50 Hz sinusoidal (continuous or pulsed) or square (continuous or pulsed) MFs at field strengths of 1 microT or 1 mT for 72 h. A significant increase in the number of SCEs/cell in the grouped experimental conditions compared to the controls was observed in both rounds. The highest SCE frequency in R1 was 10.03 for a square continuous field, and 10.39 for a square continuous field was the second highest frequency in R2. DNA crosslinking at the replication fork is proposed as a model which could explain the mechanistic link between ELF EMF exposure and increased SCE frequency. (c) 2007 Wiley-Liss, Inc.

3.4 Reviews

R1: Accounting for human variability and sensitivity in setting standards for electromagnetic fields.
Bailey WH, Erdreich LS.
Health Phys. **2007** Jun;92(6):649-57.

Abstract: Biological sensitivity and variability are key issues for risk assessment and standard setting. Variability encompasses general inter-individual variations in population responses, while sensitivity relates to unusual or extreme responses based on genetic, congenital, medical, or environmental conditions. For risk assessment and standard setting, these factors affect estimates of thresholds for effects and dose-response relationships and inform efforts to protect the more sensitive members of the population, not just the typical or average person. While issues of variability and sensitivity can be addressed by experimental and clinical studies of electromagnetic fields, investigators have paid little attention to these important issues. This paper provides examples that illustrate how default assumptions regarding variability can be incorporated into estimates of 60-Hz magnetic field exposures with no risk of cardiac stimulation and how population thresholds and variability of peripheral nerve stimulation responses at 60-Hz can be estimated from studies of pulsed gradient magnetic fields in magnetic resonance imaging studies. In the setting of standards for radiofrequency exposures, the International Commission for Non-Ionizing Radiation Protection uses inter-individual differences in thermal sensitivity as one of the considerations in the development of "safety factors." However, neither the range of sensitivity nor the sufficiency or excess of the 10-fold and the additional 5-fold safety factors have been assessed quantitatively. Data on the range of responses between median and sensitive individuals regarding heat stress and cognitive function should be evaluated to inform a reassessment of these safety factors and to identify data gaps.

R2: Fielding a current idea: exploring the public health impact of electromagnetic radiation.
Genuis SJ.
Public Health. **2007** Jun 18; [Epub ahead of print]

Abstract: Several publications in the scientific literature have raised concern about the individual and public health impact of adverse non-ionizing radiation (a-NIR) from electromagnetic field (EMF) exposure emanating from certain power, electrical and wireless devices commonly found in the home, workplace, school and community. Despite the many challenges in establishing irrefutable scientific proof of harm and the various gaps in elucidating the precise mechanisms of harm, epidemiological analyses continue to suggest considerable potential for injury and affliction as a result of a-NIR exposure. As environmental health has not been emphasized in medical education, some clinicians are not fully aware of possible EMF-related health problems and, as a result, manifestations of a-NIR may remain misdiagnosed and ineffectually managed. It is important for physicians and public health officials to be aware of the fundamental science and clinical implications of EMF exposure. A review of the scientific literature relating tothe link between electromagnetic radiation and human health, several public health recommendations, and four case histories are presented for consideration.

R3: Health risks of exposure to non-ionizing radiation--myths or science-based evidence.
Hietanen M.
Med Lav. **2006** Mar-Apr;97(2):184-8

Abstract: INTRODUCTION: The non-ionizing radiation (NIR) contains large range of wavelengths and frequencies from vacuum ultraviolet (UV) radiation to static electric and magnetic fields. Biological effects of electromagnetic (EM) radiation depend greatly on wavelength and other physical parameters. OPTICAL RADIATION: The Sun is the most significant source of environmental UV exposure, so that

outdoor workers are at risk of chronic over-exposure. Also exposure to short-wave visible light is associated with the aging and degeneration of the retina. Especially hazardous are laser beams focused to a small spot at the retina, resulting in permanent visual impairment. ELECTROMAGNETIC FIELDS: Exposure to EM fields induces body currents and energy absorption in tissues, depending on frequencies and coupling mechanisms. Thermal effects caused by temperature rise are basically understood, whereas the challenge is to understand the suspected non-thermal effects. Radiofrequency (RF) fields around frequencies of 900 MHz and 1800 MHz are of special interest because of the rapid advances in the telecommunication technology. The field levels of these sources are so low that temperature rise is unlikely to explain possible health effects. Other mechanisms of interaction have been proposed, but biological experiments have failed to confirm their existence.

R4: Transmission lines, EMF and population mixing.
Jeffers D.
Radiat Prot Dosimetry. **2007**;123(3):398-401. Epub 2006 Nov 15.

Abstract: Draper et al. found that the incidence of childhood leukaemia was slightly elevated for children living at distances of 200-600 m from high-voltage transmission lines. This elevation cannot be explained by EMF exposure and it is suggested that it may be due to population mixing in housing developments which followed the construction of the lines.

R5: Public health impact of extremely low-frequency electromagnetic fields.
Kheifets L, Afifi AA, Shimkhada R.
Environ Health Perspect. **2006** Oct;114(10):1532-7.

Abstract: INTRODUCTION: The association between exposure to extremely low-frequency electric and magnetic fields (ELF) and childhood leukemia has led to the classification of magnetic fields by the International Agency for Research on Cancer as a "possible human carcinogen." This association is regarded as the critical effect in risk assessment. Creating effective policy in light of widespread exposure and the undisputed value of safe, reliable, and economic electricity to society is difficult and requires estimates of the potential public health impact and associated uncertainties. OBJECTIVES: Although a causal relationship between magnetic fields and childhood leukemia has not been established, we present estimates of the possible pubic health impact using attributable fractions to provide a potentially useful input into policy analysis under different scenarios. METHODS: Using ELF exposure distributions from various countries and dose-response functions from two pooled analyses, we calculate country-specific and worldwide estimates of attributable fractions (AFs) and attributable cases. RESULTS: Even given a wide range of assumptions, we find that the AF remains < 10%, with point estimates ranging from < 1% to about 4%. For small countries with low exposure, the number of attributable cases is less than one extra case per year. Worldwide the range is from 100 to 2,400 cases possibly attributable to ELF exposure. CONCLUSION: The fraction of childhood leukemia cases possibly attributable to ELF exposure across the globe appears to be small. There remain, however, a number of uncertainties in these AF estimates, particularly in the exposure distributions.

R6: Electromagnetic fields (EMF): Do they play a role in children's environmental health (CEH)?
Otto M, von Mühlendahl KE.
Int J Hyg Environ Health. **2007** Aug 30; [Epub ahead of print]

Abstract: Possible adverse health effects of exposure to electric, magnetic and electromagnetic fields (EMF), and especially the question of whether there exists a special vulnerability of children, have been a much discussed topic during the last two decades. Static fields produce health effects only in very rare and exceptional circumstances at extremely high field intensities. As for low-frequency EMF, the results of epidemiological research with respect to childhood leukaemia prompted the International Agency for Research on Cancer (IARC) in 2001 to classify these fields as "possibly carcinogenic to humans". Current

hypotheses on the mechanism of such action are presented. The effect, if existent, appears to be not very important in relation to established other causes of childhood leukaemia. High-frequency EMF, as used in mobile and wireless communication (mobile telephony according to the GSM and UMTS standard, cordless DECT phones, wireless local area networks (WLAN), Bluetooth) and since many decades also in radio and television technology, are practically omnipresent. At high intensities, the generation of heat is the principal effect. Current guidelines, limits and regulations prevent any such effect. Mobile phone calls may, in certain circumstances, lead to local exposures close to limit values. Base stations typically produce exposures lower by 2-5 magnitudes. The discussion centres on the so-called non-thermal effects, which are supposedly occurring at field intensities, which are by orders of magnitude lower than those responsible for thermal effects. The reproducibility of these effects is usually poor, and no physiologic or pathogenic mechanism, so far, has been found to explain the alleged effects. Equally, epidemiologic studies have not furnished clear and reproducible data as arguments for negative health effects. Final results of the INTERPHONE study on the risk of brain tumours, acoustic neurinoma and parotid gland tumours associated with the use of mobile phones will be soon available. Preliminary results do not seem to indicate a substantial increase in risk. There are presently no scientific data supporting the concept of a special vulnerability of children and adolescents to high-frequency EMF, even if the usual caveats (developing organisms and structures may be more vulnerable, decades of life to come) are considered. The concept of precautionary measures adapted to such concerns is critically discussed.

R7: Rapporteur Report: ICNIRP international workshop on EMF dosimetry and biophysical aspects relevant to setting exposure guidelines.
Roy CR.
Health Phys. **2007** Jun; 92(6):658-67.

The International Commission on Non-Ionizing Radiation Protection has commenced the revision of its EMF guidelines in the frequency range up to 300 GHz. The ICNIRP International EMF Dosimetry Workshop has brought together a range of scientists to discuss the basis of the existing guidelines and to highlight those areas where attention needs to be given. This report is an attempt to extract the key messages from each of the presentations. A tabulation of the important issues discussed in the summary and conclusion session is provided at the end of this report.

R8: Implications from epidemiologic studies on magnetic fields and the risk of childhood leukemia on protection guidelines.
Schüz J.
Health Phys. **2007** Jun;92(6):642-8.

Abstract: The objective of this review is to discuss the impact of findings in epidemiological studies on magnetic fields and the risk of childhood leukemia on the definition of exposure limits. A large number of epidemiological studies have consistently shown an association between the risk of childhood leukemia and residential extremely low-frequency magnetic field exposures. There is virtually no supportive data from experimental research and, so far, no proposed explanation has reached a level beyond speculation. The contradictory results from epidemiological and experimental research may either be due to methodological limitations creating a spurious association in the epidemiological studies or to a failure of experimental research to examine mechanisms relevant in the complex origin of childhood leukemia. Taking this together, the overall evidence is not strong enough to demand a revision of the current guidelines for public protection. Application of precautionary measures may be an option; however, decision-makers should be advised that these measures are often not straightforward and a careful evaluation of a possible benefit needs to be performed for each individual situation. Undoubtedly there are gaps in research, and no substantial contribution for clarification of the apparent inconsistencies emerges from recent studies. However, there are important lessons to learn, either with respect to the etiology of childhood leukemia or with respect to the need for improving epidemiological methods for the identification of presumably weak associations.

4 Listing of Articles

Key Studies	Authors	Type of Study	Title	Source
	Anselmo CW, Santos AA, Freire CM, Ferreira LM, Cabral Filho JE, Catanho MT, Medeiros Mdo C.	Animal Study	Influence of a 60 Hz, 3 microT, electromagnetic field on the reflex maturation of Wistar rats offspring from mothers fed a regional basic diet during pregnancy.	Nutr Neurosci. 2006 Oct-Dec;9(5-6):201-6.
A1	Erdal N, Gürgül S, Celik A.	Animal Study	Cytogenetic effects of extremely low frequency magnetic field on Wistar rat bone marrow.	Mutat Res. 2007 Jun 15;630(1-2):69-77. Epub 2007 Mar 16.
	Manikonda PK, Rajendra P, Devendranath D, Gunasekaran B, Channakeshava , Aradhya RS, Sashidhar RB, Subramanyam C.	Animal Study	Influence of extremely low frequency magnetic fields on Ca2+ signaling and NMDA receptor functions in rat hippocampus.	Neurosci Lett. 2007 Feb 14;413(2):145-9. Epub 2006 Dec 28.
A2	Negishi T, Imai S, Shibuya K, Nishimura I, Shigemitsu T.	Animal Study	Lack of promotion effects of 50 Hz magnetic fields on 7,12-dimethylbenz(a)anthracene-induced malignant lymphoma/lymphatic leukemia in mice.	Bioelectromagnetics. 2007 Aug 10; [Epub ahead of print]
	Zapponi GA, Marcello I	Animal Study	Some non neoplastic effects of ELF magnetic fields in experimental animals.	Ann Ist Super Sanita. 2006;42(2):178-88.
O1	O'Carroll MJ, Henshaw DL.	Comment	Comment on "Developing policy in the face of scientific uncertainty: interpreting 0.3 microT or 0.4 microT cutpoints from EMF epidemiologic studies" by Kheifets et al. in Risk Analysis, 25(4), 927-935.	Risk Anal. 2007 Apr;27(2):285-7; author reply 289-90. No abstract available.
	Bowman, Joseph D.; Touchstone, Jennifer A.; Yost, Michael G..	Exposure	A Population-Based Job Exposure Matrix for Power-Frequency Magnetic Fields	Journal of Occupational and Environmental Hygiene 4.9 (2007
	Cech R, Leitgeb N, Pediaditis M	Exposure	Fetal exposure to low frequency electric and magnetic fields.	Phys Med Biol. 2007 Feb 21;52(4):879-88. Epub 2007 Jan 17.
	Ger WJ, Chang WP, Sung FC, Li CY.	Exposure	Accuracy of short-term residential measurement in the prediction of 72-h exposure to power frequency magnetic field in households very close to high-tension transmission lines.	J Expo Sci Environ Epidemiol. 2007 Jan;17(1):69-75. Epub 2006 Aug 23.
	Gobba F, Bravo G, Scaringi M, Roccatto L.	Exposure	No association between occupational exposure to ELF magnetic field and urinary 6-sulfatoximelatonin in workers.	Bioelectromagnetics. 2006 Dec;27(8):667-73.
	Jokela K.	Exposure	Assessment of complex EMF exposure situations including inhomogeneous field distribution.	Health Phys. 2007 Jun;92(6):531-40. Review.

Li CY, Mezei G, Sung FC, Silva M, Chen PC, Lee PC, Chen LM.	Exposure	Survey of residential extremely-low-frequency magnetic field exposure among children in Taiwan.	Environ Int. 2007 Feb;33(2):233-8. Epub 2006 Oct 30.
Li CY, Sung FC, Chen FL, Lee PC, Silva M, Mezei G.	Exposure	Extremely-low-frequency magnetic field exposure of children at schools near high voltage transmission lines.	Sci Total Environ. 2007 Apr 15;376(1-3):151-9. Epub 2007 Feb 20.
Maslanyj MP, Mee TJ, Renew DC, Simpson J, Ansell P, Allen SG, Roman E.	Exposure	Investigation of the sources of residential power frequency magnetic field exposure in the UK Childhood Cancer Study.	J Radiol Prot. 2007 Mar;27(1):41-58. Epub 2007 Mar 6.
Ozen S	Exposure	Low-Frequency Transient Electric And Magnetic Fields Coupling To Child Body	Radiat Prot Dosimetry. 2007 May 26; [Epub ahead of print]
Paniagua JM, Jimenez A, Rufo M, Gutierrez JA, Gomez FJ, Antolin A.	Exposure	Exposure to extremely low frequency magnetic fields in an urban area.	Radiat Environ Biophys. 2007 Mar;46(1):69-76. Epub 2006 Dec 13.
Szabo J, Janossy G, Thuroczy G.	Exposure	Survey of residential 50 Hz EMF exposure from transformer stations.	Bioelectromagnetics. 2007 Jan;28(1):48-52.
Baldi E, Baldi C, Lithgow BJ.	Human/Epidemiological	A pilot investigation of the effect of extremely low frequency pulsed electromagnetic fields on humans' heart rate variability.	Bioelectromagnetics. 2007 Jan;28(1):64-8.
Buffler PA, Kelsh MA, Kalmes RM, Lau EC, Chapman PS, Wood SM, Brorby GP, Silva JM, Hooper HC, Rizzo BD, Wood R	Human/Epidemiological	A Nested Case-Control Study of Brain Tumors Among Employees at a Petroleum Exploration and Extraction Research Facility.	J Occup Environ Med. 2007 Jul;49(7):791-802.
Davanipour Z, Tseng CC, Lee PJ, Sobel E.	Human/Epidemiological	A case-control study of occupational magnetic field exposure and Alzheimer's disease: results from the California Alzheimer's Disease Diagnosis and Treatment Centers.	BMC Neurol. 2007 Jun 9;7:13.
Di Giampaolo L, Di Donato A, Antonucci A, Paiardini G, Travaglini P, Spagnoli G, Magrini A, Reale M, Dadorante V, Iannaccone U, Di Sciascio MB, Di Gioacchino M, Boscolo P.	Human/Epidemiological	Follow up study on the immune response to low frequency electromagnetic fields in men and women working in a museum.	Int J Immunopathol Pharmacol. 2006 October-December;19(4S):37-42.

E1	Feizi AA, Arabi MA.	Human/Epidemiological	Acute childhood leukemias and exposure to magnetic fields generated by high voltage overhead power lines - a risk factor in Iran.	Asian Pac J Cancer Prev. 2007 Jan-Mar;8(1):69-72.
	Karipidis KK, Benke G, Sim MR, Kauppinen T, Giles G.	Human/Epidemiological	Occupational exposure to ionizing and non-ionizing radiation and risk of glioma.	Occup Med (Lond). 2007 Aug 29; [Epub ahead of print]
	Karipidis KK, Benke G, Sim MR, Kauppinen T, Kricker A, Hughes AM, Grulich AE, Vajdic CM, Kaldor J, Armstrong B, Fritschi L.	Human/Epidemiological	Occupational exposure to ionizing and non-ionizing radiation and risk of non-Hodgkin lymphoma.	Int Arch Occup Environ Health. 2007 Mar 2; [Epub ahead of print]
	Karipidis KK, Benke G, Sim MR, Yost M, Giles G	Human/Epidemiological	Occupational exposure to low frequency magnetic fields and the risk of low grade and high grade glioma.	Cancer Causes Control. 2007 Jan 27; [Epub ahead of print]
E2	Lowenthal RM, Tuck DM, Bray IC.	Human/Epidemiological	Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case-control study.	Intern Med J. 2007 Jun 2; [Epub ahead of print]
	McElroy JA, Egan KM, Titus-Ernstoff L, Anderson HA, Trentham-Dietz A, Hampton JM, Newcomb PA.	Human/Epidemiological	Occupational exposure to electromagnetic field and breast cancer risk in a large, population-based, case-control study in the United States.	J Occup Environ Med. 2007 Mar;49(3):266-74.
E3	Mejia-Arangure JM, Fajardo-Gutierrez A, Perez-Saldivar ML, Gorodezky C, Martinez-Avalos A, Romero-Guzman L, Campo-Martinez MA, Flores-Lujano J, Salamanca-Gomez F, Velasquez-Perez L.	Human/Epidemiological	Magnetic fields and acute leukemia in children with Down syndrome.	Epidemiology. 2007 Jan;18(1):158-61.
	Pearce MS, Hammal DM, Dorak MT, McNally RJ, Parker L.	Human/Epidemiological	Paternal occupational exposure to electro-magnetic fields as a risk factor for cancer in children and young adults: A case-control study from the North of England.	Pediatr Blood Cancer. 2007 Sep;49(3):280-6.

	Röösli M, Lörtscher M, Egger M, Pfluger D, Schreier N, Lörtscher E, Locher P, Spoerri A, Minder C.	Human/Epidemiological	Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees.	Occup Environ Med. 2007 Aug;64(8):553-9. Epub 2007 May 24.
E4	Schuz J, Svendsen AL, Linet MS, McBride ML, Roman E, Feychting M, Kheifets L, Lightfoot T, Mezei G, Simpson J, Ahlbom A.	Human/Epidemiological	Nighttime exposure to electromagnetic fields and childhood leukemia: an extended pooled analysis.	Am J Epidemiol. 2007 Aug 1;166(3):263-9. Epub 2007 May 7.
	Sorahan T, Kheifets L	Human/Epidemiological	Mortality from Alzheimer's, motor neurone and Parkinson's disease in relation to magnetic field exposure: findings from the study of UK electricity generation and transmission workers, 1973-2004.	Occup Environ Med. 2007 Jul 11; [Epub ahead of print]
E5	Svendsen AL, Weihkopf T, Kaatsch P, Schuz J	Human/Epidemiological	Exposure to magnetic fields and survival after diagnosis of childhood leukemia: a german cohort study.	Cancer Epidemiol Biomarkers Prev. 2007 Jun;16(6):1167-71.
	Akdag MZ, Dasdag S, Aksen F, Isik B, Yilmaz F	In vitro	Effect of ELF magnetic fields on lipid peroxidation, sperm count, p53, and trace elements.	Med Sci Monit. 2006 Nov;12(11):BR366-71.
	Aldinucci C, Carretta A, Maiorca S, Rossi V, Ciccoli L, Pessina GP.	In vitro	Synaptosome behaviour is unaffected by weak pulsed electromagnetic fields.	Bioelectromagnetics. 2007 Sep;28(6):477-83.
	Amaroli A, Trielli F, Bianco B, Giordano S, Moggia E, Corrado MU.	In vitro	Effects of a 50 Hz magnetic field on Dictyostelium discoideum (Protista).	Bioelectromagnetics. 2006 Oct;27(7):528-34.
	Bernabò N, Tettamanti E, Pistilli MG, Nardinocchi D, Berardinelli P, Mattioli M, Barboni B.	In vitro	Effects of 50 Hz extremely low frequency magnetic field on the morphology and function of boar spermatozoa capacitated in vitro.	Theriogenology. 2007 Mar 1;67(4):801-15. Epub 2006 Dec 29.
	Bernardini C, Zannoni A, Turba ME, Bacci ML, Forni M, Mesirca P, Remondini D, Castellani G, Bersani F.	In vitro	Effects of 50 Hz sinusoidal magnetic fields on Hsp27, Hsp70, Hsp90 expression in porcine aortic endothelial cells (PAEC).	Bioelectromagnetics. 2007 Apr;28(3):231-7.
M1	Cho YH, Jeon HK, Chung HW.	In vitro	Effects of extremely low-frequency electromagnetic fields on delayed chromosomal instability induced by bleomycin in normal human fibroblast cells.	J Toxicol Environ Health A. 2007 Aug;70(15-16):1252-8.

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