Risk Assessment of Human Exposure to Extremely Low Frequency (ELF) Fields

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Introduction

• Exposure to ELF fields at levels implicated with biological and health effects can arise from living in close proximity to transmission lines (roughly under 60 meters) or unbalanced street power lines, electric currents running on metal water piping in homes and offices as well as sources within the home.

• Most of the public concerns about possible health risk focuses on the cancer, with childhood leukemia a particular worry.

• Because of uncertainty about health risks associated with human exposure to ELF fields, the public is more likely to experience difficulty in evaluating the available information and rely more on perceptions than facts when drawing conclusions.
Ambient levels of 50/60-Hz magnetic fields in residences and most workplaces are typically in the range of 0.01-0.3 µT (0.1-3 mG). Higher levels are encountered directly under transmission and distribution lines and in some occupational settings. Some appliances produce magnetic fields of up to 100 µT (1 G) or more in their vicinity.
Whether or not there are health consequences associated with the ELF fields emanating from the generation, distribution and utilization of electricity is a controversial issue, in which the tension between risks versus indispensable advantage comes into play. This is a common debate when complex environmental issues with considerable health and economic outcomes are scientifically analyzed.

There are also economic consequences, for example, electrical utilities sometimes have had to redirect high voltage power lines around populated areas and even stop their construction. The real estate industry is also increasingly concerned. These include potential liability, property valuation, premises abandonment, and tenant concerns about potential health effects.

Concerns about hazard have often pushed manufacturers to improve products by providing better shielding which has a positive impact on the EM compatibility and performance of the product itself.

The cost–benefit ratio for making such improvements is always a concern, However gaining public trust is very important too.
ELF Fields Compared to Ionizing and Non-ionizing Radiofrequency Radiation

Why conventional wisdom has held that the ELF electric and magnetic fields at environmental levels could pose no potential risk to human health?

- There is no significant transfer of energy from ELF fields to biological systems. Unlike ionizing radiation, ELF fields do not break chemical bonds. Unlike radiofrequency radiation, ELF fields cannot cause significant tissue heating.

- All cells in the body maintain large natural electric fields across their outer membranes. These naturally occurring fields are substantially more intense than those induced by exposure to common ELF field sources.
Cellular Response to ELF Exposure

• Studies over the last forty years have demonstrated that under certain circumstances, the membranes of cells can be sensitive to even fairly weak externally imposed low frequency ELF fields. Small signal changes may trigger major biochemical responses critical to the functioning of the cell.

• Among the responses demonstrated in experimental studies using animal cells and tissues are*:
  – Modulation of ion flows.
  – Interference with DNA synthesis and RNA transcription.
  – Interaction with the response of normal cells to various agents such as hormones, neurotransmitters, and growth factors.
  – Interaction with the biochemical kinetics of cancer cells.

Scientific Controversy Regarding Biological and Health Effects of ELF EMFs

- Though the majority of *in vitro* studies indicate that exposure to ELF EMFs causes various alterations on the cellular level, it is not clear, whether or not these alterations can be directly extrapolated to effects in humans.

- “There is still no general agreement on the exact biological detrimental effects of ELF fields, on the physical mechanisms that may be behind these effects or on the extent to which these effects may be harmful to humans.” (Santini, Rainaldi and Indovina, 2009)
Only established health effects serve as a basis for exposure restriction.

Biological effects without any known adverse health consequences do not form a basis for limiting exposure.

An established adverse effect of ELF EMFs at high levels is stimulation of excitable cells (muscle cells, neurons).

These short-term, immediate effects, which are unlikely to occur at exposure levels in the environmental and most occupational settings, form the basis for international guidelines.

No firm scientific evidence exists regarding long-term health effects of occupational or environmental ELF EMF exposure.

International Guidelines: Exposure Limits for 60-Hz Fields and Contact Currents

<table>
<thead>
<tr>
<th></th>
<th>IEEE 2002</th>
<th>ICNIRP 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occupational</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Field, kV/m</td>
<td>20</td>
<td>8.3</td>
</tr>
<tr>
<td>Magnetic Field, mT</td>
<td>2.71</td>
<td>0.42</td>
</tr>
<tr>
<td>Contact Current, mA</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>General Public</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Field, kV/m</td>
<td>5</td>
<td>4.2</td>
</tr>
<tr>
<td>Magnetic Field, mT</td>
<td>0.904</td>
<td>0.083</td>
</tr>
<tr>
<td>Contact Current, mA</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

ICNIRP applies a safety factor to the threshold for acute effects and an additional safety factor for the general public.

IEEE defines a low probability adverse reaction level and then applies a safety factor to allow for uncertainties and sensitive individuals.

New ICNIRP guidelines for ELF EMFs are under review.

- The IEEE and ICNIRP standards are advisory for national standard-setting agencies.

Sources: http://www.osha.gov/SLTC/elfradiation/epri-ieee1-03d.pdf
Public Concerns

• Public concern over human effects of exposure to ELF fields is largely based on a series of key epidemiological assessment studies. Such studies identify the association between diseases and particular environmental characteristics. It may indicate a cause-and-effect relationship, depending upon the strength of the observed association.

• Epidemiological studies correlate historical biological data for a large population of people. Any biological data is purely statistical in nature; however, people usually fit a particular category based on location or occupation. The results may only show an association with a stimulus, since there are many factors involved with each person.
Exposure to ELF EMFs and Cancer

- Substantial research has been conducted after publication of a report in 1979 by Wertheimer and Leeper on an association between childhood leukemia and residence near electricity transmission lines.

- Studies of childhood cancer focused on leukemia and to a lesser extent on brain and nervous system tumors.

- Studies of cancers were conducted in adults occupationally or residentially exposed to electric and magnetic fields.

- The only relatively consistent statistical evidence of an association in epidemiological studies of cancer in relation to ELF EMF was detected for childhood leukemia.
<table>
<thead>
<tr>
<th>Investigator</th>
<th>Type/Location/Size</th>
<th>Risk Measure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wertheimer and Leeper, 1979</td>
<td>CC: USA (Denver, Colorado; &lt;19 yr) 155 cases/155 controls.</td>
<td>OR WC: 2.98 (1.78-4.98)</td>
<td>Children had double or triple the chance of developing leukemia or tumors of the nervous system if they live near transmission lines as compared to those who do not.</td>
</tr>
<tr>
<td>Savitz et al., 1988</td>
<td>CC: USA (Denver, Colorado); &lt;15 yr); ≥ 0.25 μT spot 448 cases / 466 controls.</td>
<td>OR WC: 2.75 (0.94-8.04) MF: 1.93 (0.67-5.56)</td>
<td>Increased cases of childhood cancer and leukemia associated with magnetic field exposures above 0.25 μT.</td>
</tr>
<tr>
<td>Linet et al., 1997</td>
<td>CC: USA (9 States); &lt;19 yr ≥ 0.3 μT; 24-h measurements 1026 cases/1017 controls.</td>
<td>OR WC: 0.98 (0.72-1.33) MF: 1.24 (0.86-1.79)</td>
<td>No overall correlation between the level of field exposure and risk of ALL. There was a small increase in the risk of ALL for children whose residences measured in the very highest range of magnetic fields.</td>
</tr>
<tr>
<td>McBride et al., 1999</td>
<td>CC: Canada (5 province); &lt;15 yr≥ 0.2 μT calculated Wire code/48-h measurement 596 cases/648 controls.</td>
<td>OR WC: 0.77 (0.37-1.60) MF: 1.04 (0.69-1.57)</td>
<td>Elevated risk of ALL with high wiring configurations among residences of subjects 2 years before the diagnosis/reference date (OR=1.72 compared with underground wiring, (0.54-5.45)).</td>
</tr>
<tr>
<td>Schüz et al., 2001</td>
<td>PBCC: Germany (West) &gt; 0.2 μT; 24-h measurements 514 cases/1,301 controls.</td>
<td>OR MF: 1.55 (0.65-3.67)</td>
<td>Association between childhood leukemia and magnetic field exposure during the night (OR= 3.21 (1.33-7.80)).</td>
</tr>
<tr>
<td>Skinner et al., 2002</td>
<td>PBCC: UK &gt; 20 V m⁻¹; spot measurement; 273 cases/ 276 controls.</td>
<td>OR EF: 0.90 (0.59 – 1.35) for all malignancies</td>
<td>Residential electric fields and fields from power lines (66 kV–400 kV) and electric blankets not associated with significant increase in risk of childhood cancer.</td>
</tr>
<tr>
<td>Infante–Rivard and Deadman, 2003</td>
<td>PBCC: Canada (Quebe); (&gt;0.4 μT calculated; 491 cases/491 controls</td>
<td>OR MF: 2.5 (1.2-5.0)</td>
<td>The results are compatible with an increased risk of childhood leukemia among children whose mothers were exposed to the highest occupational levels of magnetic fields during pregnancy.</td>
</tr>
</tbody>
</table>
## Pooled Studies on Childhood Leukemia

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Type/Location/Size</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahlbom et al., 2000</td>
<td>Nine studies: Canada, Denmark, Finland, Germany, New Zealand, Norway, Sweden, UK, USA.</td>
<td>ref. 1.08 (0.89–1.31) 1.11 (0.84–1.47) 2.00 (1.27–3.13)</td>
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<tr>
<td></td>
<td>3,203 cases and 10,338 controls with measured or calculated magnetic field data.</td>
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<tr>
<td>Greenland et al., 2000</td>
<td>Twelve studies: Canada, Denmark, Finland, Germany, New Zealand, Norway, Sweden, UK, USA, 2,484 cases and 6,335 controls with magnetic field measurement data.</td>
<td>ref. 1.01 (0.84–1.21) 1.06 (0.78–1.44) 1.68 (1.23–2.31)</td>
</tr>
<tr>
<td></td>
<td>3,203 cases and 10,338 controls with measured or calculated magnetic field data.</td>
<td></td>
</tr>
<tr>
<td>Schuz et al., 2007</td>
<td>Four studies from Canada, Germany, UK and USA; nighttime bedroom EMF measurements; 1,842 cases and 3,099 controls.</td>
<td>ref. 1.11 (0.91–1.36) 1.37 (0.99–1.90) 1.93 (1.11–3.35)</td>
</tr>
</tbody>
</table>
Risk Assessment Process

- The procedure for conducting health risk assessments of an agent is to collect a sufficient body of information, in the form of peer reviewed scientific publications available to conduct an identification and classification review.

- A multidisciplinary team of experts reviews all the studies, makes a thorough assessment of them and then votes to determine whether the scientific evidence fulfils the criteria for the agent fitting into any of the assigned categories: a human carcinogen, a probable human carcinogen, and a possible human carcinogen.
A consistent association between childhood leukemia and magnetic fields above 0.3-0.4 μT. “The association between childhood leukemia and high levels of magnetic fields is unlikely to be due to chance, but it may be affected by bias.”

Evidence for association between electric fields and childhood leukemia is inadequate for evaluation

Inconsistent results from smaller and of lower quality studies on residential EMFs and other childhood cancers

No discernable pattern of increased childhood cancer risks associated with electrical appliance use

No consistent evidence that residential or occupational exposures of adults to ELF electric or magnetic fields increase risk for any kind of cancer.

IARC (2002) Risk Assessment for Static and ELF EMFs

• Studies in experimental animals have not shown a consistent carcinogenic or co-carcinogenic effects of exposures to ELF magnetic fields, and no biologic mechanism has been established for the observed association of increased childhood leukemia risk with increasing residential ELF magnetic field exposure.

• IARC classified ELF magnetic fields as possibly carcinogenic to humans based on a certain consistency in the childhood leukemia epidemiological studies. The epidemiological evidence was credible but not convincing since it was not supported by laboratory studies.

All studies, with either positive or negative effects, need to be evaluated and judged on their own merit, and then all together in a weight-of-evidence approach. It is important to determine how much a set of evidence changes the probability that exposure causes an outcome. Generally, studies must be replicated or be in agreement with similar studies. The evidence for an effect is further strengthened if the results from different types of studies (epidemiology and laboratory) point to the same conclusion.”
WHO 2007 Risk Assessment

• WHO 2007 confirmed the IARC evaluation regarding cancer: “New human, animal and in vitro studies, published since the 2002 IARC monograph, do not change the overall classification of ELF magnetic fields as a possible human carcinogen.

• Other diseases evaluated for possible association with ELF magnetic field exposure included other cancers in children and adults, depression, suicide, reproductive and developmental disorders, immunological modifications, neurological and cardiovascular diseases.

• “The scientific evidence supporting a linkage between exposure to ELF magnetic fields and any of these diseases is weaker than for childhood leukemia 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.”

WHO 2007 Assessment of Possible Public Health Impact

- Based on survey results, \( \approx 0.5\text{-}7\% \) of children have average exposures over 0.3 \( \mu \text{T} \) and 0.4\text{-}3.3\% - over 0.4 \( \mu \text{T} \).
- Assuming that the association between magnetic field exposure and childhood leukemia is causal, from 100 to 2,400 cases per year worldwide might be attributable to exposure.
- These estimates are dependent on exposure distributions and other assumptions and are very imprecise.
- The estimated numbers of attributable cases would represent only from 0.2 to 4.9\% of total annual cases of childhood leukemia.
- “…in a global context, the impact on public health, if any, would be limited and uncertain.”

WHO 2007 Conclusions

• Compliance with international guidelines provides adequate protection against established acute effects of exposure to ELF EMFs.

• Despite consistent epidemiological evidence, causal relationship between exposure to ELF magnetic fields and childhood leukemia is not established. Therefore, “exposure limits based upon epidemiological evidence are not recommended, but some precautionary measures are warranted”

WHO 2007 Recommendations for Further Research

• Improving dosimetry to reduce uncertainties in exposure assessment; identifying a relevant exposure metric for epidemiological assessment.
• Elucidation of the biophysical interaction mechanisms that may explain how the signal from the low–energy source could affect biological systems.
• Laboratory studies of possible neurobehavioral effects of ELF EMFs.
• Large prospective cohort studies with good quality information on EMF exposure and other risk factors are recommended to investigate the association observed in some studies between amyotrophic lateral sclerosis and “electrical occupations.”
• Further investigate the association between ELF magnetic fields and Alzheimer’s disease.
WHO 2007 Recommendations for Further Research (continued)

• Because limited information is available on the effects of ELF exposure on the immune and hematological parameters in children, studies of these endpoints in juvenile animals are recommended.

• Further epidemiological research to investigated the association between the ELF magnetic field exposure and the risk of miscarriage observed in some studies.

• Further analysis on childhood and adult brain cancer.

• Clarification of relationship between ELF magnetic field exposure and childhood leukemia is a research priority:
  – Collaboration between epidemiologists and experimental scientists is recommended.
  – Epidemiological studies should focus on interaction with other factors, on high exposure groups.
  – Update existing pooled analyses.
• Research on the development and implementation of health protection policies, specifically on the use of precaution.

• Further research is needed on public perception of the risk (psychological and sociological factors that influence risk perception, relative importance of these factors in case of EMFs). This can inform the design of risk communication strategies related to the management of ELF health risks.
Agenda for Policy Actions

Risk assessment research is one of the costs of bringing new technologies into society. In recognition of widespread debate and conflicting views, particularly in the contexts of public health and environmental protection, government, scientists, and industry should take effective research and policy actions to address the concerns about potential health risks of ELF fields. These actions may include:

- Public access to the most up-to-date research on biological and health effects associated with ELF fields.
- Scientific risk assessment that goes beyond technical issues and identifies a need for psychometric approach including cognitive, emotional, and social demographic determinants of risk.
- Thorough risk assessment and research projects with a potential to discover even the smallest of health risk with aims and results to be well communicated to all stakeholders.
- Public participation in risk management actions taken in response to concerns about the potential health risks of ELF fields.
- Adequate communication with individuals and groups on the various levels of scientific uncertainty.
Framework for Investigating the Potential Health Risks of Exposure to ELF Fields

Science
Assessing the Health Risk

Economy
Assessing the Benefit

ELF

Communication
Communicating to Stakeholders

Policy
Managing the Potential Risk
Agenda for Risk Communication

• An effective risk-communication strategy will assist the community understanding the ELF health risk issues, and decision makers will be in a better position to make an informed decision and act on public concerns. The following questions will guide any proposed risk communication agenda:
  – How is the available scientific evidence being interpreted and how do these interpretations influence risk debate?
  – How is new scientific evidence used, or not used, in shaping public risk communication strategies related to the management of ELF health risks? What happens when the same evidence is communicated in a different way?
  – What role do public values play in perceiving ELF risk?
  – How can experts and decision makers build trust with the public for authentic public involvement in risk decisions that have an impact on their health?
A Step toward Reliable Risk Assessment

• One option to reduce actual and perceived risks to public, and to establish better foundation for trust and communication between interested parties, is to include the public as valid stakeholders in all phases of planning and routing of power transmission lines and the locations of substations. This may include adequate public representation on the relevant standard setting committees.

• Public membership on expert committees and in public submissions to those committees is very important. When all the information is said and actions are done, it is only by this process that the foundations for an accurate and reliable risk assessment for public can be implemented.