Effects of extremely low frequency electromagnetic fields on health

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This paper gives a brief review of the physical interaction and bio-effects of exposure to extremely low frequency (ELF) electromagnetic fields (EMF) along with guidelines on limits of exposure to 50/60 Hz electric and magnetic fields.

Introduction
There has been a phenomenal growth in the use of extremely low electromagnetic fields at frequencies of 50/60 Hz mainly from electric energy generation, transmission, distribution and use in the past forty years. Man-made ELF fields are several orders of magnitude greater than the naturally occurring fields. At home, EMFs are generated by a number of sources, electric appliances including nearby high voltage transmission lines, the electric grounding systems, household wiring configurations etc. In general, electric fields in the home are 2-3 orders of magnitude lower in intensity than those in the vicinity of high transmission lines. One may encounter a magnetic field of 0.01-1 μT in office and household setup; up to 12 μT in room heated using electric or oil heaters; 1-30 μT at a distance of 30 cm from various appliances; 0.1-1 mT fields at a distance of 3 cm away from electric blankets, hair dryers, electric shavers and magnetic mains stabilizers. The adverse health effects was first reported in mid 1960’s from erstwhile USSR1, that is, general malaise, headache, insomnia, upper respiratory tract infection and fatigue among workers in electric power substations. Since then, several workers have studied the effect of ELF on cells, organs and tissues by animal studies to see any adverse changes. Several epidemiological studies have been done to correlate the occurrence of cancer in persons living in close proximity of electric transmission and distribution lines.

Physical interaction and bio-effects
The electromagnetic environment typically consists of two components, an electric field and a magnetic field. In general, for time-varying fields, these two fields are coupled, but in the limit of unchanging fields, they become independent. For frequencies encountered in electric power transmission and distribution, these two fields can be considered independent to an excellent approximation. For extremely-low frequency fields, including those from power lines and home appliances and wiring, the electric component is easily attenuated by metal element in residential construction and even by trees, animals and people. The magnetic field, which is not easily attenuated, is generally assumed to be the source of any possible health hazard. In animal bodies placed in time-varying magnetic fields, induced current is reported to flow through tissues. These currents add to those that are generated internally by the function of nerve and muscle, most noticeably currents are detected in the clinically useful electroencephalograph and the electrocardiogram. The currents produced by nerve or muscle action within the body have no known physiological function themselves but rather are merely a consequence of the fact that excitable tissue (such as nerve and muscle) generate electric currents during their normal operation.

Exposure to time-varying electric field can result in perception effects due to electric charge on the surface of the body. These effects may become stressful if prolonged. The perception results from the body surface causing, for example, body hairs to vibrate. Several authors2 report that about 10% of adults can perceive the electric charge induced on the surface of their bodies and clothing by 50/60 Hz fields of 12 kV/m (mid range values – 10 to 15 kV/m). 5% can detect fields as low as 3 to 5 kV/m, levels similar to those found under some high voltage power lines. A threshold for annoyance has been reported as around 15 to 20 kV/m. No consistent effect on haematology, immunological function, rodent behaviour, growth and reproduction was
reported for exposure up to 12 kV/m. There is no direct experimental evidence of any acute adverse effect on human health due to short term exposures to static magnetic fields up to about 2 T. However, people working around a 4 T magnet experienced vertigo, nausea during head movements; sensation of flickering light, magnetic phosphenes during rapid eye movement. The volunteers exposed to fields up to 0.15 T for one hour did not exhibit a change in their performance of a number of mental tasks. Body temperature, heart rate and blood pressure are unaffected by acute exposure to fields up to 1.5 T; in one study a slight drop in heart rate in human exposed to 2 T was reported. At magnetic flux intensity levels those recommended as basic restrictions, potential hazards can arise because of the attraction or torque exerted on some metallic objects and as a result of interference with the function of implanted devices, such as pacemakers.

Cancer

Wertheimer and Leeper were the first to report an apparent association between childhood cancer risk and proximity of homes to power distribution lines. Subsequent epidemiological studies showed statistically significant elevations in the risk of childhood leukaemia and nervous tissue tumours amongst children living in close proximity to power transmission and distribution lines. Studies based on data of electric workers have shown a small increase in the risk of leukaemia, nervous tissue tumours and breast cancer, however, there is a lack of consistency in the various studies. So far, no biologically plausible mechanism has been identified through which ELF fields at low exposure levels could significantly influence the development or progression of malignant tumours. For example, the energy of a 60 Hz photon is 2.5×10^{-13} eV, which is eleven orders of magnitude smaller than the Boltzmann thermal energy, kT (=2.7×10^{-13} at 310° K), and more than thirteen orders of magnitude less than the minimum energy required to break a chemical bond. Hence, it is expected that ELF fields do not disrupt the chemical bonds in DNA, proteins or biological molecules. At present, there is little evidence for a promoting or co-promoting effect of ELF fields on tumour development, with the possible exception of mammary tumours in which endocrine alterations resulting from field exposure may play an important role.

From the available literature, there appears to be some evidence supporting the theory that exposure to magnetic fields of the type generated by power lines is of importance for development of leukaemia in children. Evidence for other childhood cancers, or for adults and occupational workers is less clear.

Guidelines

International Non-ionising Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) has issued interim guidelines on limits of exposure to 50/60 Hz electric and magnetic fields for occupational workers and members of the public. The basic criteria is to limit current densities induced in the head and trunk by continuous exposure to 50/60 Hz electric and magnetic fields to no more than 10 mA/m². ANSI, NRPB and CEN/ELC have also given the Guidelines on exposure limits for humans for low frequency (0 Hz to 10 kHz) electromagnetic fields.

Occupational

Electric field

Continuous occupational exposure during the working day should be limited to unperturbed rms electric field strengths not greater than 10 kV/m. Short term occupational exposure to rms electric field strengths between 10 and 30 kV/m is permitted provided rms electric field strength (kV/m) times the duration of exposure does not exceed 8 hours for the whole day.

Magnetic field

Continuous occupational exposure during the working day should be limited to unperturbed rms magnetic flux densities not greater than 0.5 mT. Short term occupational whole body exposure for up to 2 hour per work day should not exceed a magnetic flux density of 5 mT. When restricted to the limbs, exposure up to 25 mT can be permitted. For non-homogeneous magnetic fields, the magnetic flux densities should be average on a loop surface of 100 cm².

General public

Electric field

General public should not be exposed on a continuous basis to unperturbed rms electric field
strength exceeding 5 kV/m. This restriction applies to places like recreational areas, meeting grounds etc. Exposure to fields between 5 and 10 kV/m should be limited to a few hours per day. When necessary, exposure to fields in excess of 10 kV/m can be allowed for a few minutes per day, provided the induced current densities does not exceed 2 mA/m² and precautions are taken to prevent hazardous indirect coupling effects.

**Magnetic field**

Members of the general public should not be exposed on a continuous basis to unperturbed rms magnetic flux densities exceeding 0.1 mT. This restriction applies to areas in which members of the general public might reasonably be expected to spend a substantial part of the day. Exposures to magnetic flux densities 0.1 and 1.0 mT (rms) should be limited to a few hours per day. When necessary, exposures to magnetic flux densities in excess of 1 mT should be limited to a few minutes per day.

Table 1 gives the limits of exposure to 50/60 Hz electric and magnetic fields for occupational workers and members of the general public as given by INIRC**.

These exposure limits are based on experimental studies or evidence of exposure to 50/60 Hz fields. These limits also guarantee an adequate protection against indirect effects, such as contact current which may occur when touching charged objects in an external field. Below current density of 10 mA/m², only minor effects have been reported in the literature. Current laboratory studies suggest that these fields are not a cancer initiator but a cancer promoter. In 1991, National Research Council of United States** appointed a committee to review and evaluate the existing scientific information on the possible effects of exposure to electric and magnetic fields on the incidence of cancer, on reproduction and development abnormalities, and on neurobiologic response as reflected in learning and behaviour. The committee suggested that there is no evidence to show that the exposure to these fields at the levels normally encountered presents a human health hazard. Specifically, no conclusive and consistent evidence shows that exposures to residential electric and magnetic fields can produce cancer, adverse neurobehavioural effects, or reproductive and development effects.

| **Table 1—Limits of exposure to 50/60 Hz electric and magnetic fields** |
|-----------------|------------------|------------------|
| **Exposure**    | **Electric field strength kV/m(rms)** | **Magnetic field strength mT(rms)** |
| Occupational    |                                |                                |
| Whole working day | 10                            | 0.5                            |
| Short term      | 30²                           | 5²                             |
| For limbs       | —                             | 25                             |
| General public  |                                |                                |
| Up to 24 hr d⁻¹ | 5                             | 0.1                            |
| Few hours per day | 10                          | 1                             |

*The duration of exposure to fields 10 and 30 kV/m may be calculated from the formula t ≤ 80/E, where t is the duration in hours per work day and E is the electric field strength in kV/m.
*Maximum exposure duration is 2 hr per work day.
aThis restriction applies to open spaces in which members of the general public might reasonably be expected to spend a substantial part of the day, such as recreational areas, meeting grounds, and the like.
aThese values can be exceeded for a few minutes per day provided precautions are taken to prevent indirect coupling effects.

**Protective measures**

Epidemiological studies suggest that there is a link between exposure to 50/60 Hz fields and cancer, especially, the occurrence of leukaemia in children. Various national agencies suggested prudence avoidance to these fields and ‘ALARA’ principle may be adopted, which means that keep the exposures as low as reasonably achievable, social and economic factors taken into account. Morgan** proposed “to try to keep people out of fields when that can be done at modest cost, but not to go off the deep end with exposure controls which may be beneficial”. Some national agencies have suggested that one should take into account the following points when towns and villages are being planned and built, if this is possible at reasonable cost: (i) attempt to design and locate new high voltage power lines and electrical facilities so that magnetic fields are limited; (ii) avoid locating new homes, schools, nurseries, etc close to existing electricity facilities which generate significant magnetic fields if alternative locations are possible; (iii) attempt to limit fields of significant strength in existing homes, schools and workplaces.

**References**

1. Asanova T P & Rakov A N (1966) Gigiena truda i profesional'nye zabolovanija 5, 50-52
References:

14. CENELEC, Human exposure to electromagnetic fields low frequency (1 Hz to 10 kHz), European Prestandard 50166-1, CENELEC, Brussels (1995).