

THE DAMAGING EFFECTS OF EXPOSURE TO EXTREMELY LOW FREQUENCIES OF ELECTROMAGNETIC FIELDS

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In both living and working environment, apart from the ever present Earth's atmospheric and magnetic fields, very often there is an existing very low-frequency electromagnetic field emitted by energy plants, home, radio and TV appliances, public transport vehicles and video terminals. Low-frequency electromagnetic fields (30-300 Hz) are also present in the vicinity of high-voltage transmission lines, high and middle voltage conductors, sub-stations and industry. A large number of people who work on servicing of these plants and devices are exposed to electromagnetic fields. To a certain degree even the tenants who live and even occupy the space near high-voltage transmission lines and converters for a certain period of time as well as those who use electric home appliances in their homes are exposed to the aforementioned.

Taking into consideration the recent results obtained from contemporary epidemiological examinations, the impact of these low-frequency magnetic fields are to a large degree undesirable and damaging to health. As a result, a warning has been issued about the frequent occurrence of malignant diseases, psychological disorders, genetic material damage, cardiovascular, nervous, hematopoietic system, metabolism and the occurrence of miscarriages in the exposed population.

Correspondingly, there is a growing need for further research of biological effects of such radiation with an aim to bring forth both unified standards as well as legal regulation that would regulate maximum allowed time of exposure by which both duration of stay in places with higher radiation and building of new industrial plants and tenements will be determined. *Acta Medica Medianae 2010;49(1):54-58.*

Key words: *electromagnetic field, malignant diseases, cardiovascular system, hematopoietic system, metabolism*

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Introduction

Until the 20th century, humans were only exposed to natural electromagnetic fields (EMFs) and all biological system on the earth were accommodated to this electromagnetic fone. For billions of years, the electromagnetic environment was virtually "silent" in the spectral region below visible light which was the most abundant source of electromagnetic energy. Discovering of alternate current by Tesla, the problems of transsmision and using were resolved. This had the great impact on industry development and it changed all aspects of human's life. The earth rapidly changes its surface upon high and low voltage electrical networks and power lines were build. These lead to technological development but the number of arteficial sources of EMFs increase as a consequence of this process. In less than a century very few people realize how much and how quickly we have changed the non-ionizing electromagnetic environment we live in. Most of the changes have happened in the last 30 years. Now, all living things are subject to million of times more radiation than 50 years ago. This raised concerns about possible harmful effects of EMFs on public health as well as on profesionaly exposed workers.

Electric fields are measured in volts per meter (V/m). Electric fields can be shielded by objects such as walls and trees. Magnetic fields are

produced by the flow of current. The strength of a magnetic field is determined by the level of current flowing in the conductor (wire) as well as the distance from it. Magnetic fields are measured in units of tesla (T) or gauss (G); 1T = 10,000G. Magnetic fields are not easily shielded by most materials.

Both types of fields decrease rapidly with increasing distance from the source. In transmission lines, both electric and magnetic fields are considered strongest at the point where the conductors are nearest to the ground, usually in the middle area between two transmission towers. Power line EMFS is typically in the range of 50-60 Hertz (Hz) and is considered Extremely Low Frequency Electric and Magnetic Fields (ELF-EMFS) relative to other types of electromagnetic radiation.

Natural sources of EMFs

The earth and the air ionosphere form a huge static electric field - natural electric field. It is a very important environment which people rely on, human's every bio-phenomenon is related to this static electric field. Among this, the voltage between the air ionosphere and the earth is as high as 360KV. The strength of the electric field near ground is 130V/m (Volt per meter), the direction of this electric field vertically points at the ground and it makes a 100 to 200 voltaic discrepancy between men's head and men's foot. The electric charge in the air flows through human body to the earth. Therefore people's health and life also depend on the quantity of electricity that human body possesses A healthy man has 80% negative electricity and 20% positive electricity. The electrical field originated from potential difference between atmosphere and Earth's surface. The intensity of EMFs vary during day. EMFs is the

weaker in the morning 120 V/m, and the stronger in the afternoon 170 V/m. There are also seasonal variation. Natural EMFs are the strongest in the winter 150 - 200 V/m, and weaker in the summer 100-120 V/m. During thunder storms the intensity of EMFs could be between 3-20 KV/m. The changing of Earth's EMFS precedes to earthquakes and follow sun perturbation.

Natural Earth's magnetic field result from Earth's inner magnetic field and from outer field's component which originated from sun perturbances, meteorological activity etc. Horizontal component of Earth's magnetic field is maximal on Equator and its value is about 28 A/m (ampere per meter), which response to magnetic flux $35\mu\text{T}$ (micro Tesla) in air. Vertical component is the most prominent at Earth's magnetic poles ($48\text{-}56\text{ A/m}$) or $70\mu\text{T}$) and decrease toward zero at Equator. The Earth's magnetic field is constantly changing in long term periods and its changing is about 20 nT per year. There are silent and active magnetic days depending of solar and lunar calendar. During magnetic storm, horizontal component raise within few our for 20-50 nT, and after that it showed brisk fall of 100-500 nano Tesla under normal values. The recovering of normal values is reached under next few days. This natural changes of Earth's geomagnetic field (micropulsation) mainly depend on magnetosphere and ionosphere status. They could be of regular or irregular characters. Natural EMFS is usually of great impact on chronic ill patients and genetically predisposed individuals.

Human-made sources of electromagnetic fields

Human-made sources of electromagnetic fields includes power lines and electrical appliances which emitted EMFS with frequency (50-60 Hz), radio communications devices, AM/FM radio and television (100-500 MHz) and cordless phones, remote controls, mobile phones, Wi-Fi modems (800-900 MHz i 1800-2200 MHz). Humans are exposed everywhere in the environment including home, school, means of transportation and work place. The exposure due to electric fields and magnetic flux densities in the ELF range arises from a wide variety of sources (IARC 2002). The most prominent frequencies are 50 and 60 Hz and their harmonics, often called power frequencies. For residential exposure, the major sources are household appliances, nearby power and high voltages transmission lines, and domestic installations. In some cases trains have to be considered, too. Looking at occupational exposure, installations of the electric power industry, welding, induction heaters and electrified transporting systems are important examples of ELF exposure sources. The highest electric field strengths typically occur close to high voltage transmission lines and can reach 5 kV/m and in a few cases more. The highest magnetic flux densities can be found close to induction furnaces and welding machines. Levels of a few mT are possible.

The sources of EMFs in home

Measurement of magnetic and electrical fields strength in home environment showed average intensity of $0.1\mu\text{T}$ and 1-15 V/m (average 4,8 V/m) and the longest exposition was registered in bedrooms (1).

The measurements of EMFs in Los Angeles' homes showed great level of habitatnts exposure.

The most common sources of EMFs were: electrical blankets, electrical heating devices, electrically heated water beds, electrical watches, microwave oven, radio and TV, refrigerators, hair dryer, computers, electrical ovens, vacuum cleaner, electrical shaving machine, iron etc. These sources could generate EMFs which changing at power overload or disconnection.

The average electric field strength near the household (distance 30cm) are:

Electric bulb	2V/m
Electric watch	15 V/m
Vacuum cleaner	16 V/m
Hair dryer	40 V/m
Electric mixer	50 V/m
Refrigerator	60 V/m
Electric blanket	250 V/m
Videos	74 V/m
Color TV	30 V/m

The average magnetic field strength near the most frequent used household (distance 30cm) are (2):

Refrigerator	0.25 μT
Electric oven	4.0 μT
Hair dryer	7.0 μT
Iron	1-10 μT
Electric mixer	10 μT
Electric heating devices	17 μT
Vacuum cleaner	20 μT
Electric blanket	1.3-3.3 μT
Electric shaver (3cm distance)	1500 μT
Videos	0.13-0.3 μT
Color TV	0.1-0.5 μT
1 μT =10mG	

Exposure of the general population

Several fixed installed sources are operated in our environment. Prominent examples are high voltage transmission lines operated between 110 and 400 kV at 50 or 60 Hz. The exposure of bypassing people can reach values of 2 to 5 kV/m for the electric field strength. The exposure due to magnetic flux density depends on the actual current on the line; fields up to 40 μT are possible but are usually lower. It is important to notice that such exposure levels occur only directly below the lines; exposure decreases with the square of distance to the lines. In addition, intermediate voltage transmission lines (10 kV to 30 kV) and distribution lines (400 V) have to be considered; exposure levels are in such cases much lower. Typically values of 100 to 400 V/m and 0.5 to 3 μT can be reached. Another approach to establish power supply is the use of underground buried cables. Electric field strength exposure can be neglected in this case; the distribution of the magnetic flux density differs compared to power lines. Substations and power plants are usually not accessible to the general public. Railway power supply installations are often operated at 16 2/3 Hz. The exposure decreases linearly with the distance. The exposure levels in areas accessible for the general public are below the limits. The highest magnetic flux densities can be found close to several domestic appliances that incorporate motors, transformers, and heaters. Such exposure levels are very local and decrease rapidly with the distance. An example is a vacuum cleaner: at a distance of 5 cm magnetic flux densities of about 40 μT can occur, but at 1 m the exposure will be around 0.2 μT . Looking at the individual exposure of persons, a few percent

of the European population are in their homes exposed above a median magnetic flux density above 0.2 μT .

Exposure of the workers

In a few locations in installations of the electric power industry the exposure limits of occupational exposure can be reached or exceeded. The health risk from high exposure have workers in electric companies, workers in steel industry, electromechanist, power plants workers, workers in public means of transportation (trolleybus and trains) etc. Safety measures for such areas have to be implemented. An example is a peak electric field strength of more than 20 kV/m that was measured in a power station. Other examples of industrial applications in the ELF range are induction and light arc ovens or welding devices. The frequencies of such applications fall both in the ELF and in the intermediate frequency range. Exposure of workers has to be controlled for such devices. Next to welding devices maximum flux densities of several hundred μT are possible, depending on the welding current and the type of application.

The average magnetic field flux in industry without powerful sources of EMFs is 2-20 μT but in some circumstances workers in electric plants and near high voltage power lines could be exposed up to 20 kV/m/h daily.

Maximally limited doses

There are many associations aimed to protect public healths and to define exposure standards. They adopted standards and defined maximal levels of human exposure. But, there are the huge differences in recommendation originated from Eastern and Western countries, which indicates needs for further research.

National Radiological Protection Board recommendation for EMFs under 100 Hz appointed electric intensity under $E < 12$ kV/m and magnetic intensity $B < 2$ μT as borderline for permanent exposition (4).

International committee for non ionising radiation recommend cut off value of 10 kV/m and 0,5 μT for working spaces and 5 kV/m or 0,1 μT for public areas.

In seven US federal states there are safety precautions and safety zones near high voltage powerlines. Depending of voltage and states this zone could be between 100 - 350 ft (35 - 115m). In western literature safety zones not allowed for humans retention is marked by acronym ROW (Right Of Way).

In Russia there are regulations which limited duration of human staying in areas with strong ELF EMFs. These limitations are field strength dependent :

5kV/m	no limit
10kV/m	180 min
15kV/m	90 min
20kV/m	10 min
25kV/m	5 min

There are still many confusing questions about accepted limits and general preventive approach must be concerned. This approach comprise any unnecessary staying and human activity in areas with strong ELF EMFs.

Biological effect of EM field

In human organism that resides in changing EM field, the current is induced with E field that induces the current much stronger intensity of the magnetic field. Under the influence of this

field starts the oscillation of free ions and rotation of dipole molecules in the field frequency. The strong EMFS can perform rotation, deformation, destruction and merging cells and to disrupt the cell membrane potential. It is believed that the biological effects of these fields come from the induced currents, changing hydrated ions and protein molecules on cell membranes, changes in the orientation of RNA, DNA, modification of activities of some enzymes, changes the transfer of electrons in the Krebs cycle and the impact of oxidative phosphorylation. Experiments on animals have shown that the most sensitive nerve, endocrine system and the senses, that there is activation of the axis hypothalamus - pituitary - adrenal cortex, the effect on the testis (magnetic phenomena sterilization), changes in the blood stream, increased capillary permeability and increased blood coagulation (5-7). The influence of strong fields leads to changes in behavior, neurophysiological and haematological changes, disorders in the generative function, embryogenesis and postnatal development, cytogenetic and toxic effect on gonads, changes in the number of platelets, lowering of cholinesterase activity, slowing the absorption of radio-nucleotides, changes in the concentration of sodium and potassium and, in the and changes in urine calcium effluxion from brain tissue (8-9).

Every cell is like a condenser, storing positive and negative electricity, called cell membrane potential. This kind of electricity is the resource of life, the symbol of life it is the bio-electricity. Suppose a child stores 6V electricity, proportionately speaking, an adult should store 3V electricity, an old man stores 2V electricity.

In 2002, the "International Agency on Research on Cancer (IARC)" have published a monograph on the evaluation of carcinogenic risks of static and extremely low-frequency (ELF) electric and magnetic fields to humans. ELF magnetic fields have been classified into group "2B" ("possibly carcinogenic to humans"). While the outcome of this evaluation has already been known at the time of the last opinion report, the IARC reasons for this decision haven't been published yet. The justification states limited evidence in humans based on consistent results from sound epidemiological studies showing an association with an increased leukaemia risk in children at field strengths above 0.3/0.4 μT ., but bias in these studies could explain some of the raised risk. The findings from observational studies are not supported by studies in experimental animals, which provide inadequate evidence of carcinogenicity.

Furthermore, the IARC monograph concluded, there was no evidence for an association of ELF magnetic fields with any other type of cancer. ELF electric fields were grouped into "3" ("is not classifiable as to its carcinogenicity to humans")

Results of clinical trials

Swedish authors have described the phenomenon of "Hypersensitivity to electricity and certain neurasthenic events in people who work with video terminals or in their vicinity are electric power lines, electric motors, electrical household appliances and fluorescent lamps. Changes are on the skin as a blush, red or pink color, sensation of heat, vibration of hair and pile,

itch or feel like leather face bride. Disturbances were non-specific nature similar to neurasthenic and they manifested in the form of headaches, dizziness, tinnitus, fatigue, weakness and pricking the skin of the extremities, lack of air, palpitation, pain, digestion disorders, increased sweating, irritability, insomnia, emotional instability, reduced intellectual ability, depression, feelings light yellow twinkle in the eyes and difficulty in remembering.

Tests of EMF impact on occurrence of malignant disease of exposed persons were performed. Increased mortality from all forms of leukemia and acute leukemia in adults chronically exposed to EMFS over 0.3 μ T was found.

Also higher occurrence of cancer (lung tumors predominate, faringsa, digestive tract, respiratory sinus, thyroid gland, nervous system tumors, lymphomas and melanoma eyes and skin) in workers with an occupation related to working with electricity were determined.

Two to three times higher incidence of malignant disease in children who lived in houses near the lines that lead directly from the transformer was found. In particular, findings of frequent leukemia in children, brain tumors and Hodgkin's disease of children chronically exposed to EM field in the flat, with the malignant proliferation of especially vulnerable children with Down's syndrome were determined. It is assumed that the cause of increased incidence of malignant diseases in children was varying magnetic field around the conductor, leading directly from the transformer and domestic electrical installations. Out of possible cancerogenic mechanisms, the effects of EMFS are studied and proved to affect cell membrane and calcium transport through the membrane, the interruption of cells communication, changes in cells growth, the activation of a specific nucleotide genes sequence by modulated RNA transcription, reduction of melatonin production in epiphysis, ornithine decarboxylase activity changes, the possible termination of anticancerogenic mechanisms control (4-7).

It is a cause of chromosomes changes, affects DNA repair and has other genotoxic effects. Suppression of melatonin production findings in epiphysis, under the EM field influence, is aroused interest because it is known that this substance has an indirect oncostatical effect as it inhibits the effect of free radicals on DNA damage (8-10). Reduced levels of melatonin under the influence of EMFS would create possibility of more vulnerable DNA to the effects of free radicals, which would lead to greater opportunities of cancerogenesis process initiation. Two more possible mechanisms of cancerogenic action are described, the impact of EMFS in the synthesis of ferritin as an important factor in carcenogenesis and the specific magnetic crystals occurrence in human cells, particularly brain cells. A positive correlation is found between the intensity of EMFs and apoptosis (11).

Studies of these fields influence on the cardiovascular system have pointed to the more frequent ventricular extrasystols, ventricular fibrillation, blood pressure and circulation control disorders as well increased thromboxan B2 and triglycerides production in the exposed population.

Strong electromagnetic fields may affect the work of Pace-makers. A newer version of the pacemaker on demand, with a sensitive probe (receiving electrical impulses feedback from the heart, and sends impulses to the heart muscle through the electrodes only when no suitable cardiac activity) are much more susceptible to EM interference. There is a possibility that sensitive probe, because of EM field interference, receive "fake" signal as the heart is working and to spontaneously stop sending impulses to the heart muscle that may be dangerous if the heart is at AV block. Most current pacemakers are to some extent resistant to EM interference and rhythm disturbances may occur only in the zone of strong EM fields. Therefore, persons who have pacemaker should not come near the very high voltage conductors.

A significantly higher risk of miscarriages and birth of children with congenital malformations is found in females that used electric blankets and slept in the electrically heated water beds during an early pregnancy.

The peripheral blood changes were found (leucocytosis, retikulocytosis, T lymphocytes growth inhibition, reduced T lymphocytes ability to recognize foreign cells, impaired erythrocytes and leukocytes function, hearing impairment, endocrine and neuromuscular disorder in people exposed to very low frequency EM radiation (12-19). It should be noted that similar biological effects are registered under high frequency EM field exposure (20), and that preventive measures are needed from this kind of radiation.

Conclusion

Levels of EMFS exposure of the general population do not seem significantly high so far, but some groups of residents and workers may be exposed to something higher levels of radiation when closer to the radiation sources. Effects of such exposure may manifest in occurrence of subjective problems, malignant diseases, skin changes, genetic material changes, cardiovascular and hematopoetic systems, metabolism and more frequent occurrence of miscarriages.

There are still no uniform standards for maximum permissible exposure doses of the radiation. Protection of the EM field practically does not exist. In any case, unnecessary exposure to this radiation should be avoided. Work for development of appropriate standards with regard to this issue and legislation is needed, in terms of warning and restriction of entry and settlement of the population in areas within higher intensities of radiation and perform exposure assessment when setting up new sources of radiation and apartments construction.

Persons with cardio-stimulators may be vulnerable in areas with a greater intensity so appropriate regulations should be posting duty warnings ensured about the dangers of entrance in the zones and work on developing technically protected cardio-stimulators.

Studies are needed to reveal the cellular and molecular mechanisms underlying the biological effects and possible health consequences of exposure to EM fields.

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ŠTETNI EFEKTI ELEKTROMAGNETNIH POLJA EKSTREMNO NISKIH FREKVENCIJA

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U životnoj i radnoj sredini, pored stalno prisutnog Zemljinog atmosferskog i magnetnog polja, često postoji veoma jako niskofrekventno elektromagnetno polje koje stvaraju energetska postrojenja, aparati na radnom mestu i domaćinstvu, sredstva javnog saobraćaja, radio i televizijski predajnici i aparati i video terminali. U blizini dalekovoda, provodnika visokog i srednjeg napona, u podstanicama i u industriji prisutna su elektromagnetna polja niskih frekvencija (30-300 Hz). Veliki broj osoba koje rade na opsluživanju ovih postrojenja i uređaja profesionalno je izložen ovakvim poljima. U izvesnoj meri može biti izloženo i stanovništvo koje živi i boravi u blizini dalekovoda i transformatora i pri upotrebi električnih aparata u domaćinstvima.

Prema rezultatima savremenih epidemioloških istraživanja, uticaji ovakvih niskofrekventnih elektromagnetnih polja uglavnom su nepoželjni i štetni po zdravlje. Upozorava se na češću pojavu malignih oboljenja, psihičkih poremećaja, oštećenja genetskog materijala, kardiovaskularnog, nervnog, hematopoetskog sistema, metabolizma i pojavu spontanijih pobačaja u eksponovanoj populaciji.

Ukazuje se na potrebu daljih istraživanja bioloških efekata ovog zračenja u cilju donošenja jedinstvenih standarda o maksimalno dozvoljenim dozama ekspozicije i zakonskih propisa kojima će se regulisati boravak u zonama sa većim dozama zračenja i izgradnja novih industrijskih postrojenja i stambenih zona. *Acta Medica Medianae* 2010;49(1):54-58.

Ključne reči: elektromagnetno polje, maligne bolesti, kardiovaskularni sistem, hematopoetski sistem, metabolizam