

A REVIEW OF THE EFFECTS OF ELECTROMAGNETIC FIELDS ON THE ENVIRONMENT

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Abstract

This paper examines potential environmental effects of electromagnetic fields (EMF) of major electrical technologies including power lines and undersea cables, communication systems, solar power satellite, radar, high powered broadcast transmitters, cellular phones. Brief summaries are provided of environmental field levels produced by the technologies, considerations related to exposure assessments and mechanisms responsible for biological responses to the fields, and reported effects of fields on biota. While environmental effects from fields emitted by major technologies appear to be generally minor and localized, assessments of environmental impacts of such fields have been very scattered and open to criticism on a number of grounds. Overall, it appears that the human EMF exposure limits recommended by the International Commission on Non-Ionizing Radiation (ICNIRP, 1998) would also be protective of the environment.

Keywords: Electromagnetic fields, electric field strength, magnetic field density, field thresholds, radio frequency, specific absorption rate.

1.0 Introduction

There has been growing concern by the public all over the world in the use of large-scale electrical technologies. There has been increase in the erection of communication masks, base stations, power transmission lines and equipment, use of cellular phones etc. The public concern is; what are the possible effects, especially health wise problems of what is coming out of these devices. Has it any effect either short term or long term in the environment, especially on its terrestrial and aquatic ecosystems.

The use of large-scale electrical technologies has led to widespread environmental exposures to electromagnetic fields (EMF) over wide frequency ranges. The term "electromagnetic fields" is associated with forces experienced by accelerated charges in any medium, the major

field components are electric field strength measured in volts per meter (V/m) and the magnetic field density measured in terms of current induced exposure in micro-teslas (μ T).

The electromagnetic fields have various frequencies: Extremely low frequency (ELF), according to generally accepted usage, the region of electromagnetic spectrum from 30Hz to 300Hz is designated as extremely low frequency [1]. The natural electric fields at extremely low frequencies are very weak, while those of man-made origin are much stronger.

The natural electric field near the Earth's surface is a static field of about 130V/m [2]. High Frequency (HF) fields are microwave ovens, cellular phones, all wireless forms of communication, TV and radio broadcasts. The very strong fields are cathode ray tubes, video display terminals, TV's monitors.

Awareness of any environmental impacts of electromagnetic fields is important to ensure the preservation of terrestrial and aquatic ecosystems, which form the basis for sustainable development. Protection of the environment and conservation of nature have become matters of great interest to the public, as well as to governments. Such interests is often expressed as concern over possible environmental impacts of large technology projects, such as dams, nuclear power plants, radio frequency transmitters.

Public concern about environmental exposure to EMF has ranged from claims of reduced milk production in cows grazing under power lines to damage to trees near high power radars. Such concerns might also affect the development of new technology such as cellular phones.

2.0 Electromagnetic Fields Thresholds and Standards

As regards standards or threshold values for emissions of electromagnetic fields of all types and frequencies, countries set their own national standards for exposure to electromagnetic fields. However, the majority of these national standards draw on the guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). This non-governmental organization, formally recognized by WHO, evaluates scientific results from all over the world. Based on an in-depth review of the literature, ICNIRP produces guidelines recommending limits on exposure. These guidelines are reviewed periodically and updated if necessary. Electromagnetic field levels vary with frequency in a complex way. Listing every value in every standard and at every frequency would be difficult to understand. The table 1 is a summary of the exposure guidelines for three areas that have become the focus of public concern: electricity in the home, mobile phone base station and microwave ovens. Table 2 is

another typical maximum public exposure guideline.

Table 1: Summary of the ICNIRP

	European power frequency	Mobile Phone Frequency	Base Station Frequency	Microwave Oven Frequency
Frequency	50Hz	900MHz	1.88GHz	2.45GHz
	Electric Field (V/m)	Magnetic Field (μ T)	Power Density (W/m^2)	Power Density (W/m^2)
Public exposure Limits	5000	100	4.5	9
Occupational Exposure limit	10,000	500	22.5	45

Source: ICNIRP, EMF guideline, Health Physics 74, 494-522 (1998)

Table 2 Typical Maximum Public Exposure Guidelines

	Electric Field (V/m)	Magnetic Flux Density (μ T)
Natural Fields	200	70 (Earth's magnetic field)
Mains power (in homes not close to power lines)	100	0.1
Mains power (beneath large power lines)	10,000	20
Electric trains	300	50
TV and Computer Screens (at operator's position)	10	0.7

Source: WHO regional Office for Europe

Another very important measure is the specific absorption rate (SAR). This is a measure of the rate at which radio frequency (RF) energy is absorbed by the body when exposed to radio-frequency electromagnetic field. It varies from country to country but most countries adopt the values between 0-2watts per kilogram (W/kg). The SAR level for U.S. is 1.6W/kg taken over a volume of 1g of tissue, while EU has the

corresponding limit of 2W/kg taken over a volume of 10grams.

3.0 Interaction of Human Body with Electric Field of HV Lines

At ground level, beneath the transmission line, the electric field is essentially a vertical homogeneous field [3] and exposure to the field results in internal body currents and energy absorption in tissues that depend on the coupling mechanism, the frequency involved and the electrical conductivity of the medium (σ). Ohm's Law relates the internal electric field (E) and current density (J) (ICNIRP, 1998a) as expressed in equation (1).

$$J = \sigma E \quad (1)$$

A human body located in an electric field causes perturbation of the field which results in an uneven distribution of the field around the body. The field induced electric currents in the exposed body. The current produced within the body has the same frequency as the external field. Unlike magnetic field, electric field is attenuated by a factor of 106 from the value of the external field within the body [4, 5, 6, 7]. It has been shown that the electric-field intensity at the surface of the body and induced currents passing through various segments of the body can be determined by: the characteristics of the applied electric field; the shape of the body; and any conduction currents from the body to the ground. To mitigate the effect of electromagnetic radiation from HV lines on human beings living/working close to the lines, the Power Holding Company of Nigeria (PHCN) makes it clear that any building constructed along the HV lines must give right-of-way (RoW) of 15m and 25m for 132kV and 330kV lines respectively [8].

4.0 Major Electrical Technologies and Environmental Exposures

While all electrical technologies produce environmental EMF, those operating at high power levels produce exceptionally strong fields and are thus of particular interest. These are:

(i) High Voltage Power Lines

High voltage power lines used for long distance transport of electricity operate at 50 or 60 Hz. Line voltages range up to 765kV. The field strengths in the vicinity of a power line depend on the line voltage and current (for magnetic fields) together with design characteristics of the lines such as the configuration of the conductors and height of the towers. Electric field strengths can be very high near the surfaces of the lines themselves, approaching the dielectric breakdown strength of air, but fall off rapidly with distance from the line. At ground level beneath a very high power line carrying current 3000-4000A, the peak electric field strength is approximately 10kV/m, and the peak magnetic flux density is approximately 100 μ T. At ground level 50m from the center of the line, the electric field is of the order of 1kV/m and the magnetic flux density is about 0.1 μ T. In addition to these fields in air, substantial electric currents may flow in the ground beneath the power lines.

(ii) Undersea Power Cables

Undersea power cables are widely used in Europe, particularly to transfer power between Scandinavian countries. Most of these systems operate at DC, with loads often exceeding 1000A. Systems can be monopolar or bipolar, depending on whether the return current is carried by seawater or a separate cable. Monopolar systems pass the current into seawater via electrodes, typically graphite anodes and titanium cathodes that are located on the seabed beneath a 0.5-1m thick protective layer of stone [9].

Magnetic fields as transmission lines in air, sea cables produce a magnetic field in their vicinity, which is proportional to the current in the line. For a monopolar line, the magnetic fields fall off as the inverse of the distance from the line; those from a bipolar line fall off somewhat faster with distance (typically, as the square of the distance) because of the partial cancellation of fields from the two conductors that carry current in opposite directions.

In either case, the magnetic fields close to a line can exceed the geomagnetic field (which is approximately $50\mu\text{T}$) at distances up to several meters from the line. For example, a monopolar line carrying 1500A produces a magnetic flux density of approximately $300\mu\text{T}$ on the seabed above the cable, falling off to $50\mu\text{T}$ at a distance of 5 m above the seabed, and $13\mu\text{T}$ at 20 m above the seabed [9].

Electric fields Sea cables are isolated from the surrounding sea water by layers of insulation and metal sheathing. However, electric fields are created by a variety of mechanisms that can exceed natural ambient levels (which are about $25\mu\text{V/m}$ in the North Sea) [9]. The return current, which in monopolar systems passes through Seawater, creates an electric field due to the resistivity of seawater. Such fields, near a monopolar line carrying 1500amperes, range from approximately 1V/m at a distance 10cm from the cathode, to 0.07V/m at a distance 1m from the cathode, falling to in the range $1\text{--}50\mu\text{V/m}$ far from the electrodes [9].

The flow of seawater past the cables is another mechanism that creates electric fields in seawater, due to magnetic induction. The resulting field strength in the seawater depends on the flow velocity, whether or not the observer is moving with respect to the water, and on the electrical conductivity of nearby surfaces, but also can exceed naturally occurring levels.

(iii) Broadcast Transmitters

Numerous RF transmitters exist in modern society, some operate at a very high power levels. For example, international broadcast stations operate in the HF band (from 3 to 20 MHz) can operate at effective powers in the Megawatt range.

Very close to such transmitters, the RF fields can be very strong, perhaps exceeding acutely hazardous levels.

(iv) Radar

Radar systems operate over a broad range of frequencies from 300MHz to 15GHz, with output powers ranging from a few mW (police radar) to kW (air surveillance systems)

Most radars transmit pulsed RF energy of low duty cycle but high peak power densities, and the high peak field intensities can be very high. In front of such high-powered radar transmitters, the beam intensity can reach levels that are acutely hazardous to human and animals.

(v) HF Transmitters for Atmospheric Research

Several high-powered (300kW – 2MW) RF transmitters are in use around the world for upper atmosphere research. While the system radiates high power, the energy density in the beam is moderate, of the order of 30W/m^2 directly above the antenna array and falling to 0.03W/m^2 at the ionosphere. Exposure levels on the ground, or outside the main beam, are very much lower.

(vi) Solar Power Satellite (SPS)

There have been several proposals for large-scale power generation by satellite. The systems would employ immense arrays of solar cells in geosynchronous orbit, and beam the energy to

ground in the form of microwaves. Large arrays of "rectennas" on the ground would collect the microwave energy and convert it back to DC for distribution.

These systems vary considerably in their design. One hypothetical "reference" system was subjected to extensive environmental assessment during the 1970s. This system would generate electricity in a 50km^2 array of 10^{10} solar cells in geosynchronous orbit, and radiate it as 2.45GHz microwaves to earth via a phased array antenna 1km in diameter, to be received by a rectenna 78km^2 in area.

While the total amount of power transmitted by a full-scale SPS would be very large (5GW for the reference system), the energy density in the beam would be rather low because of its large area. In the center of the beam of the reference system, the microwave intensity would be about $250\text{W}/\text{m}^2$, falling off to $10\text{W}/\text{m}^2$ at a distance of 5 km from the rectenna center and to $1\text{W}/\text{m}^2$ at 5.7km [10].

(vii) *Mobil phones and Base Stations*

With the extensive use of mobile phones in daily life, more attention have aroused on electromagnetic field (EMF) emitted from phones and base stations. The vast majority of mobile phones use 900MHz or 1800MHz frequency bands. In addition, some have dual band function. There is a controversy that EMFs from mobile phones have harmful effects on human health. On 31/05/2011, the WHO's International Agency for Research on Cancer (IARC) classified RF from cell phones as a 'Possible Human Carcinogen' (Class 2B). The conclusion means that there could be some risk, and therefore we need to keep a close watch for a link between cell phones and cancer risk. There are published reports on the effects of mobile phone use for the auditory and the central nervous system [11]. However, not only

the potential side effects for system are of interest, but also potential side effects to the other system are of importance. It is supposed that mechanisms involved in this process are related with heat at high frequency and chemical changes at low frequency.

5.0 Electromagnetic Fields Effects

The possible effects of such exposure to biota depend on two considerations: the coupling between the external field and the body of the animal, and the biological response mechanisms.

(A) Low frequencies (DC and ELF)

(i) *Humans and Animals*

For an animal exposed to EMF in an air environment, the fields are very weakly coupled to the inside of the body. For example, in a grounded human in a vertically oriented electric field, the internal electric field is smaller than the external electric field by a factor of the order of 10^{-12} for static fields, and of the order of 10^{-6} for 50 and 60 Hz fields. In animals with smaller body size, the induced fields will be smaller still. For this reason, exposure of an animal to ELF fields at environmentally realistic levels would not be expected to induce acutely hazardous within the body. The obvious exception is when an animal is in contact with ground and touches a large conductive object in the field, where large contact currents might flow into its body. A different situation exists when animals are exposed to the field in an aqueous environment. In that case there is a direct conductive path into the body, and the electric fields inside the body and the external fields may be comparable in strength. The dominant hazard of low-frequency fields in humans is electrical shock, which arises from the excitation of cell membranes within the body. Because of the weak coupling between ELF fields and the body, the production of shock generally requires that currents be introduced

into the body by contact with a conductive surface. Thresholds for electric shock in humans vary with body size [12].

Many studies have been performed on low-frequency EMF. The low-frequency EMF has biological effects on the behavior of bone cell populations. It increases the maturation of bone trabeculae, volume and formation [13,14]. However, there are also contradictory reports mentioning no observation for effects of low-frequency EMF on bone tissue [15,16]. Moreover, Mc Elhaney et al.[17], have reported that low-frequency EMF may lead to loss in bone tissue. The controversy about potential effects associated with the exposure to EMF has recently been increased by the common use of mobile telecommunication devices [18].

(ii) Crop performance

Several authors have reported an enhancement of seed germination from exposure to DC or ELF magnetic fields of about $50\mu\text{T}$ [19]. A few studies have reported increased germination of seeds in ELF electric fields in the range of 1 – 100kV/m [20].

(iii) Aquatic Life

Kalmijn [21] suggested that electric or magnetic fields near sea cables, which would exceed ambient levels, might affect prey sensing or navigational abilities of electrically or magnetically sensitive species.

(iv) Insects

Bee hives located near high voltage power lines in fields as low as 4kV/m produce less honey and have higher mortality rates among bees. The effect is apparently due to electrical shocks that the bees receive when they contact surfaces in the hives [22].

(B) Higher Electric Field Strength

(i) Crop Performance

At electric field strength above 20kV/m, clear damage occurs to the tips of plant leaves due to corona [23]. Rogers et al.[24] noted changes in the growth rates of trees grown near a 1100kV test line in field strengths up to 123kV/m. The changes were associated with visible corona at the tips of the leaves. Other effects include delayed leaf senescence and leaf shedding in plants close to the line.

(ii) Animals

A variety of studies have exposed animals (rats, swine, and cattle) to strong ELF fields under laboratory conditions. Anderson [25] exposed animals to 60Hz electric fields ranging upwards to 150kV/m and magnetic flux densities ranging to 30mT. Anderson concluded that “most indices of general physiological status appear to be relatively unaffected by exposures to EMF”. These studies did report a variety of effects, particularly at the higher field levels, including avoidance of the fields and indications of stress responses in the exposed animals.

The “stray voltage” problem on farms occurs because of unbalanced power distribution systems or other electrical problems, which results in voltages being induced across bodies of cattle when they contact nominally or physiological changes in the animals and reduced milk production [26].

Power lines present hazards to birds, either from electrocution when they fly into the lines or by impact when they hit the lines or supporting structures. One author has suggested that birds of some endangered species are particularly vulnerable [27]. While this is not an effect of the EMF per se, it is a potential environment impact of the technology that needs to be considered.

(C) High Frequencies (RF)

At these frequencies the dominant effect is related to heating, and the appropriate measure of exposure is the specific absorption rate (SAR), which is the amount of power absorbed per kg of body mass. The SAR depends on the field intensity, polarization, body size, and other variables. In particular, animals exhibit electrical resonance due to the antenna properties of their bodies. At such resonance frequencies they become efficient absorbers of RF energy.

The dominant hazard mechanism for high frequency (RF) fields is associated with tissue heating. Exposure to high levels of RF energy will result in thermal damage to tissue (burns). A different hazard mechanism arises from excessive thermal load to the body, even in the absence of thermal damage to tissues. The threshold for such effects depends on the animal's thermoregulatory mechanism, level of activity, and environmental conditions, all of which are highly species-dependent [28, 29]. These two considerations (interspecies differences in thermal physiology and differences in absorption due to variations in body size) make it difficult to extrapolate from animals to humans to estimate thresholds for thermally injurious exposures.

6.0 Conclusion

From the above work, two major conclusions emerge: 1. There are some documented effects from the electromagnetic fields produced by electrical technologies, though the established effects are apparently of local and minor significance. 2. The attempts at environmental analysis of the effects of electromagnetic fields on environment, with few exceptions, have been scattered in focus, sporadic in publication, and uneven in quality. The major exception appears to be studies in search of environmental effects associated with high voltage power

lines, where numerous studies have been undertaken around the world.

References

- [1] Polk, C. Sources, propagation, amplitude and temporal variation of extremely low frequency (0-100Hz) electromagnetic fields 1994.
- [2] Deno, D.W. Currents induced in the human body by high- voltage transmission line electric field-measurement and calculation of distribution and dose. IEEE Trans. Power Appl. System. PAS-96; 1517-1527, 1977.
- [3] Phillips, R. D., Gillis, M. F., Kaune, W.T., and Mahlum, D. D., ed. Biological effects of extremely low frequency electromagnetic fields. Proceedings of the 18th Annual Hanford Life Sciences Symposium, Richland, Washington, Springfield, Virginia, Technical Information Center US Department of energy. Pp. 159-171 October, 1978.
- [4] Barnes, H.C., McElroy, A.J., & Chrakow, J.H. Rational analysis of electric fields in live-line working. IEEE Trans. Power Appl. Syst., Pas-86: 10-19 1967.
- [5] Kaune, W.T. & Phillips, R.D. Comparison of the coupling of grounded humans, swine, and rats to vertical, 60-Hz electric fields. Bioelectromagnetics, 1: 117-130 1980.
- [6] Kaune, W.T. & Gillis, M.F. General properties of the interaction between animals and ELF electric fields. Bioelectromagnetics, 2: 1-11, 1981.
- [7] NEPA news, October-November 2000.
- [8] Koops FBJ Electric and magnetic fields in consequence of undersea power cables. In: Proceedings of International Seminar on Effects of Electromagnetic Fields on the Living Environment, Ismaning Germany. Oberschleissheim (Germany): ICNIRP 189-210, 4-5 October 1999.
- [9] Osepchuk JM., "Solar power satellites", In: Proceedings of International Seminar on Effects of Electromagnetic Fields on the Living Environment, Ismaning Germany. Oberschleissheim (Germany): ICNIRP 135-147, 4-5 October 1999.
- [10] Kaprana AE, Karatzanis AD, et al.

- on the auditory system and the central nervous system: a review of the literature and future directions. *Euro Arch Otorhinolaryngol*. 265: 1011-9 2008.
- [11] Reilly P. *Applied Bioelectricity*. New York: Springer-Verlag 1998.
- [12] Tabrah FL, Ross P, Hoffmeier M, Gilbert F Jr. Clinical report on long-term bone density after short-term EMF application. *Bioelectromagnetics* 19: 75-8 1998.
- [13] Sent C, Mustafa D, et al. "The preventive effect on bone loss of 50-Hz 1-mT electromagnetic field in ovariectomized rats", *J Bone Miner Metab* 20 : 345-9, 2002.
- [14] Yamada S, Guenther HL, Fleisch H, "The effect of pulsed electromagnetic fields on bone cell metabolism in the live rat", *Int Orthop* 9: 129-34 1985
- [15] Giavaresi G, Fini M, et al, "Effect of pulsed electromagnetic fields on ovariectomized rats", *Electro Magnetobiol* 18: 119-31, 1999.
- [16] McElhaney JH, Stalnaker R, Bullard R., "Electric fields and bone loss of disuse", *J Biomech* 1:47-52 1968.
- [17] Yildiz M, Cicek E, et al, "Influence of electromagnetic fields and protective effect of CAPE on bone mineral density in rats", *Arch Med Res* 37: 818-21, 2006.
- [18] Jones. D, Meleod, B. Electromagnetic cell stimulation. In: *Electrical Manipulation of Cells* (Lynch PT and Davey MR, eds.). New York: Chapman & Hall, 223-247, 1996.
- [19] Morar R, et al "Electrostatic treatment of bean seed", In: *Proc. 30th IAS Annual Meeting, IEEE Industry Applications Society, Vol.1; 1335-1337, 1995.*
- [20] Kalmijn ADJ, "Electric and magnetic field detection in elamobranch fishes", *Science*, 218: 916-917 1982.
- [21] Cartensen EL. "Biological Effects of Transmission Line Fields". New York: Elsevier. 1987.
- [22] Johnson JG, Poznaniak DT, McKee GW, "Prediction of damage severity on plants due to 60Hz high- intensity electric fields", NTIS Document No CONF- 781016:172-183, Hanford Life Sciences Symposium 18th Annual Meeting October 1978.
- [23] Rogers LE, et al, "Environmental studies of a 1100kV prototype transmission line", Annual Report for the 1980 study Period, Battelle Pacific Northwest Laboratories, Portland Oregon, 1981.
- [24] Anderson L, "EMF responses in farm animals. In: *Proceedings of International Seminar on Effects of Electromagnetic Fields on the Living Environment*, 4-5 October 1999 Ismaning Germany.
- [25] Lefcourt A., "Effects of electrical voltage/current on farm animals: how to detect and remedy problems", U.S.A. Dept. of Agriculture, *Agriculture Handbook* No.696., 1991.
- [26] Bevanger K., "Biological and conservation aspects of birds mortality caused by electricity power lines: A review", *Biol Cons* 86:67-76, 1998.
- [27] Gordon CJ, Ali JS, "Comparative thermoregulatory response to passive heat loading by exposure to radiofrequency radiation", *Comp. Biochem Physiol* 88A (1): 107-112, 1987.
- [27] Berman E, Kinn JB, Ali J, et al, "Lethality in mice and rats exposed to 2450MHz circularly polarized microwaves as a union of exposure duration and environmental factors", *J Appl Toxiol* 5(1): 23-31, 1985.