ELECTROMAGNETIC FIELD AS ENVIRONMENT FACTOR AFFECTING HUMAN HEALTH

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Key words: **Electromagnetic field, Specific absorption rate, Living systems, Health effects, Protective measures.**

As an effect of the technological revolution, there has been a huge increase of the electromagnetic fields sources that may become at global level a harmful environment factor, having a negative impact on human health and safety. This paper comprises a brief presentation of the data concerning the effects of electromagnetic fields exposure on biological systems, in order to make a pertinent evaluation of human health risks. It will be provided an overview of the known biological effects of electromagnetic fields in the frequency range of 300 Hz to 300 GHz (including radiofrequency fields) for assessment of risks from occupational and general population exposure. The paper includes subjects such as natural and human-made electromagnetic field sources, the main applications of electromagnetic fields and sources of exposure, some biological effects and the most important protective measures against the harmful effect of electromagnetic field.

1. INTRODUCTION

The use of devices that emit electromagnetic fields has increased considerably in the last few decades, due to a continuous technological revolution, as is well known that the electrical devices have made our life richer, safer and easier. This proliferation has been accompanied by an increased concern about possible health effects of exposure to these electromagnetic fields.

Electromagnetic radiation can be described as waves of electric and magnetic radiation moving together through space. These are non-ionizing radiations that are not able to send enough energy to a molecule or atom to break chemical bonds or remove electrons, in contrast with ionizing radiations (X-rays) that can remove electrons from atoms and molecules, producing molecular changes and leading to damage in biological tissue [5].

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But it has been known for many years that exposure to high levels of electromagnetic fields can heat biological tissue and can cause even tissue damage, as the human body is not able to function properly with the excessive heat generated during exposure to very high electromagnetic field levels.

2. **ELECTROMAGNETIC FIELD SOURCES**

There are many sources of electromagnetic radiation around us, from both natural and human-made sources, that represent an important environmental factor, having a negative impact on the biological systems at high level of exposure.

Electromagnetic radiation is emitted by natural sources like the Earth, the Sun and the ionosphere. Radiofrequency electromagnetic radiation is emitted by artificial sources such as mobile phones, broadcast towers, radar systems, remote control and electrical and electronic equipments. The main electromagnetic field sources [4] are presented in the Table 1.

Table 1

Electromagnetic field sources

Types of electromagnetic field		**Predominant origin**
Natural sources	Atmospheric fields; frequencies 2-30 kHz	Thunderstorms
	Terrestrial emissions (black-body radiation); frequencies up to 300 GHz	Earth body Human body
	Extraterrestrial fields Solar emissions	Earth shield: atmosphere, ionosphere, and magnetosphere Sun
	Other natural sources of lesser intensity	Moon, Jupiter, hydrogen emissions from ionized clouds, the OH radical
Human-made sources	Telecommunication purposes	Radio and television transmitters
		Broadcasting systems: broadcasting towers, antennas etc.
	Non-telecommunication purposes	Industry, science and medicine applications (ISM equipments)

Taking into consideration only the human-made electromagnetic field sources that generate electromagnetic radiation in the range of 300 Hz–300 GHz, we can say that nowadays there are too many sources for non-ionizing radiation pollution, that can affect living systems and human health and safety.

The exposure conditions to electromagnetic field can be altered considerably by main following factors:

– presence of some objects;

– the degree of perturbation depending on their size, shape, orientation in the field, and electrical properties;

– geometry and electrical properties of biological systems for frequencies below the microwave range.

A very complex field distribution can take place inside and outside biological systems exposed to electromagnetic fields. Refraction within these systems can focus the transmitted energy resulting quite non-uniform fields and energy deposition. Thus, different energy absorption rates can result in thermal gradients, causing biological effects that may be generated locally. In general, energy absorption rate is difficult to anticipate and perhaps is unique for every biological system [3].

In the Table 2, there are presented some typical applications of equipment generating electromagnetic fields in the range of 300 Hz–300 GHz.

Table 2

Applications accompanied by electromagnetic field emissions [3]

Frequency	**Wavelength**	**Typical applications**
0.3-3 kHz	1000-100 km	Broadcast modulation, medical applications, electric furnaces, induction heating, hardening, soldering, melting, refining
3-30 kHz	100-10 km	Very long range communications, radio navigation, broadcast modulation, medical applications, induction heating, hardening, soldering, melting, refining, video display units
30-300 kHz	10-1 km	Radio-navigation, marine and aeronautical communications, long-range communications, radiolocation, video display units, electro-erosion treatment, induction heating and melting of metals
0.3-3 MHz	1 km-100 m	Communications, radio-navigation, marine radiophone, amateur radio, industrial equipments, welders, sealing for packaging, production of semiconductor material, medical applications etc.
3-30 MHz	100-10 m	Citizen band, amateur radio broadcasting, international communications, magnetic resonance imaging, medical applications, dielectric heating, wood drying and gluing, plasma heating
30-300 MHz	10-1 m	Police, fire, amateur FM, VHF-TV, diathermy, emergency medical radio, air traffic control, magnetic resonance imaging, dielectric heating, plastic welding, food processing, plasma heating, particle separation
0.3-3 GHz	100-10 cm	Amateur, taxi, police, fire, radar, citizen band, radio-navigation, UHF-TV, microwave ovens, medical applications, food processing, material manufacture, insecticide, plasma heating, particle acceleration
3-30 GHz	10-1 cm	Radar, satellite communications, amateur, fire, taxi, airborne weather radar, police, microwave relay, anti-intruder alarms, plasma heating, thermonuclear fusion experiments
30-300 GHz	10-1 mm	Radar, satellite communications, microwave relay, radio-navigation, amateur radio

3. **BIOLOGICAL EFFECTS OF THE ELECTROMAGNETIC FIELDS**

3.1. GENERAL CONSIDERATION

It is well known that when electromagnetic fields pass from one medium to another, they can be reflected, refracted, transmitted, or absorbed, depending on the conductivity of the exposed object and the frequency of the field.

Electromagnetic fields in the frequency range of 300 Hz–300 GHz interact with human and other animal systems through direct and indirect pathways. Indirect interactions are important at frequencies below 100 MHz, but are specific to particular situations. When metallic objects (such as automobiles, fences) in an electromagnetic field have electrical charges induced in them, they can be discharged when a body comes into contact with the charged object. Such discharges can cause local current densities that may determine shock and burns [2].

Absorbed radio-frequency energy can be converted to other forms of energy and cause interference with the functioning of the living system. Most of this energy is converted into heat.

However, not all electromagnetic field effects can be explained in terms of the biophysical mechanisms of energy absorption and conversion to heat.

The major interaction mechanism is through the currents induced in tissues. Thus, effects are dependent on frequency, wave shape, and intensity. At frequencies below about 100 kHz, it has been demonstrated that induced electric fields can stimulate nervous tissue. At the microscopic level, other interactions leading to perturbations in complex macromolecular biological systems (cell membranes, subcellular structures) have been reported. Above 100 kHz, the nervous tissue becomes less sensitive to direct stimulation by electromagnetic fields and the conversion of energy to heat becomes the main mechanism of interaction.

3.2. LABORATORY STUDIES

Many studies and laboratory testing confirm the existence of electromagnetic field interactions with living systems. Even different mechanisms for such interactions have been presented so far, the quite precise mechanism has not yet been elucidated.

The biological effects of acute exposure to electromagnetic fields consist mainly in induce heating, resulting either in rises in tissue or body temperature of about at least 1 °C.

From laboratory studies on animals it has been obtained experimental data that indicate the type of interaction and effects of electromagnetic fields on living systems that probably occur also in humans subjects. However, direct quantitative extrapolation to humans is difficult as there are important differences between species also in thermoregulatory abilities [2].

The SAR concept (Specific Absorption Rate) is a simple and useful parameter in quantifying the interactions of electromagnetic fields with living systems. This parameter enables comparison of experimentally observed biological effects for various species under various exposure conditions and it provides an effective way for extrapolating animal data to potential hazards for humans exposed to electromagnetic field.

Laboratory studies indicated that most interactions of the electromagnetic fields with tissues have been reported at specific absorption rates (SAR) above about 1–2 W/kg, in different animal species exposed under various environmental conditions.

There are relatively few studies that address directly the effects of acute or long-term exposures of humans to electromagnetic fields.

Fig. 1 illustrates the average SAR, as a function of frequency for a man exposed to a plane wave for three polarizations, and also various models used in the calculations. From this Fig. 1 we can draw the following conclusions:

– the average SAR is a function of frequency;
– the average SAR depends on the wave polarization, and is greatest for the *E* polarization (the electric field is parallel to the long axis of the body), except at higher frequencies, where it is slightly greater for the *H* polarization (magnetic field *H* is parallel to the long axis of the body);
– the average SAR for the *E* or *K* polarizations (when electric field *E* or wave propagation direction *K* are parallel to the long axis of the body) reach a maximum at certain frequencies, called the resonant frequencies [4].

In studies in the laboratory, it has been reported skin perception of fields in the 2–10 GHz range. Thresholds for important warming have been reported at power densities of 270 W/m^2–2000 W/m^2, depending on the area irradiated (13–100 cm^2) and the duration of exposure (1–180 s).

When human volunteers were exposed to SAR of 4 W/kg for 15–20 minutes, their average body temperature have increased by 0.2–0.5 °C, which is quite acceptable in healthy people.

The frequency-dependent behavior is illustrated in Fig. 2 for several human sizes. The average whole-body SAR in W/kg is represented as a function of electromagnetic field frequency (MHz) for an incident average power density of 1 W/m^2.

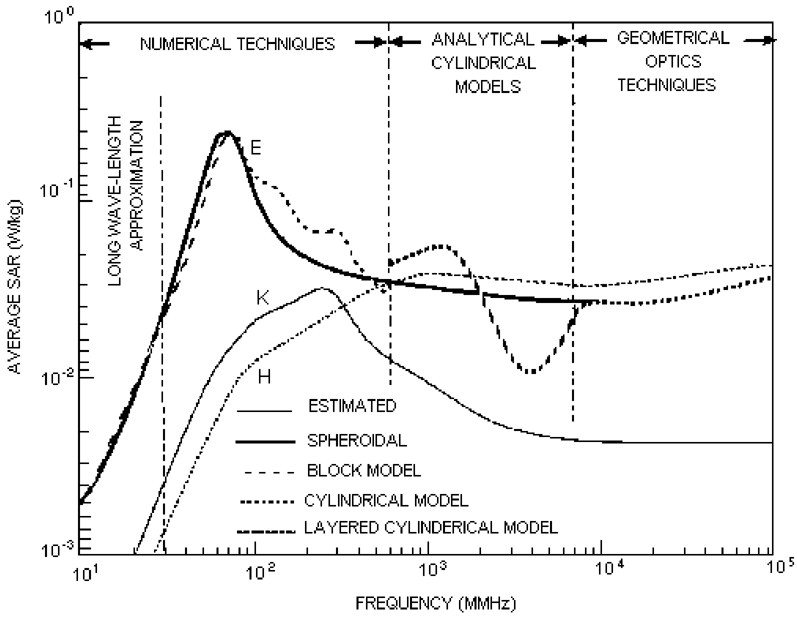

Fig. 1 – Various techniques used to calculate the average SAR for models of the average man, irradiated by an EM plane wave of 10 W/m^2 power density. *E*, *K* and *H* designate polarizations in which the incident electric field vector, propagation vector and magnetic field vector are parallel to the long axis of the body.

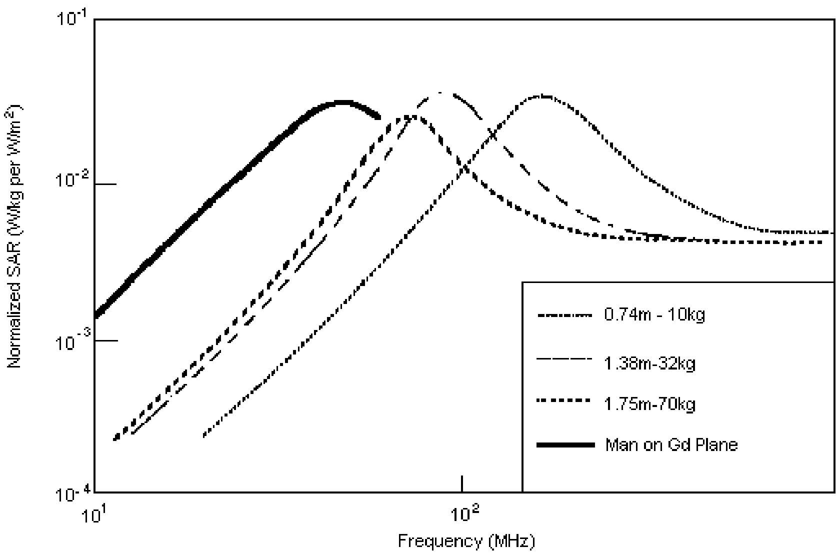

Fig. 2 – Specific absorption rate for several human sizes.

The limitations for the whole body average SAR are not sufficiently restrictive, since the distribution of the absorbed energy in the human body can be very inhomogeneous and dependent on the electromagnetic field exposure conditions. In partial body exposure situations, depending on frequency, the absorbed energy can be concentrated in a limited amount of tissue.

Therefore, additional basic limits are recommended in any other part of the body, in order to avoid excessive local temperature elevations.

The influence of the electromagnetic field on human tissue can be observed in the two diagrams from Fig. 3.

It can be noticed that the electrical properties of tissues have changed over a few orders of magnitude with frequency in the range as shown in Fig. 3.

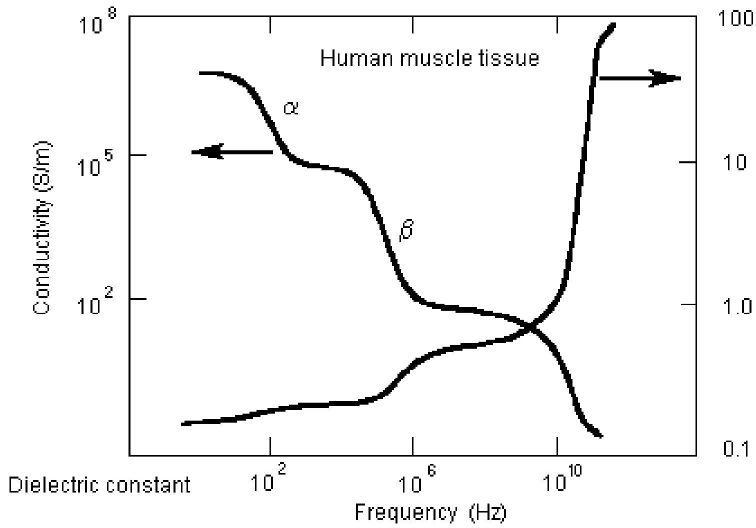

Fig. 3 – The dielectric constant and conductivity of human tissue as functions of frequency.

From many laboratory testing carried mainly on animals and very few on human subjects, we can draw the following conclusions regarding the electromagnetic field effect on living systems [1]:

- Absorption of RF energy causes tissue heating. This is recognized and has been well studied. This effect occurs from the absorption of radiofrequency fields, especially at the higher end of the frequency range (above about 1 MHz). RF heating is not directly equivalent to heating by other forms of energy, because of the very non-uniform energy deposition that occurs in biological systems;
- At frequencies below about 100 MHz, currents can be induced in humans by physical contact with ungrounded metallic objects. From 300 Hz to

approximately 100 kHz, such currents may result in the stimulation of electrically excitable tissues above the threshold for perception or pain. At frequencies between approximately 100 kHz and 100 MHz, contact currents of sufficiently high density may cause burns;

- For frequencies below several hundred kHz, the predominant effect is stimulation of excitable tissue resulting from currents directly induced in the body by the RF fields. At these lower frequencies, thermal interactions occur only at energy levels much higher than interactions with excitable tissue.

The few epidemiological studies that have been carried out on populations exposed to electromagnetic fields have not been able to produce significant associations between such exposures and shortening life. It was not proved so far that excess of electromagnetic field exposure may cause death, except for an increased incidence of death from cancer, where chemical exposure may have been an important contribution. In some studies, it was not reported the increase in the incidence of premature birth or congenital malformations. Other studies indicated that there was an association between the level of exposure and adverse effects in pregnancy [4].

4. **PROTECTIVE MEASURES**

Protective measures include workplace surveillance (exposure surveys), engineering controls, administrative controls, personal protection, and medical surveillance. Limitation in electromagnetic fields exposure can be obtained either by implementing of some administrative measures or by the use of protective screening.

Administrative controls, such as limitation of access and the use of audible and visible warnings, should be used in conjunction with engineering controls. To ensure the safety of the workers in case of high electromagnetic fields environment it must be used personal protective clothing.

Screening for people protection against electromagnetic fields may be intentional (wire fences) or incidental (walls of buildings) and may function by reflection or by absorption. For an effective attenuation of radiofrequency electric fields it can be used successfully metal sheets. In many cases, it is usual to use wire screens or perforated sheets, as these have the advantages of transparency, ventilation, light weight, etc. It is recommended to verify periodically the integrity of protective screens or shields because some faults in screens could be secondary sources of significant radiation or reactive fields [5].

5. **CONCLUSIONS**

In the environment, there are many sources of electromagnetic fields, both from natural and artificial sources, that can become a danger to living systems at high level of exposure.

Many laboratory studies underlined that the main biological effect that occur in human body consists in induce heating, resulting either in rises in tissue or body temperature of about at least 1 °C.

The distribution of the absorbed energy in the human body is quite inhomogeneous and depends on the electromagnetic field exposure conditions. Thus, the absorbed energy can be concentrated in a limited amount of tissue, causing locally damage of this tissue even the amount of electromagnetic field complies with limit values established for the entire body.

From researches performed so far, it can not confirm that exposure to high levels of electromagnetic field can shorten life or induce death, even it was reported an increased incidence of death from cancer that can be caused in association with chemical exposure.

However, it is recommended limitation in electromagnetic field exposure by following of some protective measures that include administrative measures, using of protection equipments in case of high level of electromagnetic fields exposure at workplace and medical surveillance.

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