Influence of Electromagnetic Radiation on Health of People. Limits for Exposure to EMF

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Abstract—**In the article, sources of electromagnetic radiation, their intensity and the frequency ranges in which they are manifested are discussed. Moreover, on the basis of international recommendations and regulations, specific safety measures are proposed that should be implemented by all the participants in the process of creating electromagnetic pollution.Threshold power densities of electromagnetic fields in accordance with the standards of individual countries are presented. Standards in the field of protection against electromagnetic radiation are related to the regulations, recommendations and limit values which determine the maximum allowed radiation exposure in order to protect human health**

Key words: Electromagnetic Radiation; Non-Ionizing Radiation; Biological effects;

I. INTRODUCTION

The environment also contains various sources of non-ionizing radiation. These include: power lines, cable and satellite communications, power stations, electric transportation vehicles (electric trains, trams and trolleybuses), TV and radio repeaters [1]. As a result there is an interaction between the electromagnetic fields and biological tissue. The effects of these fields can be harmful to humans if the field strength exceeds certain threshold value. This value is defined by the corresponding standards and it is determined on the basis of reaching the threshold of harmful effects. In order to analyze the biological effects of electromagnetic radiation and assess the associated hazards in a particular situation, it is necessary to know value of the field for each frequency which is present and compare it with the corresponding allowed value. The field values can be reached by applying analytical calculations, numerical methods, or by using the appropriate measurement equipment. Despite the fact that the non-ionizing electromagnetic phenomena have been well studied, interactions between electromagnetic fields and organic matter, and especially human body, are still not fully clarified.

Standards in the field of RF radiation protection are related to the regulations, recommendations and limiting values which determine the maximum radiation exposure in order to protect human health. The established safety limits are generally based on the research concerning heating effects (thermal) and stimulating (non-thermal) effects on human body.

II. NON-IONIZING RADIATION SOURCES

Electric and magnetic fields are created by the earth with its magnetism, solar activities, and the atmosphere during the creation of lightning and electrical storms. The earth produces a static magnetic field, oriented in the south-north direction. The flux density of the earth’s magnetic field varies from 20 μT to 60 μT, depending upon the geographical latitude and the composition of the earth’s crust, e.g. magnetic conductive ores or local mountains. The average magnetic flux density of the earth’s magnetic field is 40 μT. It is interesting to note that a person’s movements within the earth’s magnetic field induce an electric field within the body. For example, running at a speed of approximately 8 m/s creates an internal electric field of 400 μV/m. Such an electric field can be induced by a low frequency magnetic field of 20 μT[1]. To all of this, we can also add how natural biological processes create electric and magnetic fields within human or animal bodies. These fields are primarily the result of cardiac activity, as well as muscles, and to a much lesser extent depend upon the activities of the brain or nerves. All living cells create electric fields. Generally, the strength of the electric field of the heart is up to 50 mV/m, and that of the brain and other vital organs up to 5 mV/m. Mobile telephones are low-strength microwave devices that receive and transmit signals from/to the base stations of relatively high power. The majority of mobile telephones operate at frequencies between 800 MHz and 2 GHz. The application of higher frequencies will be used in the near future. In the vicinity of mobile telephone antennas, which are located on tall columns or on the tops of tall buildings, it is possible to be exposed to electromagnetic fields of higher strengths than the permitted limits. In the area of customary and normal access around antenna columns, the permitted limits will not be exceeded but it is necessary to limit access by the general population to the roofs of buildings where antennas are installed.

Electrical energy produced in power plants is distributed to consumer areas via high voltage power lines from 110 kV to 400 kV. The voltage is reduced by transformers to 400/230 V for local distribution. The general population is exposed to magnetic fields at the network frequency, 50 Hz, via three individual sources: high voltage transmission power lines, the local system for the distribution and low voltage electricity at home and at work, and electrical household appliances.

The high voltage transmission power lines and the local system for the distribution and low voltage electricity at home and at work create basic, so-called background magnetic radiation, known as the magnetic flux density of the environment. They average value of background induction reaches 200 nT in residential and commercial buildings. Below high-voltage overhead power lines, magnetic flux densities have been measured from 5 μT to 20 μT, but at distances from 50 m to 100 m this value rapidly decreases to the background value of the magnetic flux density. With an electric field, the situation is entirely different. Measured values of electric field strength E below high-voltage overhead power lines, at a height of 1 m above the ground, are from 600 V/m to 10 000 V/m.

A locomotive crew is exposed to electromagnetic, fields from the electric motors and other electrical equipment. Passengers are generally exposed to electromagnetic fields that are created by the high voltage alternating current from the overhead power supply line above the railway tracks. The magnetic flux density in cars is up to 50 μT, and the electric field strength is up to 300 V/m. The population living in the immediate vicinity of railway tracks may be exposed to the electromagnetic effects of the overhead supply line, as with high-voltage overhead transmission lines, but the level of exposure is significantly lower and depends upon the power supply system of the railway tracks and varies from country to country. Local trains, subways and trolley cars are supplied with alternating or direct current via overhead lines or special direct current tracks. Electric motors and track equipment are frequently located below the floors of passenger cars. Passengers are exposed to static and time-varying magnetic fields. The magnetic flux density at the floor level of these means of transportation can be very high, from 2 mT to 3 mT. The upper parts of the body can be exposed to magnetic flux densities of up to 30 μT.

III. BIOLOGICAL EFFECTS OF ELECTROMAGNETIC FIELDS (EMF)

There are three established basic coupling mechanisms through which time-varying electric and magnetic fields interact directly with living matter: coupling to low-frequency electric fields, coupling to low-frequency magnetic fields and absorption of energy from electromagnetic fields.

The interaction of time-varying low-frequency electric fields with the human body results in the flow of electric charges, the polarization of bound charge, and the reorientation of electric dipoles already present in tissue. The relative magnitudes of these different effects depend on the electrical properties of the body—that is, electrical conductivity and permittivity (governing the magnitude of polarization effects). Electrical conductivity and permittivity vary with the type of body tissue and also depend on the frequency of the applied field. Electric fields external to the body induce a surface charge on the body; this results in induced currents in the body, the distribution of which depends on exposure conditions, on the size and shape of the body, and on the body's position in the field.

The physical interaction of time-varying to low-frequency magnetic fields with the human body results in induced electric fields and circulating electric currents. The magnitudes of the induced field and the current density are proportional to the radius of the loop, the electrical conductivity of the tissue, and the rate of change and magnitude of the magnetic flux density. For a given magnitude and frequency of magnetic field, the strongest electric fields are induced where the loop dimensions are greatest. The exact path and magnitude of the resulting current induced in any part of the body will depend on the electrical conductivity of the tissue. The body is not electrically homogeneous; however, induced current densities can be calculated using anatomically and electrically realistic models of the body and computational methods, which have a high degree of anatomical resolution.

Exposure to low-frequency electric and magnetic fields normally results in negligible energy absorption and no measurable temperature rise in the body. However, exposure to electromagnetic fields at frequencies above about 100 kHz can lead to significant absorption of energy and temperature increases. In general, exposure to a uniform (plane-wave) electromagnetic field results in a highly non-uniform deposition and distribution of energy within the body, which must be assessed by dosimetric measurement and calculation. As regards absorption of energy by the human body, electromagnetic fields can be divided into four ranges:

1. frequencies from about 100 kHz to less than about 20 MHz, at which absorption in the trunk decreases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs;
2. frequencies in the range from about 20 MHz to 300 MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g., head) resonances are considered;
3. frequencies in the range from about 300 MHz to several GHz, at which significant local, non-uniform absorption occurs; and
4. frequencies above about 10 GHz, at which energy absorption occurs primarily at the body surface.

But in the final can be said that exposure to low frequency electromagnetic fields do not cause significant energy absorption and measurable increase in body temperature. However exposure to electromagnetic fields at frequencies above 100 kHz may cause a significant increase in energy absorption and temperature. In general, homogeneous exposure to electromagnetic fields leads to very inhomogeneous distribution of energy within the body which can be determined dosimetric measurements and calculations.

IV. LIMITS FOR EXPOSURE TO EMF

Standards in the field of RF radiation protection are related to the regulations, recommendations and limiting values which determine the maximum radiation exposure in order to protect human health. The established safety limits are generally based on the research concerning heating effects (thermal) and stimulating (non-thermal) effects on human body. Also, the limits are subject to changes and adjustments according to the research and acquired new knowledge, and are divided into two groups [2-6]:

- limits in the area of increased sensitivity and
- limits in the area of occupational exposure.

Areas of increased sensitivity are the areas where the resident general population exposed to EMF (electromagnetic fields) is not controlled, such as:

a) residential areas where people can stay up to 24 hours a day;
b) schools, preschool education institutions, maternity homes, hospitals, tourist accommodation facilities, and playgrounds (according to the master plan) and
c) undeveloped areas intended by the master plan for building objects a) or b).

The occupationally exposed population consists of adults who are generally exposed under known conditions and are trained to be aware of potential risk and to take appropriate precautions. By contrast, the general public comprises individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals. In many cases, members of the public are unaware of their exposure to electromagnetic fields.

Moreover, individual members of the public cannot reasonably be expected to take precautions to minimize or avoid exposure. It is these considerations that underlie the adoption of more stringent exposure restrictions for the public than for the occupationally exposed population.

International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an independent scientific organization whose task is the adoption of regulations on health risks due to exposure to non-ionizing radiation. ICNIRP regulations have been adopted by the Council of Europe as a valid standard for all EU member states.

In the ICNIRP standards are defined:

1. Fundamental limitations that must always be respected and
2. Reference levels that can be exceeded if the basic restrictions are not exceeded.

The main constraints are expressed in terms of the quantities which characterize the phenomenon within the human body and cannot be directly measured, for example SAR. On the other hand, the reference levels such as electric fields, can be measured in the absence of human beings.

V. BASIC RESTRICTIONS

This action limits for exposure to electric, magnetic and electromagnetic fields are based directly on established health standards and biological effects of these field observations.

Depending on frequency range, the physical quantities used to specify the basic restrictions are: magnetic flux density (B), current density (J), specific absorbed power (SAR) and power density (S).

The basic restrictions are based directly on established health effects and these restrictions must not be exceeded in order to protect against adverse health effects of exposure to EMF. Depending on frequency, the physical quantities used to specify the basic restrictions on exposure to EMF are current density , specific absorption rate *or* SAR , and power density .

Various scientific bases have been used in the determination of the basic restrictions for various frequency ranges:

- for the range from 1 Hz to 100 kHz, the current density has been determined as the relevant value for preventing disorders in the function of the nervous system,
- for the range from 100 kHz to 10 MHz, the current density and SAR (specific energy absorption rate) have been determined as the relevant values for preventing disorders in the functioning of the nervous system. SAR restriction is also anticipated for preventing heat stress of the entire body and excessive heating of the local tissue,
-for the range from 10 MHz to10 GHz, the basic restriction is expressed as SAR,
-between frequencies of from 10 GHz to 300 GHz, power density has been determined as a relevant value. This restriction prevents excessive heating on or near the tissue surface,
- for impulse magnetic fields in the range of from 300 MHz to 10 GHz, specific energy absorption per unit of tissue mass SA (J/kg), has been determined as a relevant value.

Lower basic restriction values for the exposure of the general population also take into consideration the differences in the age and health status of the general population in comparison to workers. In the low frequency range, there is much information on the effects of transient currents on health. The ICNIRP recommends taking the peak values of transient currents for determining the induced current density, and not the average current strength during the period of the duration of the phenomenon.

VI. REFERENCE LEVELS

The reference levels are measurable levels of radiation of electromagnetic fields through which virtually determines the fundamental limits exceeded. The reference levels are derived from relevant basic restrictions using measurements and / budget are, or are related to established and indirect impacts of exposure to harmful effects of electromagnetic fields.

The reference levels can include the following physical quantities: electric field (E), magnetic field strength (H), magnetic induction (B), power density (S), the current branch (IL), the current contact (IC) and, pulsed electromagnetic fields, specific energy absorbed (SA).

In Figures 1 and 2 give a graphical display of limit values of electric and magnetic fields depending on the frequency of occupational and general population, according to the literature [2]. Red Line indicated by occupational exposure levels for a black line for the general population.

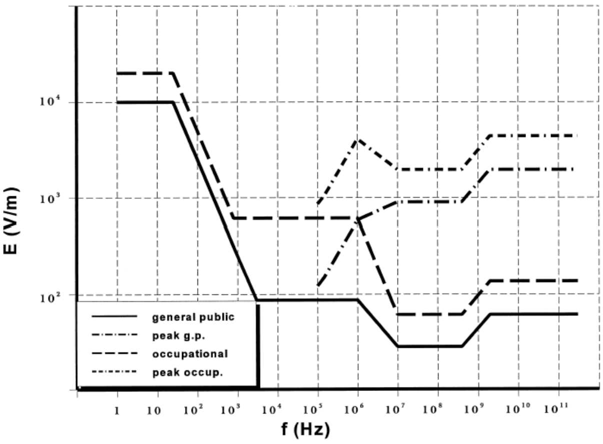

Fig. 1. Reference levels for exposure to time varying electric fields [2]

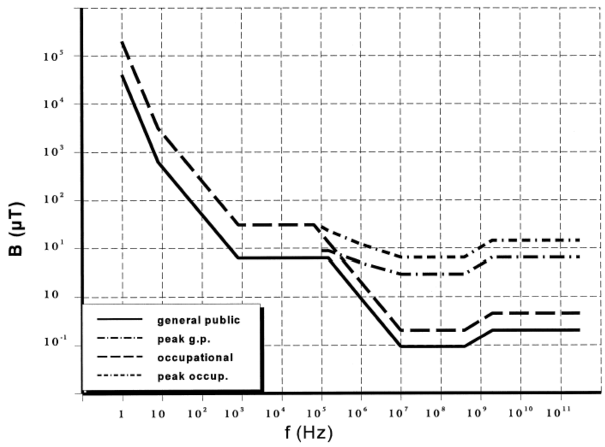

Fig. 2. Reference levels for exposure to time varying magnetic fields [2]

Current density and the specific energy absorption rate are highly unsuitable values, as are their units, in ordinary daily application because they are fairly difficult to determine. This was one of the significant reasons for determining the strength of electric fields, magnetic fields and magnetic inductions that would produce the same current density or SAR from the table of basic restrictions for each suitable frequency range, using computer programs, modeling and various calculations. Today, the strength of electric fields, magnetic fields and magnetic induction in a given place is simply measured with the suitable instruments. Based upon this, the ICNIRP [5] has recommended reference levels for restricting exposure to electromagnetic fields for occupational exposure and the general population [6]. These permit effective supervision of the exposure of persons to electromagnetic fields.

It is important to determine whether, in situations of simultaneous exposure to fields of different frequencies, these exposures are additive in their effects. Additives must be examined separately for the electrical stimulation effects and thermal effects, and the basic restrictions set out below must be met. The formulae below apply to the relevant frequencies under practical exposure conditions. For electrical stimulation, relevant for frequencies up to 10 MHz, induced current densities must be added according to:

$$\sum_{i=1Hz}^{10MHz} \frac{J_i}{J_{L,i}} \le 1 \qquad (1)$$

where:

J_i = induced current density at frequency i;

$J_{L,i}$ = induced current density basic restriction at frequency i

For thermal effects, relevant above 100 kHz, SAR and power density values must be added according to

$$\sum_{i=100kHz}^{10Ghz} \frac{SAR_i}{SAR_L} + \sum_{i>10GHz}^{300Ghz} \frac{S_i}{S_L} \le 1 \qquad (2)$$

where:

SAR_i = SAR caused by exposure at frequency i;

SAR_L = SAR basic restriction at frequency i;

S_i = power density at frequency i;

S_L = power density basic restriction at frequency i.

For electrical stimulation effects, relevant up to 10 MHz, the following two requirements should be applied to the field levels:

$$\sum_{i=1Hz}^{1Mhz} \frac{E_i}{E_{L,i}} + \sum_{i>1Hz}^{10Mhz} \frac{E_i}{a} \le 1 \qquad (3)$$

and

$$\sum_{j=1Hz}^{65KHz} \frac{H_j}{H_{L,j}} + \sum_{j>65kHz}^{10MHz} \frac{H_j}{b} \le 1 \qquad (4)$$

where:

E_i = electric field strength at frequency i;

$E_{L,i}$ = electric field strength reference level at frequency

H_j = magnetic field strength at frequency j;

$H_{L,j}$ = magnetic field strength reference level at frequency *j*

a = 610 V/m for occupational and 87 V/m for general public exposure;
b = 24.4 A/m (30.7 mT) for occupational and 5 A/m (6.25 mT) for general public exposure. The constant values ***a*** and ***b*** are used above 1 MHz for the electric field and above 65 kHz for the magnetic field, because the summation is based on induced current densities and should not be mixed with thermal considerations.

For thermal effects, relevant above 100 kHz, the following two requirements should be applied to the field levels:

$$\sum_{i=100kHz}^{1MHz}\left(\frac{E_i}{c}\right)^2+\sum_{i>1MHz}^{300GHz}\left(\frac{E_i}{E_{L,i}}\right)^2\leq 1 \qquad (5)$$

and

$$\sum_{j=100kHz}^{1MHz}\left(\frac{H_j}{d}\right)^2+\sum_{j>1MHz}^{300GHz}\left(\frac{H_j}{H_{L,j}}\right)^2\leq 1 \qquad (6)$$

where:

E_i = electric field strength at frequency *i*;

$E_{L,i}$ = electric field strength reference level at frequency *i* as

H_j = magnetic field strength at frequency *j*;

$H_{L,j}$ = magnetic field strength reference level at frequency *j*

c = 610/*f* V/m (*f* in MHz) for occupational and 87/*f*0.5 V/m for general public exposure;

d = 1.6/*f* A/m (*f* in MHz) for occupational and 0.73/*f* A/m for general public exposure.

The above summation formulae assume worst-case conditions among the fields from the multiple sources. As a result, typical exposure situations may in practice require less restrictive exposure levels than indicated by the above formulae for the reference levels.

[6]

VII. CONCLUSION

Human body should not be unnecessarily exposed to action of EM fields, but one should not suffer from phobias when in need to make use of electric home appliances, mobile phone, computer or similar. Also, long-term exposures to these fields are not recommended, and even if they are of negligible intensities, since if they have some biological effects, it is better not to allow them to become irreversible! For the jobs where the presence of significant electromagnetic field intensity is confirmed, all appropriate measures of protection should be implemented. In order to properly assess the upper limit of the allowable radiation, we should know the very nature of biological effects, then the distribution of electromagnetic energy in biological systems, as well as the characteristics of the radiation source. All these need to be confirmed by a number of experiments constituting a statistically significant sample. The experiment is very difficult to be carried out on people because it cannot be done without inflicting tissue or health damage. Therefore, measurements are carried out on animals or models of biological systems, so called phantoms, and the data are extrapolated to humans. The problem with extrapolation is due to different physiology or morphology of tissues and biological systems, and due to the effects of certain resonance frequencies that need not be at the same for humans and for models (or small animals).

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