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QUANTITATIVE ASSESSMENT OF THE EFFECTS OF ELECTROMAGNETIC FIELDS ON THE CREW OF A SHIP ACCORDING TO THE LEGISLATIVE NORMS

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Abstract: *Because of the low emitting power of radio stations present on ships, for the specific range of emitting frequencies, parameters such as radiated power density and electric field intensities meet both European and American safety standards (EN 60215: 1989/A2: 1994 Safety Requirements for Radio Transmitting Equipment, En 50371 and FCC's Rule Parts 1. 1310, 2.1091 şi 2.1093).The paper presents the limits of the field strength and power density for controlled and uncontrolled environments, for crew exposure, and the limits of field intensities and peak power density.*

Key words: *electromagnetic field, legislative rules, current density, specific absorption rate (SAR)*

Introduction

There are standardization interests regarding the influence of electromagnetic field on the human body [2-12] in the *CEI (IEC*) – by *TC 106*, as well in the *CENELEC*. These standards are published by *ICNIRP (International Commission on Non-Ionizing Radiation Protection)*. It is important to note that international organizations recommend taking measures to reduce the risk of exposure of the human body to electromagnetic fields. The standard values on the limits of electric and magnetic fields, at 50/60 Hz frequency, at which a human organism can be exposed, according to these standards are: electric field (exposure time = *8/24* ore): *10kV/m* – professional areas and *5 kV/m* – public domains; magnetic field (exposure time= *8/24* ore): *500*μT — professional areas and *100*μ*T* – public domains. At the industrial frequency of 50 / 60Hz the criteria used for the exposure limits is the induced current density - well-established effects, such as interactions with excitable membranes of muscle and nerve cells, dependent on this factor [92]. In this sense standard SR EN 50166 1 states the following ranges of values of induced current density and associated biological effects [92]: under *1 mA/m²* – no effects; between *1 and 10 mA/m²* – minimum biological effects; between *10 and 100 mA/m²* – known biological effects: visual (magnetofosfene) and possible effects on the nervous system; between *100 and 1000 mA/m²* – changes in excitability in the central nervous system, stimulation thresholds, possible health risks; over *1000 mA/m²* – possible extrasystoles and ventricular fibrillation, clear risks to health.

Analysis of field measurements

In case of permanent exposure to electric and magnetic fields of 50 Hz, the standard requires limiting the current density induced at the head and body level to values less than 10 mA/m². They were standardized both the maximum and average values; so the average value of *10 mA/m²* for continuous exposure corresponds to a value of *240 mA/m²* for one hour per day exposure (during the other 23 hours the allowed value is zero). When defining the average values of the admitted current density there were considered limitations for the magnetic induction, ***B***, between 5 mT – for 12 hours of daily exposure, to 150 mT - for only one second of daily exposure, as well as for the electric field strength, ***E***, a value of 50 V / m for all durations of daily exposure. The *SR EN 50166-1* standard also provides a restriction regarding the limitation of the discomfort and stress related to the exposure to undisturbed electric field, which is:

$$t \leq 80 / E \qquad (1)$$

where *t(hours/day)* is the exposure time limit, and ***E****(kV/m)* – electric field strength.

Normally the induced current density in the body is a resultant vector in the form of:

$$\overline{J} = \overline{J}_B + \overline{J}_E \qquad (2)$$

where J_B the density to the magnetic field and J_E – the one corresponding to the undisturbed electric field. There must also be the following inequality:

$$J_B + J_E \leq 10mA / m^2 \qquad (3)$$

In equation (2) the current densities are computed with the following formulas:

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$$J_E = k_E \cdot E; \quad k_E = 0,2 \; ; \qquad (4)$$

$$J_B = k_B \cdot B; \quad k_B = 2 \; , \qquad (5)$$

For both formulas the fields are considered homogeneous through the body.

For the controlled[1] areas the limit values allowed for B are between *5mT* – for an exposure over *12 hours* daily and *75mT* - for a daily exposure of 1 second, and for *E* – between *5 kV/m* and *30 kV/m* – for the same exposure durations.

In the free zones, with unlimited duration of exposure, the values are $B_{lim}=1\ mT$ and $E_{lim}=10\ kV/m$. To ensure these reference levels, especially near electrical transmission and distribution installations for electrical energy and electrified railways, are required antiperturbative protective measures taken by the local authorities and the companies operating these facilities. Also for medium frequencies (10 kHz - several megahertz), according to EN 50166-2 [11], the current density induced in the body is used to establish the exposure limits.

Establishing basic restrictions at such frequencies is based on standardized current density limits for low frequency, to which a safety factor of between 25 and 250 is added. As result, the current density limit for f=10kHz will be 0.1A/m^2 and increases linearly with frequency after the relationship $\frac{f_{Hz}}{100}\ A/m^2$; these values are valid for controlled environments. In uncontrolled environments a new additional factor of 2.5 is added , so that the new relationship will be $\frac{f_{Hz}}{250}\ A/m^2$.

For electromagnetic field frequencies between few MHz and few GHz, the Specific Absorption Rate (SAR) is used as a significant measure to establish the exposure limits for of the human body. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure. These 10 g of tissue are intended to be a mass of contiguous tissue with nearly homogeneous electrical properties. In specifying a contiguous mass of tissue, it is recognized that this concept can be used in computational dosimetry but may present difficulties for direct physical measurements. A simple geometry such as cubic tissue mass can be used provided that the calculated dosimetric quantities have conservative values relative to the exposure guidelines[2].

The threshold value of SAR which has shown an increased risk to health is between 1 and 4W/kg by body weight, depending on climate zone and the health of people. Setting basic derivative limits is made introducing a safety factor of 10 compared to the threshold of 4W/kg; so that the whole accepted body average SAR will be 0.4W / kg - in controlled environments and 0.08W / kg – in uncontrolled environments (in uncontrolled environments is inserted an additional safety factor of 5).

Standard SR EN 50166-2 [11] also provides the permissible limits of the electric and magnetic field intensity in the human body, starting from the basic restrictions $\frac{f}{100}\ mA/m^2$ and $\frac{f}{250}\ mA/m^2$.

So if the electric field peak values are between 1754 V/m and 702 V/m, with the specification that at 10kHz *rss*[2] values are smaller by a factor of 1.414 than the peak values, ranging from 1240 V/m and 496 V/m.

Starting from the same basic restrictions and an average body conductivity of 0.6 S/m, the calculated peak intensity magnetic field values are between 42 A/m and 16.8 A/m; with the same correction of 1.414 for the rss values at 10 kHz.

For the frequency range 10 kHz - 1 MHz it was proposed a linear evolution for the 1.414 factor, for switching from peak and average values to a value of 31.6.

Field strength limits for frequencies exceeding 1 MHz are also calculated starting from the basic restrictions.

The standard specifies that in the frequency range of 100 kHz - 300 GHz the limits of the field components, E and H, are calculated separately.

Field measurements

In case of exposure to electromagnetic fields in the form of pulses, in the microwave range (over 300 MHz), the significant magnitude is SA - Specific Absorption. The base limit is *10 mJ/kg*, in controlled environments, and *2mJ/kg* for uncontrolled environments.

In Table 1 are presented the field strengths limits, in rss values, and the power density limits for controlled environments, the continuous exposure of the body, and in Table 2 the same values for uncontrolled environments. In tables 3 and 4 one can observe the limits of field strength and peak power density for controlled, respectively uncontrolled environments.

[1] Limits for controlled areas (workers) and uncontrolled (general population) are different, in the second case being considered an additional factor of safety.

rss – equivalent field intensity (the square root of the sum of squares of components, measured in three directions, x, y and z).

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Table 1. Limits of field strength and power density for controlled environments, for continuous exposure (f $t_{exposure} \geq 6\,minutes$ [MHz])

Field frequency (MHz)	Electric field strength rss value (V/m)	Magnetic field strength rss value (A/m)	Power density, average value (W/m²)
0.01-0.045	614	35.6	-
0.045-1.000	614	1.6/f	-
$1000-10000$	614/f	1.6/f	-
$10000-400000$	61.4	0.16	10
400-2000	$3.07 \cdot \sqrt{f}$	$8.14 \cdot 10^{-3} \cdot \sqrt{f}$	f/40
2000-300.000	137	0.364	50

Table 2. Limits of field strength and power density for uncontrolled environments, for continuous exposure (f in MHz)

Field frequency (MHz)	Electric field strength rss value (V/m)	Magnetic field strength rss value (A/m)	Power density, average value (W/m²)
0.01-0.045	275	15.6	-
0.045-1	275	0.7/f	-
1-10	275/f	0.7/f	-
10-400	27.5	0.07	2
400-2000	$1.37 \cdot \sqrt{f}$	$3.64 \cdot 10^{-3} \cdot \sqrt{f}$	f/200
$2000-300000$	61.4	0.163	10

Table 3. Limits of field strength and peak power density for controlled environments (f [MHz])

Field frequency (MHz)	Electric field strength rss value (V/m)	Magnetic field strength rss value (A/m)	Peak power density (W/m²)
0.01-1	$20000 \cdot f^{0.675}$	50	-
1-10	20.000/f	50/f	-
10-400	2000	5	10.000
400-2000	$100 \cdot \sqrt{f}$	$0.25 \cdot \sqrt{f}$	25 · f
$2000-300000$	4500	11.5	50.000

Table 4. Limits of field strength and peak power density for uncontrolled environments (f [MHz])

Field frequency (MHz)	Electric field strength rss value (V/m)	Magnetic field strength rss value (A/m)	Peak power density (W/m²)
0.01-1	$8700 \cdot f^{0.675}$	22	-
1-10	8700/f	22/f	-
10-400	900	2.24	2000
400-2000	$45 \cdot \sqrt{f}$	$0.112 \cdot \sqrt{f}$	5 · f
$2000-300000$	2000	5	10.000

CONCLUSIONS

As a general conclusion on the effects of electromagnetic field on the human body one can say that, although they could not be proven so far, harmful effects due to electromagnetic field exists, only in particular situations. The power standard for civil stations that work between 156-174 MHz (sea VHF) is 1W, in port locations, and 25 W outside ports. Thus, the maximum measured values for the electric field strength do not exceed 1V/m and for the electromagnetic power density do not exceeding 0.02 μW/cm². In order to obtain conclusive values of radiated power density, measurements are required in all frequency ranges of stations and out of ports. Due to the fact that the constitutive parameters of the propagation environment (ε, μ), as well as the impedance of the air wave *(Z_0)* are practically constant, in the absence of suitable sensors one can extrapolate linearly the values measured for other frequency ranges, in order to see what values can reach the field strengths and power density. So if one extrapolates the value of electric field intensity radiated by the radio station from a power of 100 W (0.2509 V/m) to a value of transmission power of 25 kW, a value of 62.725 V/m for the radiated electric field intensity is obtained. Such a value, which is expected to be on a ship, is particularly dangerous for the human factor and exceeds by much the permitted levels for the human body, both in European and American standards. The obtained statistical data justify further research and development in this direction in order to minimize risk exposure and protect human health and life.

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[11] ***Standardele româneşti SREN 50166-1 şi SREN 50166-2, referitoare la limitele admise ale densităţii curentului indus şi efectele biologice asociate, limitele ratei specifice de absorbţie – SAR, limitele admise ale intensităţii câmpului electric ale celui magnetic şi ale densităţii de putere de vârf în corpul omenesc, pentru medii controlate şi necontrolate, în gama de frecvenţă 3kHz - 300GHz;

[12] Recomandările ICNIRP – International Commission On Non – Ionizing Radiation Protection: Guidelines for Limiting Exposure to Time – Varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)

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