"HENRI COANDA"
AIR FORCE ACADEMY
ROMANIA

"GENERAL M.R. STEFANIK"
ARMED FORCES ACADEMY
SLOVAK REPUBLIC

INTERNATIONAL CONFERENCE of SCIENTIFIC PAPER
AFASES 2014
Brasov, 22-24 May 2014

RULES FOR LIMITING RISK EXPOSURE OF THE HUMAN BODY TO ELECTROMAGNETIC FIELDS

Gheorghe SAMOILESCU*, Radu SERGHEI, Florențiu DELIU*, Laura CIZER***

* Mircea cel Bătrân Naval Academy, Constan□a, România, ** Barklav Company, Constan□a, România

Abstract: *This paper provides an analysis of the risk exposure of the human body to electromagnetic fields based on the European and American reference exposure levels for the general population, in controlled and uncontrolled environments, which are corroborated with our national documents regarding technical norms for ship equipment and products, stipulated by the international conventions to which Romania has adhered.*

1. INTRODUCTION

In order to interpret the data measured both with and without protective equipment, a comprehensive documentation was carried out based on [1, 2, 3,4, 5, 6, 7, 8, 9, 11, 12, 13, 14].

a) recommendations by Specific Directive 96/98/EC on the "maritime equipment", implemented in Romania by Law no. 582/2003 of the Minister of Public Works, Transport and Housing approving technical type norms regarding marine equipment and products, stipulated by international conventions to which Romania has adhered, MLPLTL.ANR-EM 2003 code;

b) SREN 55011:2001 Romanian standard provisions – industrial radio-frequency, scientific and medical equipment (ISM). Radio and electrical disturbance characteristics. Limits and methods of measurement;

c) SREN 60945:2001 Romanian standard provisions – Navigation equipment and systems, and maritime radiocommunication. General rules. Testing methods and outcomes;

d) comparative analysis of European and American norms regarding limits of human body exposure to the electromagnetic field within in a frequency range from *0 Hz* to *300GHz* ("Radio-Frequency Radiation for Transmitters: A Comparison of U.S. and European Requirements"- paper authors: Steve Dillingham and Nick Cobb);

e) recommendations by 1999/519/EC European document - Council Recommandation on the Limitation of Exposure of the General Public to Electromagnetic Fields (*0 Hz* to *300 GHz*);

f) provisions of FCC American standard: Radio-Frequency Radiation Exposure Limits. Rule Parts 1.1310, 2.1091, and 2.1036 (frequency range from *3 GHz* to *300 GHz*);

g) provisions of "General safety rules" no. 880/06.12.2002, Sections 4 and 5, Annexes 72, 73, 74 and 75;

h) provisions of 50166-1 and 50166-2 SREN standards regarding the permissible limits of induced current density and the biological effects associated, the specific absorption rate – SAR, the permissible limits of the electric field and magnet intensities, of the peak power density in the human body in controlled and uncontrolled environments within the frequency range *3kHz - 300GHz*;

i) Government Decision HG no. 59 of 06.09.2006 on the minimum health and safety requirements regarding the exposure of workers to electromagnetic field hazards - Annex: Exposure limits and activation values for electromagnetic fields;

j) rules for limiting general public exposure to electromagnetic fields ranging from *0 Hz* to *300 GHz*, passed by the Ministry of Public Health and published in the Official Gazette of Romania, Part I, no. 895/03.11.2006;

k) NATO standard: Evaluation and Control of Personnel Exposure To Radio Frequency Fields - *3 kHz* to *300 GHz*, promulgated in February 13th, 2003;

l) ICNIRP recommendations – International Commission On Non – Ionizing Radiation Protection: Guidelines for Limiting Exposure to Time – Varying Electric, Magnetic and Electromagnetic Fields (up to *300 GHz*);

m) recommendations by 2004/40/EC Directive of the European Parliament and the European Council, as of 29 April 2004, with regard to minimum safety requirements for workers' exposure to electromagnetic fields;

n) restrictions regarding "specific norms on labor protection", Volume 6, 1977, ch. NSSM for non-ionizing radiations, DoD, Occupational Safety and Health Inspectorate.

International organizations recommend taking measures to reduce the risk of human body exposure to electromagnetic fields. The standard values regarding the limits of both electric and magnetic fields with a frequency of *50/60 Hz* to which the human body may be exposed are: the electric field (exposure time = *8/24 hrs.*): *10kV/m* - professional areas; *5kV/m* - public domain, the magnetic field (exposure time = *8/24hrs.*): *500μT* - professional areas; *100 μT* – public domain.

At the industrial frequency of *50/60Hz*, the criterion for exposure limits is the induced current density since the well-established effects such as interactions with excitable membranes of nerve and muscle cells depend on this factor [10].

In this respect, the SR EN 50166 1 standard stipulates the following ranges of values of the induced current density and the associated biological effects [8]: under $1mA/m^2$ - lack of effects; between $1\text{-}10mA/m^2$ - minor biological effects; between *10mA/m* and $100mA/m^2$ –biological effects that are already known such as: visual (magnetophosphenes) and possible effects on the nervous system; between $100\text{-}1000\ mA/m^2$ - changes in the excitability in the central nervous system; stimulation thresholds; possible health risks; over $1000\ mA/m^2$ - potential extrasystoles and ventricular fibrillation, imminent health risks.

In case of permanent exposure to electric and magnetic fields of *50 Hz*, the norm requires limitation of induced current density in the head and trunk to less than $10\ mA/m^2$.

In defining the standard values for the average current density, the following limits of magnetic induction – B – have been taken into consideration: ranging from *5 mT* – for 12 hours of daily exposure to *150 mT* - for one second of daily exposure; the limits of the electric field strength – *E* – have also been considered: *50 V/m*, for all times of daily exposure.

$$t \le 80 / E, \tag{1}$$

where t (hours/day) is the exposure time limit, and *E (kV/m)* is the electric field strength. Normally the induced current density in the body is a resulting vector expressed by:

$$\overline{J} = \overline{J}_B + \overline{J}_E, \tag{2}$$

where JB is the density corresponding to the magnetic flux while JE - the one corresponding to the unperturbed electric field. Thus, the basic restriction has to be interpreted as follows:

$$J_B + J_E \le 10mA / m^2. \tag{3}$$

Normally the summation of the two densities is a vector product, acknowledging this simplification involves a significant safety margin.

Current densities are calculated by the following relations:

$$J_E = k_E \cdot E; \quad k_E = 0,2; \tag{4}$$

$$J_B = k_B \cdot B; \quad k_B = 2, \tag{5}$$

considering that the fields through the bodies are homogeneous. [14, 17]

The current density limit for *f = 10 kHz* will be *0.1 A/m²* and it will linearly increase, proportional to frequency as expressed by the relation: *f/100 A/m²*; these values are valid for controlled environments. In uncontrolled environments, a new additional factor of 2.5 is applied, so that the new relation will be *f/250 A/m²*.

For frequencies of the electromagnetic field ranging from a few *MHz* or *GHz*, the Specific Absorption Rate – SAR – is used as a significant size in order to establish the exposure limits of the human body.

An increased risk to health was reported at the threshold value of the SAR ranging between *1* and *4W/ body kg*, depending on the climate area (temperature, humidity), people's health, their clothing, etc.

Establishing the basic derivative limits is done by entering a safety factor of *10* compared to *4W/kg* (the threshold value), so that the whole body will accept an average SAR of *0.4 W/kg* - in controlled environments, and of *0.08 W/kg* – in uncontrolled environments (in uncontrolled environments an additional safety factor of *5* is entered).

The EN 50166-2 Standard stipulates the allowed limits of the electric field strength as well as the ones of the magnetic field in the human body, starting from the basic restrictions *f/100 A/m²* and *f/250 A/m²*.

When exposed to pulses of the electromagnetic fields in the microwave range (over *300 MHz*), the Specific absorption - SA - represents a significant measure, its basic limit is *10 mJ /kg*, in controlled environments, and *2mJ/kg* in uncontrolled environments [15,16].

Table no. 1. Limits of field strength and power density in controlled environments, in case of continuous exposure

Field Frequency (MHz)	Value of Electric Field Strength (V/m)	Value of Magnetic Field Strength (A/m)	Power Density, average value (W/m^2)
0.01-0.045	614	35.6	-
0.045-1.000	614	1.6/f	-
1.000-10.000	614/f	1.6/f	-
10,000-400,000	61,4	0.16	10
400-2000	$3.07 \times f^{1/2}$	$8.14 \times 10^{-3} \times f^{1/2}$	f/40
2000-300,000	137	0.364	50

Table no. 2. Limits of field strength and power density in uncontrolled environments, in case of continuous exposure

Field Frequency (MHz)	Value of Electric Field Strength (V/m)	Value of Magnetic Field Strength (A/m)	Power Density, average value (W/m^2)
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

Field Frequency (MHz)	Value of Electric Field Strength (V/m)	Value of Magnetic Field Strength (A/m)	Power Density, average value (W/m^2)
400-2000	$1.37 \times f^{1/2}$	$3.64 \times 10^{-3} \times f^{1/2}$	f/200
2000-300,000	61.4	0.163	10

Table no. 3. Limits of field strength and peak power density in controlled environments

Field Frequency (MHz)	Value of Electric Field Strength (V/m)	Value of Magnetic Field Strength (A/m)	Peak Power Density (W/m^2)
0.01-1	$20,000 \times f^{0,675}$	50	-
1-10	20,000/f	50/f	-
10-400	2000	5	10, 000
400-2000	$100 \times f^{1/2}$	$0.25 \times f^{1/2}$	25 x f
2000-300,000	4500	11.5	50, 000

Table no. 4. Limits of field strength and peak power density in uncontrolled environments

Field Frequency (MHz)	Value of Electric Field Strength (V/m)	Value of Magnetic Field Strength (A/m)	Peak Power Density (W/m^2)
0.01-1	$8700 \times f^{0,675}$	22	-
1-10	8700/f	22/f	-
10-400	900	2.24	2000
400-2000	$45 \times f^{1/2}$	$0.112 \times f^{1/2}$	5 x f
2000-300,000	2000	5	10.000

In case of simultaneous exposure of the body to multiple independent sources of field of various frequencies, the assessment of actual reference levels was made on the principle of the accumulation of heat effects or electrical stimulation effects on the body.

Table no. 5. A comparison between the European and American reference exposure levels for the general public in controlled and uncontrolled environments

Frequency Range	Magnetic Flux Density (mT)	Current Density (mA/m^2) (rms)	Whole Body Average SAR (W/kg)	Localized SAR (Head and Trunk) (W/kg)	Localized SAR (limbs) (W/kg)	Power Density, S (W/m^2)
0 Hz	40	—	—	—	—	—
0–>1 Hz	—	8	—	—	—	—
1–4 Hz	—	8/f	—	—	—	—
4–1000 Hz	—	2	—	—	—	—
1.0–100 kHz	—	f/500	—	—	—	—
0.1–10 MHz	—	f/500	0.08	2	4	—
0.01–10 GHz	—	—	0.08	2	4	—
10–300 GHz	—	—	—	—	—	10

E-field Strength (V/m)	H-field Strength (A/m)	B-field (μT)	Frequency Range	Equivalent Plane-Wave Power Density $S_{eq}(W/m^2)$
0–1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	4000/f	5000/f	—
25–800 Hz	250/f	4/f	5/f	—
0.8–3 kHz	250/f	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	0.73/f	0.92/f	—
1–10 MHz	$87/f^{1/2}$	0.73/f	0.92/f	—
10–400 MHz	28	0.073	0.092	2
0.4–2 GHz	$1375\ f^{1/2}$	$0.0037\ f^{1/2}$	$0.0046\ f^{1/2}$	f/200
2–300 GHz	61	0.16	0.20	10

2. COMPARATIVE ANALYSIS OF THE RESULTS OF FIELD MEASUREMENTS, WITH AND WITHOUT PROTECTIVE EQUIPMENT

Following a well-documented research work, our choice for comparison was "The reference levels for occupational exposure to electric and magnetic fields and time varying electromagnetic fields (unperturbed RMS values)" drawn up by ICNIRP - International Commission on Non-Ionizing Radiation Protection, also mentioned in the Romanian Labor Protection Rules no. 880 as well as the NATO - STANAG standard regulations - Evaluation And Control of Personnel Exposure to Radio Frequency Fields - *3 kHz* to *300 GHz*.

Table no. 6. Reference levels for occupational exposure to time varying electric and magnetic fields, and electromagnetic fields (unperturbed RMS values)

Frequency Range	E - Electric Field Strength (V/m)	H- Magnetic Field Strength (A/m)	B- Magnetic Flux Density (μT)	Equivalent Plane Wave Power Density - Sech (W/m^2)
Up to 1 Hz	-	$1.63 \cdot 10^5$	2×10^5	-
1 – 8 Hz	20,000	$1.63 \cdot 10^5/f^2$		-
8 – 25 Hz	20.000	$2 \times 10^4/f$	$2 \times 10^5/f^2$	-
0.025 – 0.82 kHz	500/f	20/f	25/f	-
0.82 – 65 kHz	610	24,4	30.7	-
0.065 – 1 MHz	610	1.6/f	2.0/f	-
1 – 10 MHz	610/f	1.6/f	2.0/f	-
10 – 400 MHz	61	0.16	0.2	10
400 – 2000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.001f^{1/2}$	f/40
2 – 300 GHz	137	0.36	0.45	50

Table no. 7. Permissible levels of RF field exposure, uncontrolled environments

Frequency Range (MHz)	E - Electric Field (V/m)	H- Magnetic Field (A/m)	Power Density, S (mW/cm^2)	Medium Time, Tmed (min) E^2, S sau H^2	
0.003 – 0.1	614	163	$(10^2; 10^6)$	6	6
0.1 – 1.34	614	16.3/f	$(10^2; 10^4/f^2)$	6	6
1,34 - 3	823,8/f	16.3/f	$(180/f^2; 10^4/f^2)$	$f^2/3$	6
3 - 30	823,8/f	16,3/f	$(180/f^2; 10^4/f^2)$	30	6
30 – 100	27.5	$158.3/f^{1,668}$	$(0.2; 9,4 \times 10^5/f^{3,336})$	30 $0.0636f^{1,337}$	
100 - 300	27.5	0.0729	0,2	30	30
300 - 3000	-	-	f/1500	30	-
3000 – 15,000	-	-	f/1500	90,000/f	
15,000 – 300,000	-	-	10	$616,000/f^{1/2}$	

With reference to the above tables the foolowing remarks are to be pointed out:

1. At a mains frequency of *50/60 Hz*, the reference level of the electric field strength is *10 kV/m* (according to the table) and *0.5 mT* for the magnetic field.;

2. For frequencies (occupational exposure) of up to *100 kHz*, the limit for the electric fields may be exceeded by a factor of 2.

The data resulted from measurements reveal that within the considered frequency ranges (*88-200 MHz* and *200 MHz - 2.2 GHz*) the electric field strengths and radiated power densities do not exceed the basic restrictions for the health protection according to both the European norms and the U.S. standards due to the fact that the power strengths of the radio stations working in the frequency ranges covered by the measurements are of small values. The power standard of stations working in the range of *156-174 MHz* (maritime VHF) is *1W* in ports, and *25 W* outside them.

Thus, the maximum values measured for the electric field strength do not exceed 1 V/m, whereas for the electromagnetic power density they do not exceed *0,02* $\mu W/cm^2$.

The European Standard stipulates levels of: *28-61 V/m* - for the electric field, *0.073 - 0.16 A/m* – for the magnetic field and *2-10W/m²* – for the power density in the range of *10-400 MHz*, and respectively a level of $1.375 \cdot f^{1/2} - 3 \cdot f^{1/2}$ *V/m* - for the electric field, $0.0037 \cdot f^{1/2} – 0.08 \cdot f^{1/2}$ *A/m* - for the magnetic field and *f/200 – f/40 W/m²* - for the power density in the range of *400 - 2000 MHz*. The NATO - STANAG standard regulations stipulate levels of: *27.5-61.4 V/m* - for the electric field, *0.0729-0.163 A/m* - for the magnetic field and *2-10W/m²* - for the power density in the range of *100 - 300 MHz*, and respectively a level of *f/1500 – f/300 mW/cm²,* or *f/150 – f/30 W/m²* for the power density in the range of *300 - 3000 MHz* .

3. CONCLUSIONS

Due to the lack of measurement sensors in the analyzer used in frequency ranges below *80 MHz* and above *2 GHz*, no measurements were taken for the frequency ranges with powerful signal sources (radio and radar) onboard the ship, which are the main risk factors for the onboard personnel. For certain radio stations in the range of *4-30 MHz* (marine HF) the power strength ranges between *400-750 W*, while for other stations, strengths of up to *1.5 kW* are used. For some radar stations, the *9 GHz*- range transmission strengths are *15* and *25 kW*.

Due to the fact that both the constitutive parameters of the propagation medium (ε, μ)

and the air wave impedance (Z_0)are practically constant, in the absence of suitable sensors the measured values can be linearly extrapolated to other frequency ranges in order to see the exact values that can be reached by the field strengths and power density. Thus, by extrapolating the electric field strength radiated by the radio station at the power of *100 W* (*0.2509 V m* - value measured on the bridge), at *25 kW* (the value of the transmission strength power), a value of the radiated electric field strength of *62 725 V / m* is obtained. This value is particularly dangerous for the human factor onboard the ship and exceeds by far the permissible levels for the human body, according to both European and American standards.

The standard values of the electric field strength allowed are *27 V/m* in the frequency range of *100-300 MHz*.

Since all regulations in force stipulate the limitation of emission power in VHF range to 1 W when in port, the power densities measured on deck have small values. In order to obtain conclusive values of the radiated power density, onboard measurements are required in all frequency ranges of stations outside the port as well, while sailing in formation.

REFERENCES

1. Directiva Specifică 96/98/EC, referitoare la „Echipamentul maritim", obligatorie de la 1 ianuarie 1999, transpusă în România prin Ordinul ministrului lucrărilor publice, transporturilor şi locuinţei nr. 582/2003, pentru aprobarea normelor tehnice de tip a echipamentelor şi produselor pentru nave maritime, prevăzute de convenţiile internaţionale la care România este parte, cod MLPLTL.ANR-EM 2003;
2. Standardul românesc SREN 55011:2001 – Echipamente de radiofrecvenţă industriale, ştiinţifice şi medicale (ISM). Caracteristici de perturbaţii radioelectrice. Limite şi metode de măsurare;
3. Standardul românesc SREN 60945:2001 – Echipamente şi sisteme de navigaţie şi radiocomunicaţii maritime. Reguli generale. Metode de încercare şi rezultate impuse;
4. Analiza comparativă a normelor europene şi americane cu privire la limitele de expunere la câmp electromagnetic a organismului uman în gama de frecvenţa O Hz la 300 GHz, lucrarea „Radio-Freqnency Radiation for Transmitters: A Comparison of U.S. and European Requirements", autori: Steve Dillingham şi Nick Cobb);
5. Documentul european 1999/519/EC – Council Recommandation, of 12 Iuly 1999, on the Limitation of Exposure of the General Public to Electromagnetic Fields (OHz to 300 GHz);
6. Standardul american FCC Radio-Frequency Radiation Exposure Limits. Rule Parts 1.1310, 2.1091, and 2.1036 (gama de frecvenţă 3 GHz – 300 GHz);
7. Normele generale de protecţia muncii nr. 880/06.12.2002, Secţiunile 4 şi 5, Anexele nr. 72, 73, 74 şi 75;
8. 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;
9. Hotărârea Guvernului României, HG nr. 59, din 06.09.2006, privind cerinţele minime de securitate şi sănătate referitoare la expunerea lucrătorilor la riscuri generate de câmpurile electromagnetice – Anexă: Valori limită de expunere şi valori de declanşare a acţiunii pentru câmpurile electromagnetice;
10. Normele privind limitarea expunerii populaţiei generale la câmpuri electromagnetice de la 0Hz la 300GHz, elaborate de Ministerul Sănătăţii Publice şi publicate în Monitorul Oficial al României, Partea I, Nr. 895/03.11.2006;
11. Standardul NATO: Evaluation and Control of Personnel Exposure To Radio Frequency Fields – 3 KHz to 300 GHz, promulgat la 13 febr.2003;

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);
13. Directiva 2004/40/EC a Parlamentului European şi a Consiliului European, din 29 aprilie 2004, privind cerinţele minime de siguranţă a lucrătorilor la expunerea în câmpuri electromagnetice;
14. Radu, S., *Introducere în Compatibilitate Electromagnetică*, vol.I, *Ecranarea aparaturii electronice*, Editura Gheorghe Asachi, Iaşi, 1995
15. Hortopan, G., *Principii şi tehnici de COMPATIBILITATE ELECTROMAGNETICĂ*, Editura Tehnică, Bucureşti, 1998
16. Ignea, A., *Măsurări şi teste în Compatibilitatea Electromagnetică*, Editura Waldpress, Timişoara, 1996
17. Schwab, J.A., *Compatibilitatea Electromagnetică*, Editura Tehnică, Bucureşti, 1996
18. Sotir, A., Moşoiu, T., *Compatibilitate Electromagnetică*, Editura Militară, Bucureşti, 1997