20 YEARS OF BIOELECTROMAGNETIC RESEARCH AT THE INSTITUTE OF PUBLIC HEALTH IAŞI: SCIENTIFIC AND TECHNICAL ACHIEVEMENTS#

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Abstract. At the Institute of Public Health Iaşi, bioelectromagnetic research started late 1992, with epidemiological studies of health effects due to occupational exposure to electromagnetic fields. Later, biological experiments have been carried out on animals and various vegetal systems. To achieve electromagnetic exposure of biological bodies, an exposure system has been designed and built: a transverse electromagnetic cell optimized for biological experiments. Our group also got involved in health protection issues like measurement of environmental levels of electromagnetic fields and assessment of human exposure. Research activities concerning characterization and limitation of electromagnetic exposure included calculation and optimization of exposure metrics and exposure limits. To help good practice in the domain of electromagnetic exposure determination, we developed methodologies for electromagnetic field evaluation and measurement. The results of our research also contributed to the development of national and international exposure standards and of standardized methods for compliance testing.

Key words: Bioelectromagnetics, electromagnetic fields, non-ionizing radiation protection.

INTRODUCTION

Bioelectromagnetics (BEM) is the life science that studies the interaction of electromagnetic fields (EMF) with biological systems and its consequences. Areas of interest include investigation of adverse and beneficial biological and health effects of electromagnetic exposure, as well as diagnostic and therapeutic use of EMF. The study of possible health effects related to the use of existing and new developed man-made sources of EMF, characterization of exposure fields and assessment of human exposure to such fields, as well as protection of health against exposure to EMF are major topics in this domain.

The domain of BEM has roots in the18th century when Luigi Galvani (1737–1798), applied electric current on frogs' legs and observed that they contracted

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[35]. However, modern BEM started to develop after the Word War II by the invention of microwave oven and the improvement of devices used for therapeutic applications of EMF. In 50's and 60's, some health effects like cataracts and auditory effect have been associated with exposure to microwave fields generated by radar equipments and, consequently, safety standards for human exposure to EMF have been set up [57]. During following decades, investigation of biological and health effects of EMF exposure continued by epidemiological and experimental studies. Consequently, experimental exposure systems and dosimetric methods have been set up and the results of studies concerning EMF exposure were used as a base for setting exposure limits.

In 90's and first decade of the 21th century, the research of subtle EMF effects has become a priority and, therefore, the methods used for the investigation of biological and health effects, as well as for human exposure assessment, were improved. The work on harmonization of various national and international EMF exposure standards has also been started [95]. Moreover, after 2000, technical standards for EMF measurement, human exposure assessment and compliance testing were developed to help good practice in this domain [6]. However, despite the large efforts during last decades, the issues of bioeffects and interaction mechanisms to be used as a base for setting exposure limits and suitable exposure metrics are still hot topics in the domain of EMF exposure standards development.

In Romania, BEM research started in 60's by studies on the effects of static and low-frequency magnetic fields on animals. Magnetotherapeutic devices were developed and scientists investigated health consequences of therapeutic applications of electromagnetic fields. The results of research carried out by some Romanian scientists in the 60's and 70's concerning beneficial effects after magnetic exposure of various animal species, as well as the efficiency of magnetotherapy in patients with various diagnostics are summarized in a book edited by Jitariu [65]. Some other studies concerning geomagnetic field influence on living systems and human behavior were also carried out. However, during communist regime, the study of adverse health consequences of EMF was not encouraged by authorities.

After the fall of the communist regime in Romania, at the end of 1989, several groups of scientists started biological experiments, investigating both beneficial and adverse effects of EMF. Various biological systems were exposed to EMF, especially to static or low-frequency magnetic fields and to microwaves. We mention the experiments on vegetal systems and blood cells of the group coordinated by Creangă [12–14, 108–110], the studies of quasi-zero magnetic field effects on biological systems of Morariu [10, 15, 83, 94], as well as various EMF exposure experiments coordinated by Kovacs [68, 69, 79–81, 93, 99, 102–104]. Later, dosimetric assessment of EMF exposure was accomplished by Sajin [97, 98], Miclăuş [4, 74–78], and Morega [87, 88]. Last, but not the least, diagnosis and therapeutic applications of EMF were studied by teams of Baltag [1, 2, 11, 106, 107], Morega [84–86] and Sajin [96].

In this national and international context, late 1992, in the framework of the Institute of Public Health Iaşi, a small group of scientists started to work in the domain of Bioelectromagnetics, with a special interest in biological and health effects of non-ionizing electromagnetic radiation, as well as in non-ionizing radiation protection (NIRP). The Institute of Public Health Iaşi was founded in 1930 and currently is part of the National Institute of Public Health, as a Regional Center. Prevention activities concerning health protection of general public and occupational population are main priorities of our institute. Therefore, our BEM & NIRP group involved in various activities: determination of human exposure to EMF, epidemiological studies on health effects of EMF, experimental studies on biological EMF exposure, as well as health protection issues.

Early 90's in Romania there was a strong need of investigating occupational EMF exposure and its possible health consequences. Therefore, our research in the field of Bioelectromagnetics began with the study of health effects of radiofrequency and microwave fields [3, 18–21]. Later, studies concerning the effects of extremely low frequency fields were carried out, especially for high-voltage power lines, transformation stations and electric trains [25–27, 31].

Since 1998, experimental studies have been started in collaboration with the Faculty of Physics from "Al.I Cuza" University of Iaşi. In the beginning, dielectric properties at high frequencies of some animal tissues have been measured [100]. EMF exposure experiments have also been carried out on different biological systems: small animals [38, 41, 42, 47], animal tissues [16], blood [89], and vegetal samples [39, 40, 82, 101, 111]. To achieve the needed EMF exposure of biological bodies, an EMF exposure system has been designed, built and optimized for biological exposure requirements [46].

During our studies, various and complex types of measurements have been carried out: from dielectric properties of biological tissues, electrophysiological and biochemical parameters, to environmental EMF levels and body contact currents or limbs induced currents. Computation of induced currents [43] and energy absorption [8] in human body has been accomplished, partly in collaboration with Swiss Federal Institute of Technology, Zurich.

Concerning non-ionizing radiation protection, our group involved in various activities like determination of environmental EMF levels [25, 48, 51–53] and assessment of human exposure to low-frequency and high-frequency fields [43], [53]. Other activities concerned improvement of exposure standards at national level (since 1999) [22, 37] and international level (since 2003) [43, 44], as well as elaboration of EMF measurement and evaluation methodologies [36, 49, 50].

In what follows, the main types of activities developed by our research group in the domain of Bioelectromagnetics are presented. The main outputs of our research studies and health protection activities are presented and the main priorities and original results are emphasized.

HUMAN STUDIES

At the beginning of 90's, in Romania there was a strong need of investigating human EMF exposure, especially at workplaces where intentional EMF sources were used or where installations unintentionally generating EMF were present. Given the lack of large and complex epidemiological studies concerning occupational EMF exposure, our Bioelectromagnetic research began in 1992 with epidemiological studies concerning health effects of EMF exposure at workplace. Epidemiological studies were carried out by our group, for various categories of workers and for different kinds of fields generated by various sources.

We carried out studies concerning occupational exposure to radiofrequency and microwave fields, as well as possible health effects, especially on nervous and endocrine systems [3, 18–21]. Nervous system was studied both at peripheral and at central level by anamnesis, clinical examinations, electro-neurophysiological methods, questionnaires and psychological tests. Specific endocrinologic investigations, including hormone levels assessment were aimed to substantiate neuroendocrine effects. A study on radar mechanics exposed to pulsed microwaves revealed peripheral nervous system symptoms related to electromyography changes [23], central nervous system symptoms related electroencephalography and psychological changes, as well as neuroendocrine effects, especially calcium phosphorus balance changes and signs of thyroid dysfunction [29, 30].

Other studies focused on exposure to extremely low frequency (ELF) electric and magnetic fields in various working environments: power plants, electric transformation stations and electrified railways. Health effect studies were based on clinical, electrophysiological, as well as laboratory (biochemistry, hematology, immunology, endocrinology) investigations and, also, on anamnesis, questionnaires and psychological tests. The results showed peripheral nervous system changes (significant decreases of nervous conduction velocities and increased distal motor latencies) [26, 27, 31] and, also, cardiovascular changes (arrhythmias, conduction disturbances and myocardial ischemia) [25, 31], both statistically associated with occupational exposure to ELF fields. During the assessment of PNS function, electroneuromyography (EMG) emphasised decreases of nerve motor conduction velocities (MCV) and sensitive conduction velocities (SCV) for ulnar and median nerves, as shown in Fig. 1 [31].

The human studies we carried out emphasised changes in central and peripheral nervous system function that put in evidence possible and plausible biological effects of EMF on structures of nervous system. Some of our findings such as precocious peripheral nervous system changes seem to support a mechanism in which the myelin is primarily damaged and the axon is subsequently injured (increased excitability thresholds). The subtle effects of EMF exposure on nervous system emphasized by our studies are consistent with results reported by other studies regarding nervous systems effects in humans long-term exposed to EMF [5, 61, 66, 71, 90], as well as by the results of studies on nervous cells and on the nervous systems in animal studies [34, 91, 112].

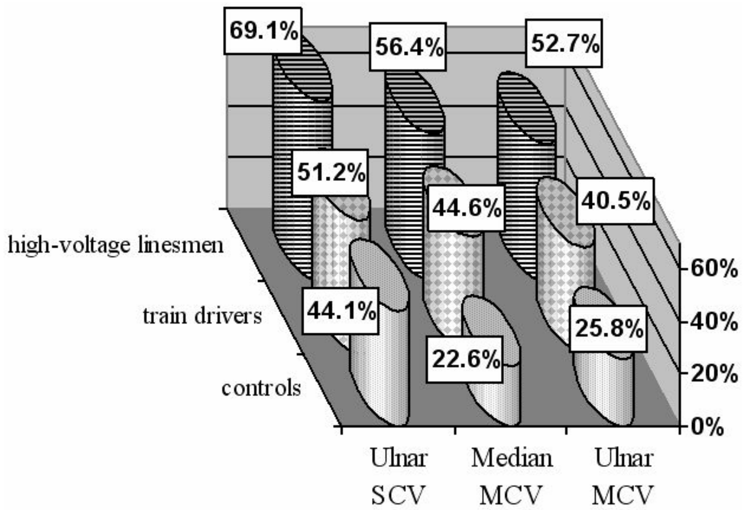

Fig. 1. Incidence of nerve conduction velocities decreases in workers exposed to extremely low frequency fields *versus* controls [31].

DESIGN AND BUILDING OF AN EXPOSURE SYSTEM

Experimental EMF exposure of biological systems requires a well-defined field inside the volume occupied by exposed biological objects [7, 58, 59]. Electromagnetic exposure system has to generate a controlled EMF having the same magnitude for all biological samples. Transverse electromagnetic (TEM) cell is an exposure system that combines several important qualities: it is a shielded environment, operates over a wide frequency range, generates a plane-wave and the field magnitude can be computed from the power travelling the cell.

To achieve a controlled EMF exposure of biological bodies, we designed and built a TEM cell (Fig. 2), optimized for biological experiments [46]. We decided for an elongated and flattened geometry of the TEM cell having small holes for illumination and ventilation regularly distributed on side walls. Dislike the TEM cells designed for electromagnetic compatibility (EMC) testing [73] that mainly requires a minimum distance between septum and the wall parallel to the septum in order to place tested equipments while avoiding field disturbances and higher order modes, the flattened TEM cell we designed for biological experiments has a different cross section geometry, having an enlarged dimension on the other transversal direction: septum width.

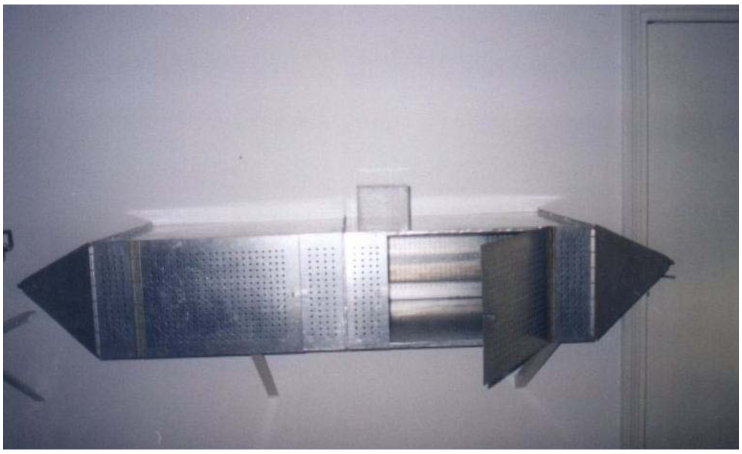

Fig. 2. Especially designed TEM cell for EMF exposure of biological systems [46].

Comparing to usual TEM cells [58, 73], our TEM cell is enlarged also on the propagation direction, providing an increased usable exposure area: transversal dimensions of the rectangular section are 715 mm and 340 mm, while the total length of the cell is about 2300 mm. Therefore, the designed TEM cell with flattened and elongated structure allows hosting of a higher number of animals, EMF exposure field being similar and quantifiable.

By using the TEM cell optimized for biological exposure experiments – the first one of this kind in Romania – we carried out various EMF exposure studies on different biological systems: small animals, plants and other vegetal samples. Both short-term and long-term exposure studies have been carried out within the built TEM cell.

ANIMAL EXPOSURE STUDIES

To further investigate possible nervous system effects after long-term low-level exposure to EMF, animal exposure studies were performed. Our first animal exposure experiment searched for any possible subtle effect on behavior and central nervous activity of mice exposed to ultra high frequency (UHF) fields [38], [41]. Inside the built TEM cell, Swiss male mice were exposed to ultra high frequency field with a frequency of 400 MHz and power density level equal to human exposure limit at this frequency: 1 mW/cm^2. Electromagnetic exposure of animals lasted 8 hours a day, five days a week, for 13 weeks. To minimize the field perturbation in a location of a specific mouse due to the presence of other mice in its neighborhood, inside the TEM cell each mouse was restrained by placing in its own plexiglas cage. The behavior of mice was assessed using a battery of three tests that investigate the exploring behavior and motor activity of animals: *open field* test, *perforated plate* test and *evasion* test. A control (sham exposed) lot of ten male mice was used to compare test results.

Applied behavioral tests revealed a reduction of the investigative potential of animals during the entire exposure period. The study also emphasized a phasic evolution of the exploratory ability consisting in two stages of psychomotor activity: activation and, respectively, inhibition of mice exploratory behavior (Table 1). In our experiment, the last stage of activation suggests that the phasic evolution may be repeatable, becoming a cyclic evolution, due probably to the interference of EMF with the central nervous system of animals.

Taking into account the entire evolution of performances in the two lots, it seems that EMF, interacting with nervous system, could act like as an exciting factor. EMF exposure could temporarily enhance mice performances, but in time, as a result of enhanced energy consumption during excitation stages, it induces a state of tiredness that leads to a decrease in animal performances [42, 47]. Subtle effects of EMF upon nervous system are reported in literature [17, 70, 72] sometimes having a phasic evolution, but in our experiment the phasic evolution seems to be a cyclic evolution during EMF exposure. However, long-term EMF exposure could affect the nervous activity of animals, leading to reduction of the investigative potential and inducing a certain psychological stress causing a state of indifference, apathy.

Table 1

Relevant stages of performance evolution in the exposed mice compared to control ones

DAY	EFFECT
0 – 15	Uncertain tendency
15 – 45	Exciting effect
45 – 60	Inhibitory effect
60 – 75	No visible effect
75 – 90	New stage of excitation

In a short-term exposure experiment, 5 lots of mice were exposed to ultra high frequency fields with the same characteristics as above. UHF exposure lasted 15 days too, but each lot had different daily exposure duration 1, 2, 4, 8, and 12 h per day. Oxidative stress was assessed by means of relevant markers, thiobarbituric acid reactive substances (TBARS) and superoxide dismutase (SOD) in muscle and in liver samples. Enhancement of oxidative stress was emphasized by both markers, i.e. increasing of tissue TBARS content and inhibition of tissue SOD activity, more evident in the liver than in muscle samples [56]. Our results are in line with literature data which have demonstrated similar enhancement of lipid peroxidation in experimental exposure to EMF manifested by augmentation of lipoperoxidative index (malondialdehyde or TBARS) and SOD activity inhibition.

EXPOSURE STUDIES ON VEGETAL ORGANISMS

There is a significant amount of literature reports concerning the effects of static and low frequency magnetic fields on plant species, especially regarding seed germination or initial growth stages. Few studies were focused upon exposure of vegetal systems to high frequency fields [105]. Moreover, it seems to be a significant lack of information regarding ultra high frequency fields influence on arbor saplings.

In collaboration with the Biophysics Laboratory from the Faculty of Physics, "Al.I. Cuza" University of Iasi, several biological exposure experiments were carried out on vegetal systems. Electromagnetic exposure of various vegetal organisms was accomplished: seeds, seedlings, plants. In all experiments, vegetal bodies were exposed to ultra high frequency field with a power density of 1 mW/cm^2 and, in one experiment, exposure to microwaves (super high frequency) was also accomplished for separate lots.

A short-term exposure of grain (*Triticum aestivum*) caryopsides was carried out inside TEM cell. Sample exposure was accomplished for different durations: 1, 2, 4, and 8 h, for five consecutive days. One week later the catalase activity was measured on part of caryopsides, the other part being watered for initiation of plantlet growth. Relatively high constant humidity level was assured during plantlets growth, i.e. for about eight days, until the spectrophotometric assay of photosynthesis pigment was carried out. Electromagnetic exposure determined the stimulation of catalase activity (Fig. 3) for relatively short (1, 2, 4) daily exposure times as well as the stimulation of secondary pigment biosynthesis (Fig. 4). On the other hand, relatively long daily exposure time (8 h) led to a lower catalase activity than in the controls and to the diminishing of chlorophyll a concentration compared to controls [39].

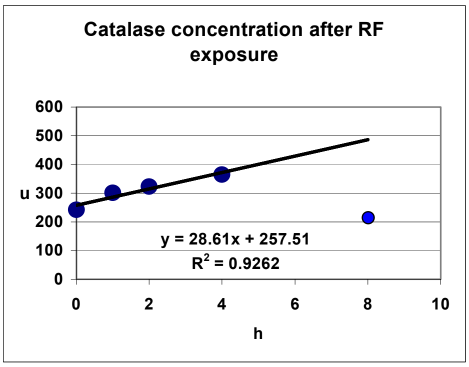

Fig. 3. Catalase concentration after electromagnetic treatment.

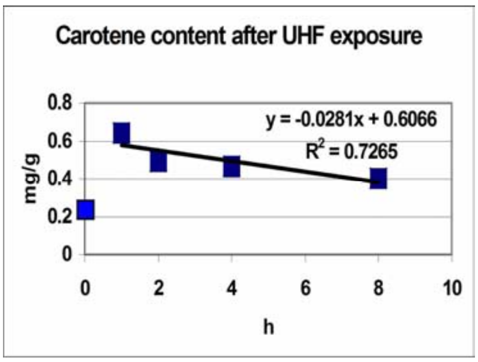

Fig. 4. Carotene content after electromagnetic treatment.

A separate exposure experiment was carried out on black locust (*Robinia pseudoacacia* L.) seedlings. Selected seeds were let to germinate in vessels containing natural soil and, after germination, all the vessels were exposed to light (12 hours light / 12 hours darkness) and maintained to constant temperature. The seedlings grown this way during three months in quasi-natural conditions of soil, water and temperature were exposed three weeks to ultra high frequency fields. Daily exposures duration was different for various lots: 1, 2, 3, and 8 h. Then assimilatory pigments were evaluated in the seedling leaves, analyzing five replies for both control and exposed samples. The levels of assimilatory pigments in leaves were significantly modified [40, 101]. Most sensitive appeared to be the level of chlorophyll **b** which is first enhanced in 2 h/day exposed samples and then diminished (3 and 8 h). The ratio between chlorophyll **a** and chlorophyll **b** is slightly diminished following electromagnetic exposure. A non-thermal effect of UHF in ion channels from cell system of membranes is supposed to be induced, but the complexity of metabolism processes related to photosynthesis requires further experimental research.

Another experiment investigated the possible effects of radiofrequency (ultra high frequency) or microwave irradiation of maize (*Zea mays* L.). Maize grains were selected from single plant genitor in order to assure genofond uniformity. The plantlet growth was conducted within *Angelantoni scientifica* microclimate room at 12:12 hours light-dark cycle, at 24ºC thermostated environment. After 14 days, when the nourishing stocks from the initial caryopsides have been finished, either radiofrequency or microwave exposure has been carried out. The level of power density was 1 mW/cm^2 at both frequencies (400 MHz and 10.75 GHz), daily exposure time being of 1, 2, 4, and 12 h. Direct measurements of the levels of chlorophylls and carotenes have been carried out. Measured levels of chlorophylls and carotenes showed a stimulatory effect on the biosynthesis processes from vegetal green tissues when the daily exposure duration is relatively short (couple of hours per day). The radiofrequency or microwave exposure of relatively long duration (over 10 hours) resulted in inhibitory effects on the same biochemical parameters [111].

In all exposure experiments carried out on vegetal organisms, some general features of the biological effects due to EMF exposure were noticed. Pigment content was generally increased for short daily exposure times, while for longer daily exposure times decreasing tendencies were noticed. Electromagnetic treatment seems to have a stimulatory effect on the biosynthesis processes from the vegetal green tissues, as other scientists also reported [67], but in our experiments the stimulatory effect occurred only for relatively short daily exposure durations. Relatively long duration of daily exposure resulted in inhibitory effects on the same biochemical parameters.

DIELECTRIC MEASUREMENTS

Given the importance of dielectric properties of tissues for the dosimetric assessment of EMF absorption in tissues, measurements on dielectric properties of various biological tissues have been fulfilled. In collaboration with Microwave Laboratory from the Faculty of Physics, "Al.I. Cuza" University of Iaşi, microwave dielectric measurements on biological tissues and liquids excised from animals were carried out. Biological liquids (blood, urine) and many solid tissues (blood, urine, kidney, liver, fat, brain – mixture of white and gray matter) excised from mice were measured. Solid tissue samples were homogenised by fine cutting and trituration without adding solvents or any other material, because their different permittivity values can be a source of errors. Dielectric measurements were performed in two microwave ranges: S-band (f = 3 GHz) by a perturbation method of the resonant cavity and X-band (f = 9.3 GHz) by a differential interferometer method. All measurements were carried out within a four hours period in order to reduce the possible influence of unexpected source of errors due to a longer period of time after tissue excision and the results are shown in Table 2.

For the same tissue specimen measured permittivity values were different at 3 GHz and 9.3 GHz, respectively, but this difference is in accordance with known tissue permittivity decrease with frequency. The real part of tissue permittivity decrease with frequency in several major steps corresponding to α, β, γ and δ dispersions [32, 33]. In GHz range, the permittivity decreases with frequency according to γ dispersion due to free water orientational relaxation and δ dispersion due to orientational relaxation of bound water and water associated with protein or tissue surfaces. In conclusion, the results are in good agreement with those provided by literature [32, 92] and the difference in permittivity values measured at the two frequencies is basically a result of permittivity variation with frequency.

Later, low-frequency measurements of some liquids and polymers were accomplished in the laboratories of Bayreuth University, Germany. By employing several low-frequency methods and measurement equipments, determination of complex dielectric properties was accurately accomplished for all samples [41].

Table 2

Permittivities of excised samples at 3 GHz and 9.3 GHz

Tissue	**Permittivity at 3 GHz**		**Permittivity at 9.3 GHz**	
	measured	references [32, 92]	measured	references [32, 92]
blood	53.35	55 – 56	51.7	45 – 52
urine	52	–	53.3	–
liver	42	42 – 53	31.4	34 – 38
brain	32.5	33 – 41	30.9	25 – 40
fat	5.25	4 – 7	4.8	3.5 – 4
kidney	40.5	35 – 47.5	–	–
skeletal muscle	–	–	30.2	35 – 42

DETERMINATION OF ENVIRONMENTAL ELECTROMAGNETIC FIELDS

Two categories of methods are available for determining EMF levels: theoretical estimation and measurement. Theoretical estimation is needed before installing EMF generating equipments, in order to avoid human exposure to strong fields. As a part of our professional activity, we estimate EMF levels expected to occur when emitting antennas are installed.

The other method of EMF level determination relies on measuring EMF levels or other parameters related to EMF exposure. Our institute has EMF measurement instruments for various types of fields and related parameters:

- static magnetic fields,
- low-frequency electric and magnetic fields,
- high-frequency electromagnetic fields,
- currents induced in limbs.

Fig. 5. Measurement of high-frequency radiation emitted by various antennas.

Fig. 6. Test measurement of low-frequency fields emitted by power generation installations.

Fig. 7. Measurement of low-frequency electric fields under high voltage power lines.

Fig. 8. Measurement of low-frequency magnetic fields in the proximity of a power transformer.

Using modern measuring equipments, we measured EMF levels in domestic [51, 52], as well as in work environments [48, 51, 53] (Figs 5–8), for various types of EMF sources:

- antennas for communication and broadcasting,
- medical equipments,
- computer monitors,
- EMF sources from BEM & EMC laboratories,
- non destructive control devices,
- power plants (electric generators)
- high voltage power lines and electric transformers,
- electrified railways and electric trains,
- welding devices (induced current),
- electric discharge furnaces,
- electrolysis equipments.

ASSESSMENT OF HUMAN EXPOSURE

Health protection against electromagnetic exposure involves, besides external field level measurement, the assessment of human exposure to EMF, i.e. assessment of induced fields and currents in body tissues, as well as the absorption of electromagnetic energy in tissues. Computation of these quantities may be achieved in dosimetric studies using simplified models of tissue structure or digital biological models.

A high-frequency study concerned general public exposure to EMF when using mobile phone terminal equipments and other wireless devices. The first author of present review was involved in the assessment of human EMF exposure carried out by IT'IS Foundation in collaboration with Swiss Federal Institute of Technology from Zurich [8]. During this study, the EMF absorption in tissue structures was computed for head (Fig. 9) and body regions and the worst-case absorption was assessed.

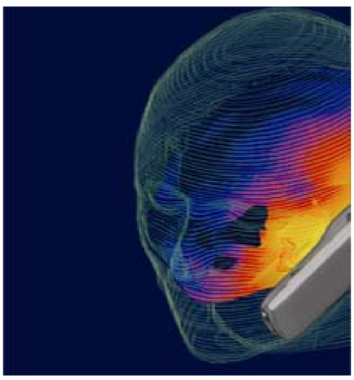

Fig. 9. Electromagnetic energy absorption in the head of mobile phone user [113].

When compliance testing methods for wireless devices had been set, assessment of human exposure was firstly focused on head exposure from mobile phones. The *SAR* distribution in head tissues was computed and the wort-case peak *SAR* was estimated. Our dosimetric study aimed to extent the study of EMF absorption for any tissue composition that might occur at any location of the human body. Compared to the head, in trunk region higher peaks of *SAR* were emphasized, as a consequence of different tissue structures: type of tissues, sequence and dimensions. Alternation of high and low water content tissues in abdominal region leads to a standing wave effect that accounts for maximum peak *SAR* values that are localized in the skin [8]. The study focused on far-field like exposure conditions while near-field conditions were examined elsewhere [9].

Assessment of occupational exposure to pulsed microwave fields was also accomplished, as a part of an epidemiological study on radar mechanics. As current safety standards [62] specify, exposure characterization included power density measurement and computation of specific absorption rate (*SAR*). Moreover, some additional radiometric and dosimetric quantities were computed in our study [53] to better characterize exposure to pulsed microwaves. Compliance of occupational exposure with thermal effect limits was emphasized by low values of typical quantities used by standards: mean power density and *SAR*. However, non-thermal effects were correlated with some high values of additional quantities we calculated: peak energy density and specific absorption. The additional quantities we employed proved to be useful for better characterization of exposure to pulsed microwaves. Our findings point to the exposure metrics as important clues in the assessment of human exposure to pulsed EMF and the possible correlation of additional quantities with subtle effects.

DEVELOPMENT OF METHODS, METHODOLOGIES AND STANDARDS

The health protection activities we carry out also involved, besides practical activities like measurement of EMF levels, assessment of human exposure and recommendation of measures to reduce exposure, some research activities concerning development of EMF characterization methods, as well as limitation of allowable exposure levels. Our work on these topics finalized with the following main results:

- optimization of exposure metrics for pulsed microwaves [53];
- calculation and optimization of EMF exposure limits [43, 44];
- development of procedures for compliance test of wireless devices [8];
- proposal of national exposure standards [37];
- proposed improvements of ICNIRP international standards [43, 44],
- elaboration of national methodologies for EMF determination [50].

OPTIMIZATION OF EXPOSURE METRICS

Various exposure metrics have been tested if suitable for EMF characterization, especially for pulsed microwaves. The study on radar mechanics put in evidence central nervous system effects such as symptoms of neurasthenia (NAS). Associations between the exposure metrics and the presence and the stage of NAS were tested using Spearman R nonparametric correlation and t test [30]. Significant and mean correlations and also a significant difference (p = 0.02) between Spearman R for last year dose versus daily dose concerning NAS stage were found. The symptoms of asthenia were significantly correlated (Spearman) with peak power density (peak *S*), energy density (*ED*) and specific absorption (*SA*), especially for the last month *SA* and the last year *SA* [30].

To better characterize pulsed microwave exposure in relation with emphasized health effects, additional quantities were employed (e.g. *ED*, *SA* during specific time periods) to quantify EMF and to assess human exposure [53]. Some of additional quantities we used proved to be useful and they could be employed in further studies and even incorporated in exposure standards as additional limits.

OPTIMIZATION OF EXPOSURE LIMITS

For slowly-variable magnetic fields with frequencies below 1 Hz, we optimized exposure limits for occupational exposure [43, 44]. Taking into account the specific mechanisms of interaction of static and slow-varying magnetic fields, the dosimetric aspects, as well as some lacks of provisions in international regulations concerning the frequency-dependency of limits, we calculated frequency-dependent additional limits (Fig. 10, ceiling limits). Additional limits were designed to be simply added to restrictions of ICNIRP guidelines (Fig. 10, TWA – time weighted average – and static field limits) from 1998 [62]. Proposed frequency-dependent limits are described in a paper [43] published in *Health Physics*, the journal where ICNIRP guidelines are published. Currently, the work on optimizing exposure limits of the latest ICNIRP guidelines is in progress.

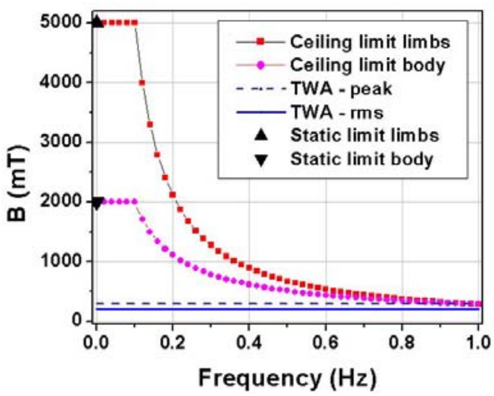

Fig. 10. Proposed frequency-dependent additional limits for slowly-variable magnetic fields [44].

DEVELOPMENT OF COMPLIANCE TESTING METHODS

The first standards for compliance testing of wireless devices with safety limits were developed for the assessment of *SAR* in the head of a mobile phone user. These standards define dielectric parameters for head and body tissue simulating liquid to fill shaped phantoms. Currently, compliance testing standards are extended to more general exposure situations: mobile phones carried in a pocket or on a belt, as well as use of other portable or wearable wireless devices.

During the study on human exposure from wireless devices developed by IT'IS Foundation & Swiss Federal Institute of Technology, parametric studies were conducted [8]. In the framework of EUREKA project "SARSYS BWP: Development of Procedures for the Assessment of Electromagnetic Exposure from Body-Mounted, Wearable, Portable Wireless Telecommunication Equipment", standardized procedures for compliance of mobile phone terminals, as well as other body-mounted, wearable and portable wireless equipments were developed.

For trunk region, computed absorption in anatomical tissue sequences showed a significant increase of 2.2 dB to 4.7 dB of the peak spatial *SAR* in comparison to the values assessed with current standard liquids derived from tissue structure of head [8]. The *SAR* increase is due to a more general composition of tissues at different locations of the body in comparison to head region: sequences of high and low water content tissue and the thicknesses of the respective layers.

The increased peak *SAR* in trunk region is related to standing wave effects in tissues with low water content. For a certain distance between the antenna and the body, these standing wave effects dominate the coupling mechanism. However, a conservative exposure assessment can be obtained by measuring the peak spatial average *SAR* with the current standard liquids and applying a scaling factor (between 1 and 3) which can be derived from the results reported in our study [8].

DEVELOPMENT OF METHODOLOGIES FOR EMF DETERMINATION

One of the main focuses of our work consists in the development of methodologies for EMF determination [36, 49, 54, 55]. To help third parties in the process of determining EMF levels, we elaborate methods, algorithms, good practice procedures and other materials. Beyond these materials, we elaborated or contributed to the elaboration of methodologies to be applied at national level:

- methods for fast checking of compliance with exposure standards when multiple-frequency fields are present [54];
- national methodology for evaluation of EMF level generated by mobile phone base stations antennas;
- practical guide for the determination of EMF levels in work environment – first book of this kind in Romania [50].

NIRP PROFESSIONAL SOCIETY

Before 1996, a coordination of research in Romania within the domain of biological effects and protection against exposure to NIR did not exist. Excepting the collaboration of a few groups, generally from the same town or from the same kind of institutions, there was a quite poor connection between scientists and even a poor knowledge of other groups of scientists working in this domain.

In 1997, as an initiative of the Bioelectromagnetics (BEMs) & NIRP groups from the Institute of Public Health Iaşi, it was founded the Working Group On Non-Ionizing Radiation Protection (WGNIRP) in the frame of the Institutes of Public Health of Bucharest, Iaşi, Cluj and Timişoara, coordinator being Dr. Răzvan Dănulescu. A decade later, in 2008, scientists from various other institutions joined the core from the Institutes of Public Health and the working group was transformed into a professional society: Romanian Society for Non-Ionising Radiation Protection (RS-NIRP).

INTERNATIONAL COLLABORATIONS

Scientific international collaboration has been accomplished by contacting scientists and by involving in research studies and in scientific events:

- international research projects:
  - EUREKA,
  - German Research Foundation, DFG,
  - Balkan Environmental Association, B.EN.A.
- organizing international NIRP meetings and workshops:
  - Romanian-Japanese NIRP Meetings (2002, 2008),
  - German-Romanian Symposia on Occupational Health – NIRP Workshops (2004 – 2007).
- presenting invited lectures and talks at universities and conferences.

Collaboration with international organizations has also been developed by participating in activities of various organizations concerning health protection against exposure to electromagnetic fields:

- revising ICNIRP drafts of human exposure guidelines;
- elaboration of EMF-NET (ElectroMagnetic Fields NETwork) Reports;
- consultation of EC DG Employment Social Affairs and Equal Opportunities regarding restrictions on occupational EMF exposure.

CONCLUSIONS

Starting early 90's, our activities in the field of Bioelectromagnetics contributed to the development of this domain in Romania, at the beginning by carrying out the first large epidemiological studies on occupational exposure to electromagnetic fields. These studies emphasized some nervous system effects correlated with some exposure metrics we tested. Experimental work started by designing and building a large electromagnetic exposure system of TEM cell type, optimized for biological experiments, the first TEM cell of this kind in Romania. Using this exposure system we carried out exposure experiments on animals and various vegetal systems, revealing subtle effects of electromagnetic fields that showed phasic evolutions during exposure period. Concerning the determination of electromagnetic field levels, our work finalized by development of methodologies of evaluation and measurement of exposure fields. The results of our work on optimizing exposure limits contributed to the improvement of national and international standards concerning limitation of human exposure to electromagnetic fields, as well as setting of standardized methods for exposure assessment and compliance testing of wireless devices.

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