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Occupational exposure to electromagnetic fields. The situation in Greece

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ABSTRACT

Purpose: The management of the occupational exposure to electromagnetic fields (EMF), an Occupational Health and Safety (OHS) issue of great scientific, social and economic significance, was under intense negotiations at European level over the last twenty years; the Directive 2013/35/EU is the new legislative tool. The presented study deals with the practical aspects of the Directive's implementation.

Methods: The appropriate, extensive measurements and the overall EMF exposure assessments (i.e. exposure mapping, identification of hot spots, proposition of solutions) were conducted in specific workplaces, including power production, railway, broadcasting, clinical Magnetic Resonance Imaging (MRI) systems, industrial and research sites, as well as common office workplaces.

Results: The vast majority of the performed EMF assessments did not reveal occupational overexposures; moreover in most of the cases, even the general public exposure limits (in the above occupational areas) were not exceeded. The very few localized overexposures detected, were manageable on the basis of the technical and organizational OHS principles.

On the contrary, the maintenance procedures of the EMF emitting equipment, as recorded in this survey, presented overexposures revealing a challenging field.

Conclusions: This study lays a firm basis for the clarification of the occupational EMF environment, where potential exposures might be high. The proper risk assessment demands precise exposure identification and deep understanding of the EMF nature and hazards. Misconceptions range from the common exposure overestimation to the rarer case of the maintenance hazards underestimation, while attention is needed concerning the proper application of the complex limiting system of the Directive.

1. Introduction

The adoption at European level of the Directive 2013/35/EU, that repeals the 'old' 2004/40/EC one and its consequent implementation into national legislation, completes a long period of intense negotiations, concerning the protection of workers from exposure to electromagnetic fields (EMF).

Even though many efforts to assess occupational exposure have been reported [1], starting many years ago with the relevant ILO Guides [2] and continuing until today [3] and certain European basic or product standards exist (e.g. EN 50499, EN 50519, EN 50527-1, EN 50527-2-1, EN 50647), occupational exposure monitoring remains a challenge. The Hellenic Ministry of Labor took advantage of the three years' implementation period of the Directive into national law, to map the Hellenic occupational EMF exposure. This was made possible through specific measurements in preselected workplaces, where EMF exposure may reach significant values. Measurements were mainly performed by the Non-Ionizing Radiation Office of the Greek Atomic Energy Commission (EEAE), which is an accredited laboratory, in accordance with the requirements of the EN ISO/IEC 17025 standard for performing high and low frequency EMF measurements, as well as by the Laboratory of Hazardous Physical Agents of the Ministry of Labor (former KYAE) and by the University of Thessaly.

The whole project ultimately determined the workplaces where EMF exposure might require the implementation of the appropriate corrective actions, but it also clarified the numerous workplaces where there is no need for further actions or concern. It can therefore be an important lever for the practical and proper implementation, not only

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of the EMF exposure assessment, but also for the activation of the total Occupational Health and Safety (OHS) framework. Additionally, the provided results clarify the scientific evidence around EMF effects, as the related information is incomplete, leading to a plethora of misconceptions around the EMF impact [4].

2. Materials and methods

2.1. Basic EMF interaction – absorption mechanisms

Dealing with EMF and their interactions with matter, the Maxwell's equations are modified by appropriate coefficients, which characterize the electric and the magnetic properties of the various components (e.g. conductors, insulators, tissues). The EMF within the body (internal field) is the essential one for the determination of any possible effect, but it is quite difficult to be identified. On the contrary, it is relatively easier to specify the EMF around the body (external field), using the appropriate equipment and measuring methods. External field values are related to the expected internal field values through appropriate inverse modeling [5].

In general, the magnetic field (MF) penetrates the body almost unperturbed (the body's magnetic permeability μ is approximately the same as that of the vacuum μ_0), generating induced currents perpendicular to the field. On the other hand, the electric field (EF) sustains a strong shielding entering the body, creating much smaller induced currents in the direction of the field. The interaction of the EF with the human body depends on its dielectric properties (electric conductivity σ and dielectric constant ε), which generally decrease as the frequency increases [6].

For low frequencies, external EFs of the order of kV/m create internal fields of the order of mV/m [7]. The central nervous system (CNS – sensory organs) and/or the peripheral nervous system (PNS – nerves and muscles) can be possibly affected. When the current density (mA/m^2) inside the human body is of the order of 10–100, CNS electrostimulation (phosphines, vertigo, nausea) with potential PNS electrostimulation may occur; that last one is particularly evident between 100 and 1000 [7]. At higher current density values, a serious malfunction of the heart occurs. The safety thresholds are set in order to prevent CNS and PNS stimulation.

As the frequency increases, the electrostimulation gradually gives way to the deposition of the EMF energy, as kinetic energy of the water dipoles, increasing the tissue temperature. Thus, the corresponding safety threshold involves thermal protection, set to 1 °C body temperature increase and reached when the whole-body energy absorption rate (SAR: Specific Absorption Rate), is 4 W/kg. Different safety factors (margins) are applied for the workers and for the general public [5]. The penetration depth of the EMF and thus the % of the body mass affected can be calculated from the Maxwell equations; in general it decreases as the frequency increases [8].

EMF exposure is not cumulative; if an exposed person leaves the field, there is no way to detect any after effects, except for the case of burns [3].

2.2. Biological effects of EMF

Important reviews have been recently published by the SCHEER (Scientific Committee on Health, Environmental and Emerging Risks – former SCENHIR), and by the ICNIRP (International Commission of Non-Ionizing Radiation Protection). Hundreds of scientific papers have been reviewed, focusing inter alia in: i) hypothesis testing for tumors; ii) effects on the nervous system, reproduction and growth; and also iii) annoying symptoms such as headache, nausea, nervousness, etc. [9,10], through epidemiological studies, *in vivo* animal studies and *in vitro* cell trials.

SCHEER's opinion concludes on the importance of defining specific scientific protocols during any hypothesis investigation. These protocols should have, among others, well defined endpoints and exposure conditions, in order to allow for their repeatability; conflicting studies are very common. In this sense, there are no such effects detected that can mobilize controls and restriction procedures other than the already existing ones specified in the scientific and legislative framework. In the few cases where some authors claim to have detected adverse effects, such as: i) a slight increase of childhood leukemia near power lines; ii) DNA brakes on patients undergoing MRI scans and also concerning *in vitro* studies; iii) EEG changes; iv) slight correlation between cancer and intensive mobile phone use; up to v) childhood obesity or asthma [9], there is no acceptable mechanism which could be attributed and/or sufficient (if any) repeatability of the allegations. At the same time, there are many alternative explanations for the observed phenomena, because the quantum energy of the non-ionizing radiation is many orders of magnitude smaller than that of the ionizing, in which such effects can be attributed. Furthermore, in epidemiological studies it is very difficult to establish control groups, free from prosthetic factors, not to mention the criticism for the proper use of the statistical indicators. Serious concerns have been also expressed for the *in vivo* and in particular for the *in vitro* reported EMF effects, as humans have significantly more advanced thermoregulation than that of the test animals and also significantly more advanced respective cell damage repair mechanisms. Many of the reported cell damages happen anyway in the physical environment (i.e. from natural ionizing radiation) or they can be attributed to numerous causes other than EMF (i.e. chemicals); for example, this may be the case with DNA damage claims after MRI scanning [11].

Finally, the thermal stress itself, produced by high intensity RF fields, leads to a variety of adverse effects and significant generalized physiological alterations on living organisms, and can also selectively affect specific body regions with incomplete heat dissipation, such as the knee, the lens of the eye, the testis, but mainly the implants and the fillings; in extreme cases burns may be caused [10].

2.3. Directive 2013/35/EU on occupational EMF exposure

The Directive 2013/35/EU is the legislative framework for the protection of workers from EMF exposure (0–300 GHz), through a complex system of measurable (Action Levels – ALs) and non-measureable (Exposure Limit Values – ELVs) 'limits'. Direct (tissue electrostimulation and heating) and indirect (e.g. projectile risk, interaction with devices) effects are considered.

The ALs constitute the operational limits of the external field, established in order to simplify the compliance process to the relevant, internal field's ELVs [12]. Specific dosimetric issues are used in order to specify the ALs [5]. In the case of implants, the AL approach is not adequate and an integrated risk assessment must be conducted [3].

The limiting system is further specialized including low, high and limb ALs, contact currents (I_C) and limb currents (I_L).

Apart from each separate frequency comparison of the measured EMF values to the appropriate, frequency dependent AL, an overall comparison of the whole harmonic content of the signal (total exposure ratio) is required, acquiring a much more realistic picture of the actual worker's exposure. This control is performed separately for the low (0–10 MHz) and for the high (100 kHz–300 GHz) frequencies, but not in total, except for the intermediate overlapping region (100 kHz–10 MHz) where both electrostimulation and heating occur. Additionally, the result might also be given as a percentage of the exposure limits; this is rather straight forward for complicated installations, where the rich harmonic content is responsible for increased exposure [13]. An 'evolution' of the exposure ratio concerning the low frequencies, is the WPM (weighted peak method), which apart from the various frequencies, takes also into account the phases [5], leading to more realistic results.

The ALs are maximum instantaneous rms values for the low frequencies, and averaged over 6 min for the high frequencies. Additionally, they should be also spatially averaged over the body of