La Medicina del Lavoro

Original article

Med Lav 2022; 113 (2): e2022016
DOI: 10.23749/mdl.v113i2.12636

Occupational electromagnetic spectrum hazards and the significance of artificial optical radiation: country report for Greece

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Key words: Artificial optical radiation (AOR); laser safety; risk assessment; electromagnetic fields (EMF); occupational health and safety (OHS)

Abstract

Background: *The electromagnetic spectrum spans over an enormous range from 0 up to more than 10^{20} Hz in the deep ionizing region, significant exposures exist in specific occupational environments. Between the ionizing and the electromagnetic fields (EMF) part of the spectrum, the 'optical radiation' (OR) region has specific properties. Comparative and concise evaluation enables action prioritization.* **Methods:** *Following the transposition and implementation periods of the artificial optical radiation (AOR) and EMF European Directives, the Hellenic Ministry of Labour in collaboration with the Greek Atomic Energy Commission (EEAE) and the National Technical University of Athens, conducted thorough occupational exposure investigation in Greece. Using dedicated measuring equipment and procedures, the majority of EMF emitting installations in Greece and also AOR emitting installations including arc welding, lasers and PC monitors has been assessed.* **Results:** *Measurement results from occupational settings reveal that it is the non-coherent metal arc welding AOR that can pose even sub-second overexposures. Rare EMF overexposures are manageable and EMF concern is not justified. Maintenance procedures demand proper attention. Preliminary laser safety assessment reveals OHS gaps and potential eye and skin hazards. Blue light exposure from computer monitors is well below safety limits.* **Conclusions:** *This electromagnetic spectrum risk assessment conducted in Greece enables the justification of the real occupational hazards, in this sense: i) EMF exposure assessment has to be concentrated to maintenance procedures; ii) AOR measuring setups are challenging and standardized measurement procedures are missing, and iii) AOR overexposures from arc welding pose significant eye and skin hazards.*

Introduction

The will to uphold high standards for Occupational Health and Safety (OHS) in the European Union (EU), expressed in its latest form under the Treaty of the EU, found its primary legislative means through the Framework Directive [1]. Individual Directives were then specialized on the various aspects of the occupational environment and thus also on the artificial optical radiation (AOR), that

Received 2.12.2021–Accepted 1.3.2022
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is ultraviolet (UV), infrared (IR) and visible (VIS) radiation, for both laser and non-coherent radiation [2] and electromagnetic fields (EMF, 0 – 300 GHz) [3]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines provide the principal scientific basis for limiting AOR and EMF exposures. Ionizing radiation is treated separately, on a completely different scientific basis, under the 2013/59 EURATOM Directive [4].

Starting from Maxwell's equations and applying the appropriate 'electric' tissue properties (ε, σ, μ), the complete interactions of both the EMF and the AOR with living organisms are revealed [5–7]. The use of the bioheat equation [8, 9] has been considered effective for the RF thermal protection on the basis of specific absorption rate (SAR), considering the advanced heat dissipation mechanisms of the human body [10–12]. Investigation on the interactions of the central (CNS) and the peripheral (PNS) nervous system with the low frequency EMF (ELF) set the protection system on the basis of electrostimulation [5]. The EMF limiting system ensures sufficient protection from the above health effects containing several quantities, that is (measurable, external field) Action Levels (ALs) and (non-measurable, internal field) Exposure Limit Values (ELVs) [3]. The AOR limiting exposure system also contains several ELVs, based directly on established health effects and biological considerations (thermal and photochemical), ranging from erythema, burns and irritations to cataracts, retinal damage and skin cancer [2].

In Greece, the Hellenic Ministry of Labour and Social Affairs is the responsible Authority for both EMF and AOR, but ionizing radiation assessment is under the auspices of the Greek Atomic Energy Commission (EEAE). What really remains a challenge is the practical implementation of the demanding scientific, administrative, and legislative OHS framework. In this sense, the identification of the workplaces that need to be assessed is the initial crucial task, following a complete risk assessment procedure; proper measurements, when needed, are a vital part ensuring that: i) appropriate measuring equipment is used; ii) the measuring methods are in accordance with the relevant standards; and iii) proper processing of results and reporting is performed by qualified experts [9, 13].

In the occupational environment, potentially increased EMF values compared to those of general public exposures reveal [14] that: i) a variety of measurement results is available, suggesting that the measuring procedure is not standardized in all cases; ii) information regarding the position of the workers, the workload, the type of the devices under investigation, and the contribution of the various frequencies present in the workplace is also in many cases missing; iii) results, especially those related to Magnetic Resonance Imaging (MRI), are often derived from calculations, not from measurements, and often these calculations are used to support epidemiological surveys. This last remark indicates that MRI is a highly challenging EMF measuring site in Greece due to: i) the applied Directive derogation and the consequent need for increased health surveillance of the workers [3]; ii) the technical difficulties as the high static magnetic field poses limitations on the measuring equipment [15]; iii) the lack of measurement standardization and theoretical background for RF measurements in near-field conditions inside strong static magnetic field, and iv) the co-existence of four different fields (static, ELF, RF and motion induced low frequencies) [15]. Maintenance procedures also demand attention, as they may present overexposures [9] and their identification is an important risk assessment task.

When the assessment comes to the AOR, additional issues are revealed. The majority of the vast amount of AOR sources in use are 'trivial' [2, 7]; that is they are not considered at all during risk assessment. Those that are really demanding are arc welding, industrial, cosmetic [16], and medical applications. The latter pose the additional problem that the measurements have to be conducted during real time treatment of humans [17]. Moreover, AOR medical applications (i.e. lasers, UV sources, incubators, etc.) lack standardized quality assurance procedures [17].

Despite the work done on the arc welding field [18–21], the overall insufficient AOR references [22] may reflect that: i) it is a relatively 'new' field; ii) the interpretation of the Directive's limits is challenging; iii) technical difficulties (e.g. heat sparks in arc welding) limit the performance of experiments, and iv) risk assessment techniques are needed for exposure/accident scenarios in laser and other applications.

Welding procedures produce a large amount of visible and non-visible radiation in the region of UV [18], VIS [19] and IR. In most cases, the emitted energy is perceived by the user in terms of glary point light source and local heat production. Despite the improvements in OHS in this field, ocular hazards do exist [20] and there is also increased risk of skin cancer for the unprotected body parts of the welders [21] as well as of the nearby workers.

Another issue rises from a specific part of AOR called blue light, covering the frequency range from 400 to 500 nm [2, 7] and employing light sources, medical instruments and display screens. Although blue light limits for adverse health effects are included in the AOR Directive, it has also been hypothesized that long term blue light exposure may play a role in influencing the regular circadian rhythm [23] Research on the circadian and neurophysiological photobiology states that this may be done via the suppression of the melatonin production [24]. This effect originates from the stimulation of special ocular photoreceptors; apart from the well-known types of vision photoreceptors, the three types of 'cones' for colour (short-wavelengths S, medium-wavelengths M, long-wavelengths L) and the 'rods' for contrast, the human eye has additional photoreceptors known as intrinsically-photosensitive retinal ganglion cells (ipRGCs) [25]. The sensitivity of the ipRGCs, called melanopic sensitivity, is based on the photopigment of melanopsin (a light sensitive retinal protein).

The enormous amount of laser applications [7, 26], most of them 'hidden' in closed systems, indicates a need for identification. Open beam installations are by far the most dangerous, but even the closed systems may expose the maintenance personnel to open beams. Additionally, the way a laser system may interact with the eyes and the skin demands the definition of an appropriate exposure/accident scenario. In this sense, risk assessment principles and procedures must be applied. Among the many laser associated hazards, only open beam hazards, affecting the eyes and the skin have been previously considered in laser surveys in Greece [26–28], but every potential hazard can eventually lead to an accident as several related reports state [26, 29, 30]. Moreover, a number of reports highlight the necessity of recording, classification, evaluation and re-evaluation of laser systems [26, 31, 32] but the need for specific laser safety measurements is not highlighted.

Theoretical framework and limitation approach

In order to highlight the disparity between the various regions of the electromagnetic spectrum, the established and quite different effects along with the rather complicated limitation and safety approach for the entire electromagnetic spectrum (ionizing, optical radiation, EMF), concerning single photon interactions, are summarized and provided in Table 1.

In a recent statement [33], ICNIRP presented its principles for protection against adverse health effects from exposure to non-ionizing radiation. These are based upon the principles for protection against ionizing radiation of the International Commission for Radiological Protection (ICRP) in order to come to a comprehensive and consistent system of protection throughout the entire electromagnetic spectrum.

The implementation of this well-established framework is a major task of the relevant Authorities in Greece and it is outlined in the present country report.

To address the above challenges, we propose the complete investigation, through precise measurements and comprehensive risk assessment, over the entire electromagnetic spectrum, that is over static, low (ELF) and high (RF) frequency EMF, artificial optical radiation (AOR: UV, VIS, IR) and in some cases even ionizing radiation (i.e. radon exposure). This approach enables: i) the identification and verification of the real over the alleged health effects; ii) the provision of epidemiological surveys with reliable data and iii) the justification of the real occupational hazards and, thus, the prioritization of the appropriate corrective actions as the inappropriate implementation of the OHS implies high costs [9, 15]. In this country report for Greece, we used information from the literature together with measurements taken at different occupational settings with various equipment, measurement approaches, and calculations for the assessed regions of the electromagnetic

Table 1. Basic interactions, established effects and limitation approach concerning the entire electromagnetic spectrum.

	Basic Interactions & Effects	Units – Basic limitation approach	Limits
Ionizing electromagnetic radiation	**Main single photon interactions with energy absorption**: Photoelectric, Compton, Pair production. Single photons of ≈ 4eV are capable of producing ions **Direct effects**: Free radical production, DNA brakes Deterministic & stochastic effects	**Energy absorption → Dose** (cumulative DNA brakes): **Gy** (dose averaged over a tissue or an organ), **Sv** (equivalent or effective dose), weighting factors: w_T (tissue), w_R (radiation) **Justification**, **optimization** and **(ALARA)** principles	Dose limitation & **dose constraints** **g.p.**: 1 mSv/y **occ**. whole body: 20 mSv/y, eye lens: 20 mSv/y, skin, extremities: 500 mSv /y and also **medical** & **emergency** exposures
Artificial Optical Radiation (AOR)	Eye and skin thermal and photochemical effects: erythema, burns, DNA damage → **cancer** Deterministic & stochastic effects	W/m^2, J/m^2, W/m^2sr Spectral weighting factors: S(λ), B(λ), R(λ) Laser correction factors: C_A, C_B, C_C, C_E **Dose & geometrical factors**	A variety of **occ**. e.g. non-coherent ELVs UVA,B,C, H_{eff}: 30 J/m^2 – laser 1064 nm, 10 ms pulse duration, H_{eye}: 0.506 Jm^2
Electromagnetic Fields (EMF)	Laplace forces on the bipolar water molecules – **Heat** (stress) – burns Electrical interference with cellular membranes **Electrostimulation** (CNS & PNS) Deterministic effects	**ELVs (**internal field**)** e.g.: i) **50 Hz**, g.p.: **0.02 V/m**, occ.: **1.1 V/m**, ii) **1 GHz** g.p.: **0.08 W/kg** whole body **SAR**, occ.: **0.4 W/kg → ALs** (external field values): **E(V/m), B(T)** **On – off effects****	A variety of ALs, e.g. 50 Hz g.p.: 100* μT – occ. low: 500 μT & high: 1000 μT, **1 GHz** g.p.: **36 V/m** – occ.: **61 V/m**

CNS: central nervous system, PNS: peripheral nervous system, SAR: specific absorption rate, ELV: Exposure limit value, AL: Action level, g.p.: general public, occ.: occupational, ALARA: As Low As Reasonable Achievable.
**increased to 200 μT (in ICNIRP 2010 guidelines compared to 100 μT in ICNIRP 1998 guidelines)*
***when someone leaves the field area, there is no way to detect 'remaining' effects, except from burns.*

spectrum, revealing that even if EMF is at the top of public concern in terms of radiation exposures (due to reasons discussed below), AOR is the main issue that needs to be addressed. In this sense, original data, together with new processing of the data from conducted surveys and preliminary results of ongoing projects are presented to describe the situation in Greece. The well established ionizing radiation assessment is not part of this country report.

METHODS

Occupational EMF exposure assessment

Mainly during the transposition period of the EMF Directive into the Hellenic legislation and in order to contribute reliable field data, dedicated workplaces in Greece were selected to be assessed [9, 15] using specific measuring equipment, and standardized measuring, calculating, and reporting procedures, under the collaboration of the Hellenic Ministry of Labour with the Non-Ionizing Radiation Office of the Greek Atomic Energy Commission (EEAE). The main equipment used was the hand-held spectrum analyzer SRM-3006 (Narda Safety Test Solutions) with a 3-axial electric field antenna for the high frequencies (27 MHz - 3 GHz) and the 3-axial portable spectrum meter EFA-300 (Narda Safety Test Solutions) for the low frequencies (5 Hz - 32 kHz) [9]. The selection criteria were to access big EMF emitting installations under, in general, normal working conditions (Table 3). The measurements were conducted, in close collaboration with the Safety Officers of the installations, by competent professionals of the Ministry of Labour and of EEAE. Measurements are still going on, including mainly maintenance procedures (as they are difficult to be spotted and assessed). As an example, telecommunications field workers (pole workers/climbers) may experience instantaneous high exposures, even close to the occupational limits [34]. Nevertheless they are trained to leave the site immediately after they have heard the alarm of the exposure monitor Nardalert XT (Narda Safety Test Solutions, Personal Monitor, 100 kHz – 100 GHz) they carry with them, ensuring that their exposure, averaged over 6 min, is below the limit.

In the same manner, high exposures but below limits were found for physiotherapists that work close to diathermies [35] using a similar personal exposure monitor, the RadMan XT (Narda Safety Test Solutions) measuring in the frequency range 27 MHz - 40 GHz. Appropriate risk management acts ensure that their exposure remains below the limit [35].

A summary of the measurements sites and the overexposures detected is presented in Table 3.

Non-coherent AOR exposure assessment

The collaboration of the Hellenic Ministry of Labour with the National Technical University of Athens concerning the implementation of the AOR Directive [2] enabled the assessment of a laboratory robotic welding system against the various ELVs (J/m^2 - W/m^2), revealing that in some cases the allowed exposure limit will be reached in a few seconds or even in less than one second [22]. The methodology was expanded to investigate the widely used hand-held Shielded Metal Arc Welding (SMAW) technique, using a similar experimental approach (controlled laboratory conditions). In the initially used sensors (190 – 400 nm roughly UVA+B+C, 250 – 400 nm roughly UVA and 400 – 510 nm blue light), an additional infrared (IR) sensor with sensitivity from 695 nm to 1050 nm has been used together with the high sensitivity research radiometer ILT1700 [22]. The whole equipment was placed 2 m away from the welding point to avoid heat sparks and the corresponding calculations were done using inverse square law.

Blue-enriched light assessment

A close relation is revealed (Figure 1) between the emitted light of typical LEDs (colour temperatures 3000 K, 4000 K and 6000 K) and the melanopic and cyanopic spectral sensitivities of the human eye [25]. A significant portion of the LED spectrum (especially of the 4000 K and 6000 K), even if it lies

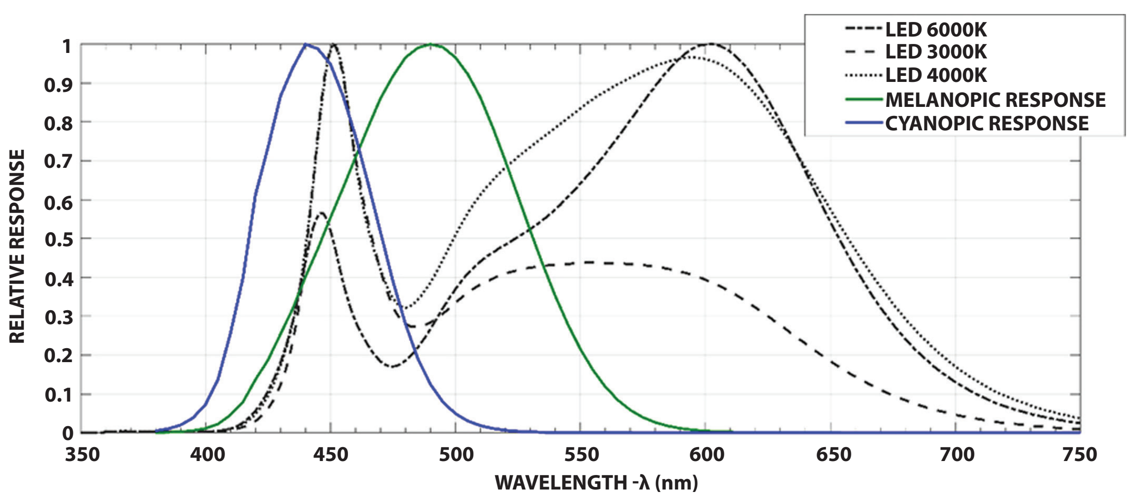

Figure 1. Typical LED emitted spectrums vs the melanopic (attributed to intrinsically-photosensitive retinal ganglion cells: ipRFCs) and cyanopic (attributed to S-cones cells) spectral sensitivity of human eye.

in the hardly visible radiation (far blue ~ 450 nm), it also affects the photoreceptors that are sensitive in this region.

The electronic devices used for work and leisure are equipped with blue light emitting LED technology (as backlight light source for their screens) [36]. In addition, indoor artificial light is more and more dominated by LED driven luminaries with colour temperatures of 4000 K or more. ICNIRP identifies that additional work must be done concerning the viewing conditions of workers [23].

To investigate the blue light produced by computer monitors (that is, to characterize the colour reproduction of each screen), there is an ongoing dedicated project engaging the Hellenic Ministry of Labour and the Lighting Lab of the National Technical University of Athens. In the context of this research, an experimental setup for the characterization of few typical computer monitors has been set. Spectral measurements were carried out at 9 selected measurement points on the visual display terminal, set to maximum brightness, while displaying test images of RGB color patches (various red, green and blue values), without screen light filters. The output data are used as an input in an image processing algorithm, which simulates views of common applications used in office environments, such as Excel, Google Drive, Gmail, etc., while it calculates the total spectral radiance of each simulated image. Various monitors of different screen sizes typically used across Greece are assessed while assuming that the human positioning is the typical working position (typical observer). According to the European Directive [2], and given the fact that most office workers use a PC for more than 10,000 sec (2.7h) per day, the maximum permitted radiance is set to $L_B = 100\ W \cdot m^{-2} \cdot sr^{-1}$.

Laser safety and risk assessment

In order to also consider the coherent part of the AOR Directive, the Hellenic Ministry of Labour collaborates with the National Technical University of Athens assessing various workplaces (cosmetology, research laboratory, industry), for both primary and scattered laser beams, under the development of exposure/accident scenarios [17, 26]. The measuring equipment mainly comprised of hand held digital (Vega OPHIR, probe: 30A-P-SH-V1, range 1mW-30W, pulse and single shot mode) and oscilloscope driven (LeCroy 9361 Dual 300 MHz Oscilloscope) energy meters that enabled the calculation of the radiant exposure H (J/m^2) [17, 26]. The primary beam obvious overexposure for the cosmetology installation set the basis for the quality assurance (QA) procedures. The energy meters were set normal to the primary and the reflected beams [26]. Concerning the research laboratory and industrial installation, reflected beam overexposures were detected, under the development of accident scenarios [17]. Safety gaps have been detected, revealing that unprotected working activities were performed inside the area that limits may be exceeded (namely: Nominal Ocular Hazard Distance). Three open beam medical lasers (CO_2 SHARPLAN, Nd:YAG DORNIER MEDILAS and M3000 Level Simed) used for gynecological, dermatological and otolaryngological cases were further assessed using the F300A-SH-EOS, Ophir (200 mW – 300 W) power meter, concerning both QA and safety procedures in hospital environment. In this sense, in this preliminary approach, characteristic cases of the health care, industry and research sectors were approached.

Regarding risk assessment, the challenging issue of developing realistic exposure/accident scenarios can be further enabled by the application of the OHS tool of risk assessment [13]. This overall quantification process of risk identification, risk analysis and risk evaluation, validates the decision making and actions prioritization for the occupational environment.

Risk is defined as the combination of the severity of harm resulting from the considered hazard and the occurrence probability of that harm [37, 38]. Severity addresses the degree of injury or illness that could occur (such as slight, serious, or death), as well as the harm extent (such as how many workers could be affected). Probability of occurrence is estimated taking into account the frequency, duration and extent of exposure, human errors, training and awareness and the characteristics of the hazard. The occurrence probability of an accident or incident is further divided into three influencing factors: i) the exposure of workers to the hazard, ii) the occurrence of a hazardous event, and iii) the possibility of avoiding or limiting harm (Table 2) [38].

Results

EMF

The occupational EMF exposures, even in big industrial installations didn't reveal substantial overexposures [9]; manageable hot-spots were detected. The measuring procedure, according to the relevant standards, was comprised of a thorough survey of the whole workplace and the recording of the points with the highest field values. A cumulative graph from a thorough investigation (of a characteristic big installation) to a natural gas power plant reveals that the majority of ELF magnetic field measurements (~ 94%) were even below the g.p. limits (Figure 2).

The overall occupational EMF measuring sites are summarized in Table 3 [9, 15, 35].

Table 2. The basic risk assessment scheme.

RISK related to the considered hazard	=	**SEVERITY OF HARM** that can result from the considered hazard: **Degree** (slight, serious, death) **Extent** (how many workers affected)	&	**PROBABILITY OF OCCURRENCE** of that harm: **Exposure**[1] of workers to the hazard **Occurrence**[2] of a hazardous event **Possibility**[3] to avoid or limit the harm

[1] *it may include the: i) need for access to the hazard (e.g. during normal operation, maintenance), ii) nature of the access (e.g. manual feeding of material), iii) time spent in the hazard zone, iv) number of workers requiring access, v) frequency of access*
[2] *it may result from either a technical or human origin, and factors include: i) statistical data, ii) accident/incident history, iii) comparison of risks (either on identical or similar equipment)*
[3] *it may include: i) workers categories exposed to the hazard (e.g. skilled vs unskilled), ii) how quickly the hazardous situation could lead to harm, iii) awareness of risk, if any (e.g. identified in the user manual/information for use, awareness means), iv) human ability to avoid or limit harm (e.g., reflex, escape possibility), v) practical experience and knowledge, if any, of the existing or similar equipment.*

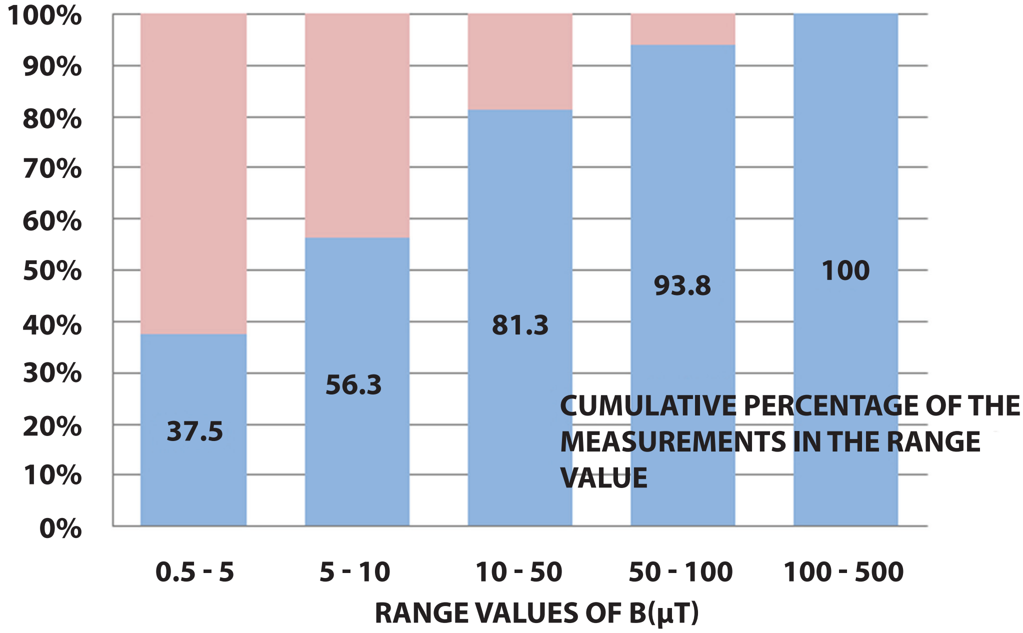

Figure 2. Cumulative percentage distribution of the ELF measurements, arranged to the presented B (μT) range values, in various workplaces of a natural gas power plant. (50 Hz limits: g.p. ICNIRP 1998 = 100 μT, g.p. ICNIRP 2010 = 200 μT, occupational low AL(B) = 1000 μT).

Table 3. Summary of the occupational EMF installations measured [9, 15, 35].

Installation	Field range	Occupational overexposure	g.p. overexposure	Operating conditions	Hazard
NMR	Static	NO	YES	Normal	Pacemaker interference Projectile risk
MRI 1.5T	Static, RF, ELF	NO	YES	Normal	Pacemaker/implants interference Projectile risk
MRI 3T	Static, RF, ELF	YES	YES	Mainly maintenance	Pacemaker/implants interference Projectile risk Electrostimulation
Railway	ELF	NO	NO	Normal	
FM Broadcasting	RF	NO	YES	Normal	
AM Broadcasting	RF	YES	YES	Normal	Burns
RF plasma generator	RF	YES	YES	Maintenance	Burns
Port bridge cranes	ELF	NO	NO	Normal	
MIG welding	ELF	NO	NO	Normal	
Industrial furnace	ELF	NO	YES	Normal	
Industrial motors	ELF	NO	YES	Normal	
Industial Electrolysis	ELF, Static	NO	YES	Normal	Pacemaker interference Projectile risk
Power plants	ELF	YES	YES	Normal	Electrostimulation
Power Substations	ELF	NO	NO	Normal	
Physiotherapy diathermy	RF	NO	YES	Normal	
Common work office	ELF, RF	NO	NO	Normal	

NMR: Nuclear magnetic resonance, Static: 0 Hz, g.p.: general public

Maintenance procedures are the most demanding and many of the above installations that were measured during normal operating conditions, might be completely different during maintenance. In this sense, telecommunications field workers may experience instantaneous high exposures. Nevertheless they are trained to leave the site immediately after they have heard the alarm of the exposure monitor, ensuring that their exposure is below the limit (Figure 3).

AOR

Preliminary results from the handheld SWAM welding technique indicate that the emitted irradiance in the three spectral bands (UV, Blue, and IR) lies in the regions of 100, 500 and 5000 mW/m^2 respectively, when the observer is located at around 2 m away from the welding point (Figure 4).

A rough comparison with the robotic system, at the same distance of observation, indicates that the measured values are an order of magnitude below. These values are high enough to justify skin and eye overexposures, but due to the fact that this widely used hand-held technique employs much smaller exposure distances, the final exposure result is expected to be of the same or even worst order.

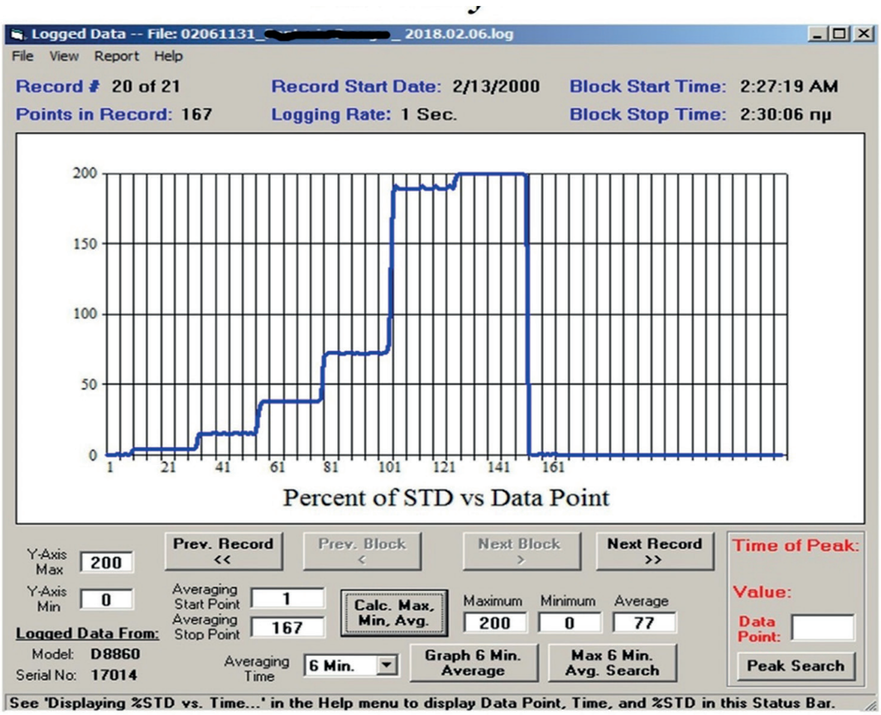

Figure 3. Graph from a personal exposure monitor (Nardalert XT) worn by a pole worker/climber. The maximum instantaneous exposure reached 200% of the limit, but the real exposure (average over 6 min) was only 77% of the limit, as the worker left the area after hearing the alarm.

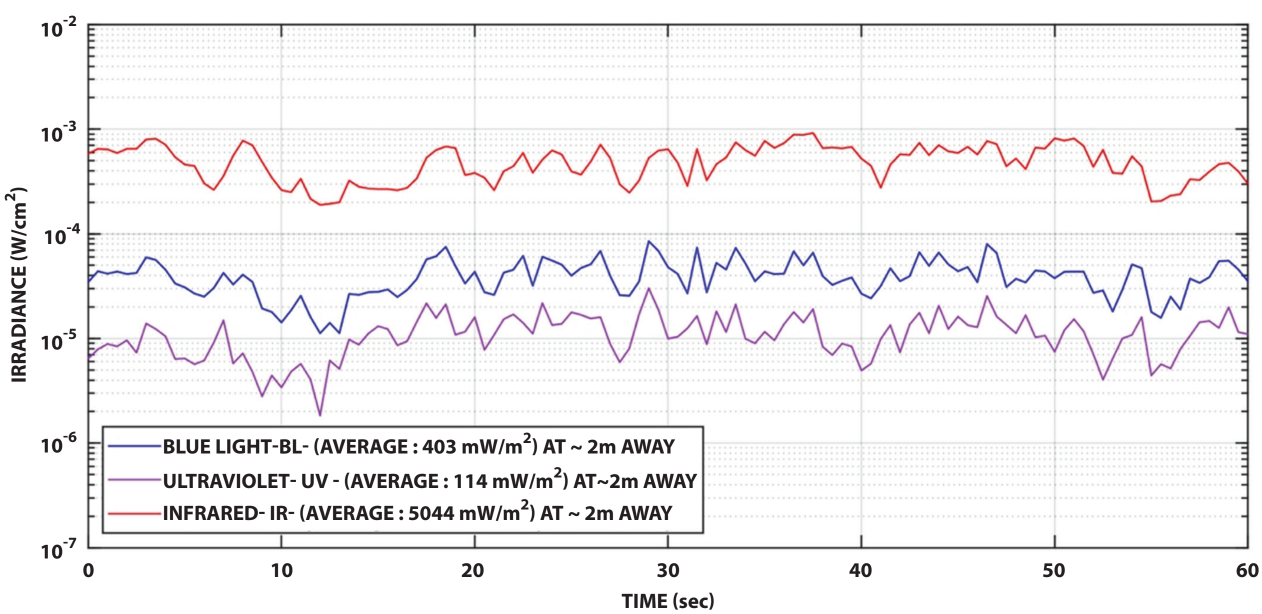

Figure 4. Irradiance measurements of SWAM arc welding technique at three spectral bands (UV, blue light, IR) from around 2 m away from the welding point, using a common welding rod size.

Exposure to blue-enriched light

The first set of experiments was carried out using four monitors having different backlight technology (i.e., fluorescent or LED) and of different year of manufacturing (2 years up to 10 years old). Each monitor was assessed at the full backlight setting (max brightness) and while the software settings were set to normal. The calculation results for the generated radiance of the monitors for five major software applications are presented in Table 4. Therefore, the exposure levels are very low.

Lasers

Results from three medical lasers reveal energy degradation from 40 % up to 70 % from the original nominal energy output. The beam profile was checked to be Gaussian type using thermographic paper. This kind of paper was also used to check the coincidence of the (invisible) laser beam to the (red) pilot beam. Cumulative table from all the examined installations (industrial, cosmetic, research lab and medical) reveals safety gaps (Table 5).

Discussion

The use of the term 'radiation' over the entire electromagnetic spectrum has proven to be deceiving; not only ionizing radiation is completely different from non-ionizing, but the latter has two distinct EMF regions of high (RF) and low (ELF) frequencies and also AOR.

Table 4. Blue light hazard assessment for PC monitors under normal function. Radiance ($Wm^{-2}sr^{-1}$) values. Limit: 100 $Wm^{-2}sr^{-1}$.

	Night tone function	**Office**	**Browser**	**Email**	**Programming**	**Dark mode app**
Monitor 1	OFF	0.222	0.221	0.222	0.036	0.074
Monitor 2	OFF	0.193	0.190	0.192	0.031	0.064
Monitor 3	OFF	0.173	0.174	0.173	0.028	0.058
Monitor 4	OFF	0.199	0.200	0.199	0.032	0.073
	Average	**0.197**	**0.198**	**0.197**	**0.032**	**0.068**

Table 5. Summary of the availability of the basic laser safety procedures in the assessed workplaces. PPE stands for personal protective equipment (i.e. goggles and gloves).

	Workplaces			
Safety procedures	**Cosmetology**	**Research lab**	**Industry**	**Medical**
Risk assessment conducted	NO	NO	NO	NO
Estimated Risk level	High	High	High	High
Appointment of Laser Safety Officer (LSO)	NO	YES	YES	NO
Warning signaling	NO	YES	YES	NO
Protection curtains	NO	NO	YES	NO
Warning lights	NO	NO	YES	NO
Emergency buttons	YES	NO	YES	YES
Interlocks	NO	YES	NO	NO
Availability of eye PPE	YES	YES	YES	YES
Availability of skin PPE	NO	NO	NO	YES
Use of PPE	NO	NO	NO	YES

Like people from many other countries, many Greeks are sceptical and some are afraid of EMF. At the same time, mobile phone (RF emitting) base stations are at the top of the perceived environmental hazards for a large part of society. The exposure perception is the key indicator of the risk perception [39], as most of the interviewed individuals seem to believe that a safe distance from a base station is to be thousands of meters away from them. On the other hand, it is challenging to scientifically prove the absence of an effect, leading to a critical risk communication issue: the chances of creating a strong and undisputable message are asymmetrically distributed between the risk and the no-risk messages; in principle, warning people is more easily substantiated than reassuring people. Unfortunately, this corresponds to a preference of human nature for negative information, as negative information weights stronger in human information processing than positive information [40]. Additionally, previous studies have observed instigation of public concerns regarding adverse health effects from EMF by non-expert external parties [13]. At the same time, individuals with little or, sometimes, no expertise often present their views in mass and social media about EMF issues and perpetuate the popularity of untrustworthy internet references. The controversy on these issues is further fuelled by the reported slight increase of childhood leukaemia as a result of ELF magnetic field exposure in the order of 0.4 μT [8]. There is good evidence [41] that epidemiologic studies do not provide justification for setting exposure limits at levels of 0.4 μT, taking also into account that additional factors, like the socioeconomic status of the people living near high voltage lines, must be considered. The argument over EMF effects has reached a point at which some individuals report a variety of non-specific physical symptoms when an EMF source is present or perceived as present, a condition called "electro-hypersensitivity" or "idiopathic environmental intolerance" attributed to EMF [8]. Not only is it difficult to identify the criteria for this condition [42], but also scientific studies have provided no evidence for its existence through double-blind trials [8]. At the same time, therapeutic aspects of EMF have been reported [43]. Nevertheless, the procedure for assessing EMF is ongoing and ICNIRP has suggested some changes in its new RF guidelines. The main changes in the new guidelines are that the reference values for whole-body exposure are calculated over 30 minutes [12] (instead of 6 minutes) and for frequencies above 6 GHz, the additions of a restriction for whole-body exposure and a restriction for brief (less than 6 minute) exposures to small regions of the body along with a reduction of the maximum exposure permitted over a small region of the body, have been implemented [44].

AOR, being in general non-ionizing radiation, lies to the border of ionizing radiation and in this sense is expected to be more hazardous; cancer is a registered hazard in the UV region. It is important to emphasize the discrimination threshold between ionizing and non-ionizing radiation, practically based on the quantum properties of photons during their interactions with matter. Single photons with energies in the order of 4 eV are capable of producing ions in matter by extracting external or internal electrons from the atomic structure.

Reliable measurements are the crucial part of the proper occupational risk assessment. Completely different measuring approaches were applied for the various regions of the electromagnetic spectrum, while the corrective OHS actions follow the same principles.

Late in 2015, an evaluation of the AOR Directive's practical implementation was reported at EU level, concluding that it appears to attract clearly no consensus over its need and value [22]. Nevertheless, quantification especially of the non-coherent UV part was achieved under controlled lab welding conditions, revealing that AOR measurements, despite initial doubts, are comparable to the complex Directive's limits and can be expanded to the whole optical range for different welding techniques and arrangements, revealing overexposures not only close to the welding point, but also away from it. The first results from the widely used hand-held SWAM arc welding technique further justify the above mentioned concerns and the much smaller exposure distances that the SWAM workers face in comparison to the robotic system further increase them. References support the health issues for welders.

The practical implementation of the AOR Directive was further tested concerning laser (coherent) radiation. The laser installations are many and difficult to be identified. Risk assessment tools enable prioritization. The first measurement results set a basis to approach laser OHS. The cosmetology results revealed enormous primary beam overexposures for both the eyes and the skin, but overexposures were also detected for the scattered beams of the research and industrial installations. In the controlled environment of the research lab, it was possible to measure the scattered beams from various materials and for various reflecting angles (that is an active risk assessment procedure), a procedure that detected overexposures. Safety procedures at the detected installations were totally or partially missing; even when safety measures were present (industry), an accident scenario that revealed overexposure was applicable and the worldwide recorded accidents support it. Further results concerning medical lasers are provided, demonstrating a lack of standardised quality assurance procedures which, additionally to the detected safety issues, reveals a gap that has to be filled. Therefore, the investigation of the related medical procedures is challenging. Preliminary quality assurance actions may include: i) primary beam energy verification, ii) beam profile, iii) laser and visible light coincidence. The first results from the clinical environment further sustain the need for acceptance criteria.

Blue-enriched light and its implication for human circadian rhythm, mandates further research; light, in general, affects working psychology and performance. Measurements from PC monitors are well below the AOR Directive's limits, as they are set in terms of eye safety. Apart from the artificial light for general illumination purposes, an extended research regarding the devices that people are using many hours per day (computers, phones, gaming, etc.) is on. Teleworking is expected to increase exposure. The viewing conditions of the users and the technical specifications of monitors are under investigation.

EMF exposures seem to monopolize public concerns in Greece. Occupational EMF exposures may reach high values, but they are usually well below limits, even resembling g.p. exposure. Maintenance procedures may reveal overexposures, but even in these cases, proper risk management can ensure that the workers are safe. In this sense, working near base stations does not necessarily lead to high occupational exposures, even when the workers are exposed, for a short time, to high field, as they are advised to leave the area immediately. Note that the exposure in our measurements was calculated over a 6 minutes and not over the newly suggested 30 minutes averaging period [44]. In any case, the working procedure of shutting down the radio-systems of the base stations is followed by the operators, ensuring that the usual exposures are well below the limits. In the above sense, measurement results in MRI installations point to specific ELF overexposures behind the bore of a 3 T system, rather significant only for the technical staff during maintenance [13]. RF measurement results, even below limits were substantially higher for the 3 T system compared to the 1.5 T ones [15]. The applied Directives' derogation concerning MRI systems has to be followed by increased health surveillance of the corresponding workers.

Broadcasting exposures are overwhelmingly affected by analogue FM radio [9]. This is also detected at the urban g.p. environment in Greece, as RF measurement results indicate [45–47] : i) very low electric field levels, most of them well below 1 V/m (broadband value); ii) considerable contribution from Radio (FM)/Television sources; and iii) many 'hidden & unknown' to the g. p. EMF sources like meteorological and aviation radar signals.

As far as the forthcoming 5G EMF technology is concerned, it is not expected to drastically increase EMF exposure levels in Greece, being well below the established limits, with TV and FM emissions remaining the predominant sources due to their high power and their wide radiation pattern [45–47]. New antenna systems will be capable (using Multiple Input / Multiple Output and the beamforming technology) to drive the field directly to the 'users', decreasing the emissions reaching 'non- users'. Smart antenna systems and self-organizing networks (SON) are expected to keep radio-emissions as low as possible depending on the traffic conditions. A dense base stations network will further ensure low emission of the terminals (mobile phones). Moreover, new frequency bands will be added in the region of millimetre-waves (mmWave: 24.25 – 29.5 GHz). These bands are under scientific survey, even if their emission range will be short (fast attenuated beams). Detailed 5G measurements will further clarify all issues.

Overall and in order to derive credible results, the standardized EMF exposure assessment should be comprised of: i) the identification of the EMF characteristics (e.g. frequency composition, spatial distribution); ii) the selection of the appropriate measurement protocols; iii) the selection of the measuring devices (e.g. specifications, proper maintenance and calibration, appropriate software); and iv) the proper measurements performance and analysis of the results (e.g. spatial and time averaging, correction/extrapolation factors, evaluation of the measurement uncertainty). AOR measurements have still a long way to reach standardization. Nevertheless, the presented results not only indicate that the practical implementation of the AOR Directive is possible, but also that some aspects of AOR are much more important than EMF, concerning occupational safety; welding and laser procedures may cause serious injuries and long-term effects. In general, EMF exposures in Greece remain typically low and manageable, but AOR exposures may be high and/or unidentified. Finally, apart from conducting specialized measurements and applying the overall OHS framework (employing also the proper actions prioritizing), clarification of what really occurs in the various spectrum regions is an important task for experts in Greece.

Major limitation of the presented survey is the identification and the access to the workplaces that are worth to the assessed. Concerning EMF, many characteristic installations have been assessed but this is not an exhaustive procedure. Additional installations may include welding procedures, electrosurgery and Transcranial Magnetic Stimulation (TMS). When it comes to AOR there is much more to be done, as arc welding measurements have been conducted under controlled laboratory conditions, only a few characteristic laser installations have been assessed and the blue light measuring project from PC monitors is ongoing. Additionally, the introduction of new technologies (like the UVC sterilization systems for SARS-CoV-2) demand alertness.

Future work in Greece is expected for the maximum permissible exposure (MPE) concerning the widely used hand-held SMAW welding technique. Dedicated blue-light measurements will clarify the overall exposure from all kind of sources. Dedicated laser risk assessment tools may improve laser OHS management, as measurements seem to be a quite difficult task. Laser quality assurance procedures will enhance medical treatment quality. The demanded by the EMF Directive enhanced health surveillance in MRI installations is expected to be practically expressed.

Conclusions

Electromagnetic spectrum risk assessment is a demanding ongoing process performed under the auspices of an integrated Occupational Health and Safety approach. Results derived from this country report of Greece indicate that: i) EMF detected overexposures are manageable and efforts have to be concentrated to the maintenance procedures; ii) much more AOR installations have to assessed, taking into account that measuring setups, both for the non-coherent (i.e. arc-welding, blue light emitting screens) and the coherent part (lasers) are challenging and standardized measurement procedures are missing, iii) AOR overexposures from arc welding and potentially from laser misuse pose significant eye and skin hazards and iv) new technologies demand proper vigilance.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: We would like to thank Mrs. Triantafyllia Totou for being so kind to make substantial linguistic improvements and Dr. D. Matalliotakis for his useful suggestions. We would also like to thank the personnel of Attikon hospital and especially Dr. I. Antonako, Dr. E. Spyratou, Prof. P. Platoni and Prof. E. Efstathopoulo for their help to assess and measure the medical lasers.

Declaration of Interest: The authors declare no conflict of interest.

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