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Development of a flowchart system for the risk assessment of occupational exposure to low and high frequency electromagnetic fields

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ABSTRACT

Purpose: The assessment of occupational electromagnetic field (EMF) exposure currently falls under the legislative framework of the Directive 2013/35/EU. However, this framework has difficulties in many practical aspects, which were not dealt by the released practical guides.
Material and Methods: For the vast majority of occupational exposures there is no need for the execution of in situ measurements since they are not expected to be high. Nevertheless, whenever needed, the appropriate measurements remain always the most reliable approach. Expanding the general EMF exposure assessment approach, the standard EN 50499 proposes certain exposure zones (0, 1 and 2); moreover, for the low frequencies an extra exposure zone (3) as well as a number of handy flowcharts have been proposed in the literature, in order to clarify and facilitate the EMF protection scheme.
Results: The need to clarify the occupational EMF exposure management framework as a whole, including: i) the low, intermediate and high frequencies; ii) all the "additions" of the Directive, such as the Weighted Peak Method (WPM); iii) the entire limiting system; iv) the appropriate corrective Occupational Health & Safety (OHS) measures as well as v) the possibility of introducing derogations, led to the introduction of the proposed handy occupational EMF exposure assessment tool, in the form of flowcharts.
Conclusions: Most of the occupational and the general public exposures have been proven to fall into the first exposure zone, i.e. zone 0, while additional measurements are needed when it comes to the "higher" exposures zones.

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KEY WORDS
Directive 2013/35/EU; Electromagnetic fields (EMFs); Occupational EMF exposure; Risk assessment

Introduction

The assessment of occupational exposure to electromagnetic fields (EMFs) is based on the European Directive 2013/35/EU, which has incorporated the current, valid and concise scientific knowledge and guidelines, mainly derived from International Commission on Non-Ionising Radiation Protection (ICNIRP). Thus, a comprehensive but complicated limiting protection system has been built. Additionally, useful relevant information has been provided by the practical guides accompanying the Directive [1]. The aforementioned protection system initially demands *the identification of the workers' exposure* through assessment and/or appropriate measurements (if needed) and is further specifying a variety of practical measures, based on the Occupational Health & Safety (OHS) principles.

Published studies on the occupational EMF exposure [2, 3] have highlighted a number of interesting issues, such as i) that the majority of occupational exposures are essentially the same as those of the general public (g.p.); ii) that there is a need to perform reliable measurements, as "hot-spots" do exist at particular installations; and iii) that there are gaps in the practical implementation of the legislation's requirements, mainly as far as the reliable determination of the workers' EMF exposure is concerned. It must be noted that there is an issue regarding the workers' information requirements–the bigger the installation, the better the workers' information and training.

On this basis, an overall mapping of the necessary actions regarding the assessment of occupational EMF exposures has been depicted in the form of a handy system of flowcharts, using certain *zones* of specific exposures and conditions; this is the so-called EMF zoning approach (see the detailed presentation below). The zoning approach has already been introduced by related standards [4] and is applicable to the armed forces [5]. Though this approach had been proposed in the early stages of the Directive [6], it was not adopted. There is a set of published data of how it can be implemented and expanded in practice [7, 8].

The flowcharts system is also applicable for healthcare professionals. Depending on the treating/imaging procedure, different parts of the flowcharts can be used. Most of healthcare applications emit low frequency EMFs as the results of the use of 50 Hz medical devices, some applications emit high frequency EMF (i.e. physiotherapy), but the most interesting EMF case is, by far, magnetic resonance imaging (MRI), where all the EMF frequencies ranges (static, low and high) co-exist [1, 3].

Material and Methods

The recording of the EMF exposure

Conducting the appropriate EMF *measurements* is, obviously, the most reliable way to record EMF exposures [9]; nevertheless this is not always possible. The cost to acquire and maintain the measuring equipment, the level of skills and competence of the laboratories that will carry out the measurements, but mainly the huge amount of EMF sources (most of which are nevertheless quite common), are some of the reasons that make this task difficult to accomplish. Moreover, the effort to detect EMF effects through *epidemiological surveys* demands the estimation, in a broad scale, of the fields that the workers and/or the general public were exposed to. This task, relying heavily on actions that took place in the past, is characterised by significant *intrinsic uncertainties*, which are further magnified by the non-proper use of the various statistical indicators [10, 11].

An alternative estimation approach concerning occupational exposure is the Job Exposure Matrix (JEM). In this sense, a reliable EMF exposure value (or range of values), based on the recorded experience and/or measurements, is *attributed to various codified occupational activities*, where apart from EMFs, many other hazardous agents, mainly chemicals, are also taken into account [12]. Nevertheless, significant exposure differences have been recorded within a given occupational activity [13] and an expansion of the JEM notion to the Task Exposure Matrix (TEM) has been also pro-

posed, in order to record the exact tasks of the worker. The validation of the JEM by a group of experts, namely the Individual Expert Exposure Assessment (IEEA), is believed to have further developed this approach [12].

Finally, *databases* constitute the most organised effort to assess exposure, as they contain specific measurements per activity and equipment [14, 15]. Although a lot of recorded data are available, significant differences still exist.

In any case, the exposure assessment and the overall management of the OHS issues that are related to the EMFs, demand the collaboration of various experts, with the non-ionising radiation experts being of key importance; note that even the limiting system itself is complicated, as in practice the "external" field limits, the Action Levels (ALs-low, high and limb) are used, while the "real" limits are the Exposure Limit Values (ELVs - based on sensory and health effects). However, the ELVs correspond to the fields inside the human body, which cannot be directly measured. So, compliance with them is ensured through the ALs. The ALs have been derived from the ELVs through theoretical modelling, which also introduces sufficient safety margins [6, 16]. Moreover, when the EMF signals carry a lot of frequency components, the *exposure ratio* for the high frequencies, and the *exposure percentage* and the *Weighted Peak Method* (*WPM*) for the low frequencies are used [3, 16]. Note that the *exposure ratio* is the sum of the measured exposure parameters, at a specified location and for each operating frequency of a source, expressed as the sum of the fractions of the related ALs. The *exposure percentage* is the percentage of the exposure ratio as it comes directly from the measuring equipment. Finally, the *WPM* also takes into account the various phases of the waveforms, assuring much more realistic results [6].

The limiting approach presented above concerns *direct biophysical effects*, i.e. tissue electrostimulation and heating, while there are also ALs for *indirect effects* (projectile risk, interference with implants, sparks, interference with detonators, etc.) [6], which in many cases may be proven *fatal*. In order to protect workers from these indirect effects, technical OHS measures like specialised risk assessment, signaling, prohibition of access, training of the personnel, etc. should be applied [1]; risk assessment is a specialised survey for each specific installation, which not only identifies the hazards and the related risks, but also introduces the appropriate solutions [16].

Zoning system

The European standard EN 50499 introduces the occupational EMF exposure zoning system approach (zones 0, 1 and 2) mainly as an administrative procedure, as it is the employer who shall define the workplace's zone area and the application of any corrective actions, according to the workplace's characteristics. In this sense, a whole building or area that contains equipment, giving rise to local overexposures only, could constitute such a zone. Moreover, the employer has the right to limit the access of certain categories of people (i.e. visitors) to certain zones or respectively to allow it only when the appropriate information about EMFs has been given (exposure levels, protection measures, etc.) [4].

More specifically, the exposure levels of zone 0 correspond either to g.p. exposure, or to the cases where the available workplace equipment is common (i.e. screens, P/C, Wi-Fi, etc.). In zone 1, the g.p. exposure limits may be exceeded, but not the occupational ones. Finally in zone 2, the occupational limits may be exceeded, meaning that if this zone is accessible, corrective actions to reduce exposure or access limitation should be taken [4].

As an extension of the above approach, an additional zone 3 for the low frequencies is introduced, taking also into consideration the exposure percentage and the frequency analysis of the magnetic field components [7]. In zone 3 the high ALs may be exceeded, demanding clear boundaries determination and access permission only to specialised personnel, for a specific duration in time according to the maintenance needs of the installed equipment. Maintenance procedures have been identified to be of core importance during the occupational EMF exposure assessment [2, 3].

Even if the zoning approach is a valuable tool of controlling the occupational exposure, already used in military installations worldwide [5], in Greece there is currently no related legislation. Consequently, the need to clarify the *overall occupational EMF exposure protection framework*, both for the high and the low frequencies, including the WPM, the complete limiting system (low, high, limb ALs and ELVs) and the availa-

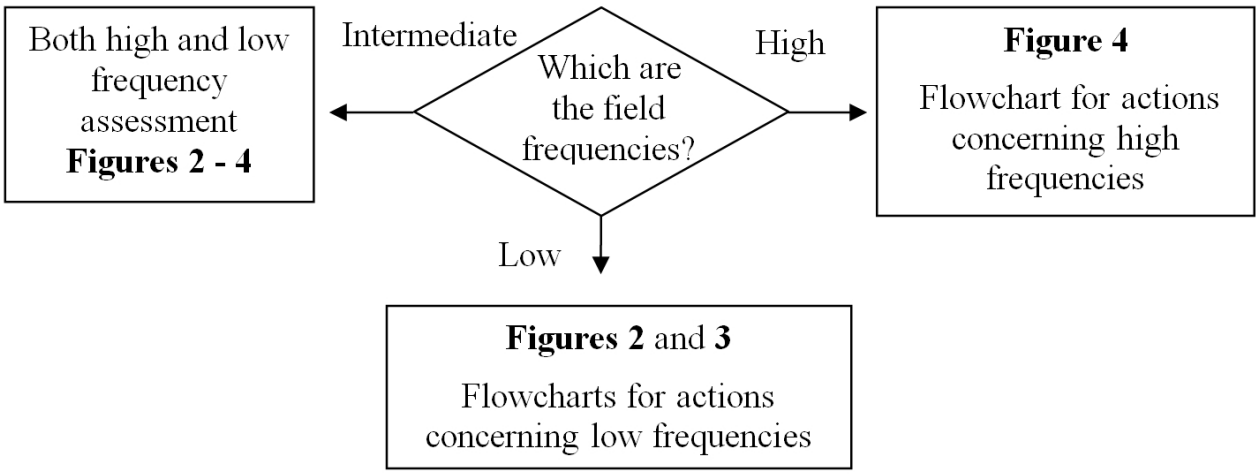

Fig. 1. *Flowchart for the initial assessment according to the existing EMF frequencies. The low frequencies range from 0-100 kHz, the high frequencies range from 10 MHz-300 GHz and the intermediate frequencies range from 100 kHz-10 MHz.*

bility to introduce corrective actions and derogations concerning the direct biophysical effects (indirect effects have to be treated through the risk assessment), led to the creation of the proposed system of flowcharts.

Results

On the basis of the (compulsory) occupational EMF *risk assessment* process [1], the workers are divided into three categories: i) those not at particular risk; ii) those at particular risk, i.e. pregnant workers; and iii) those carrying active implants (i.e. medical devices). The proposed flowcharts apply to the first category, i.e. to the workers which are not at particular risk, since for the other two categories, a specialised risk assessment process is needed [1, 6, 17]. Initially, the existing EMF frequencies shall be defined applying frequency analysis. The *low frequencies* extend from 0-100 kHz, the *high frequencies* extend from 10 MHz-300 GHz and the *intermediate frequencies* range from 100 kHz-10 MHz. Based on this classification the respective flowchart will be used **(Fig. 1)**. The appropriate actions, concerning direct biophysical effects, are indicated for the low frequencies **(Figs. 2, 3)** and for the high frequencies **(Fig. 4)**, while for the intermediate frequencies both types of actions indicated for the low and the high frequencies should be applied.

The occupational EMF exposure assessment is initially treated as assessment of the g.p. EMF exposure [1], and in this sense, zone 0 corresponds to exposures that do not require any action, even for the g.p. **(Figs. 2, 4)**. The need or not to initiate the occupational EMF exposure assessment is implied by the necessity (or not) to conduct a specialised occupational risk assessment (indirect EMF effects are a vital part of the risk assessment); the practical guides provide useful relevant information concerning various activities for the three abovementioned categories of workers.

Additionally:

- As the ALs are frequency dependent, the flowcharts differentiate the appropriate actions according to the various spectral bands.
- In zone 1, the exposures may exceed the g.p. limits but not the occupational ones.
- In zone 2, the exposures may exceed the low ALs for the low frequencies and the ALs for the high frequencies.
- In zone 3, exposures may exceed ELVs; nevertheless, this has to be proven through the complicated approach of computer modeling.
- In zone 3, corrective actions should be specified on the basis of the OHS principles and of the EMF assessment expertise; the possibility of properly justified derogations is also given by the Directive. In the United Kingdom, a justified derogation has been already reported [18].
- The occupational risk assessment study is a principal OHS tool and also a legal obligation of the

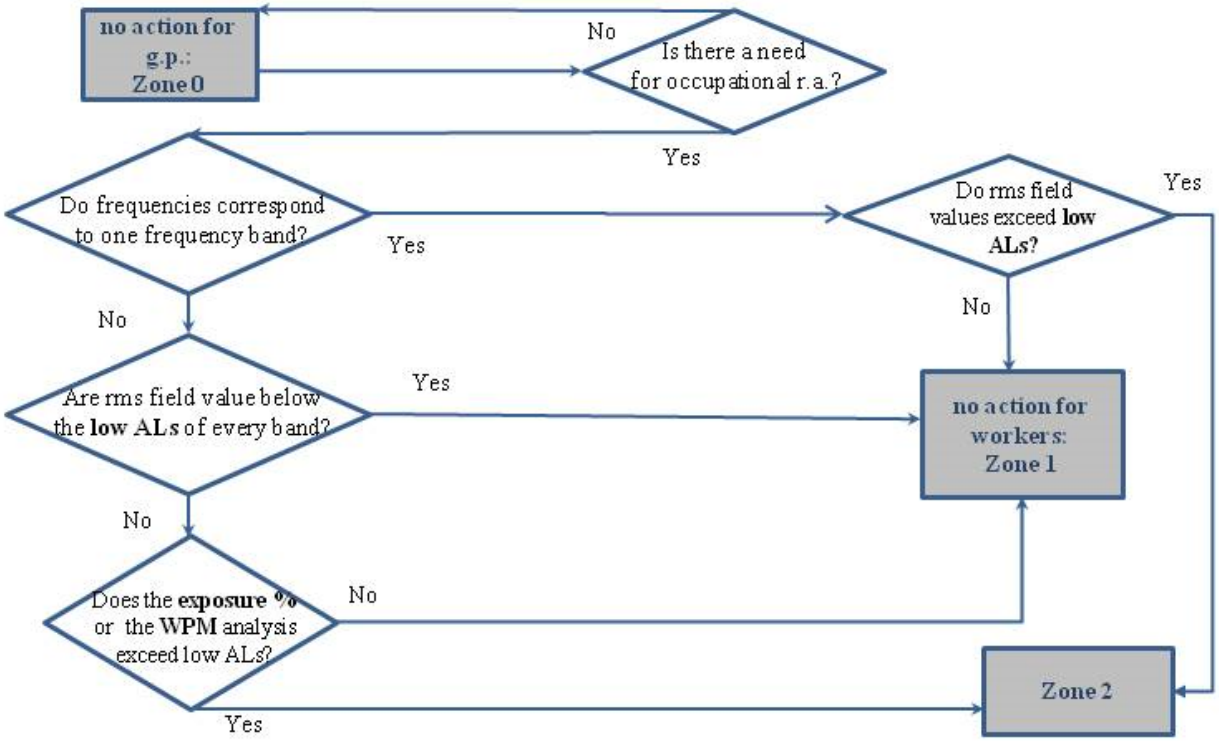

Fig. 2. *Flowchart for low frequency measurements concerning direct biophysical effects (part 1). r.a. is the risk assessment study (indirect EMF effects are treated here), g.p. is the general public, exposure % is the exposure percentage of the exposure ratio as it comes directly from the measuring equipment, AL is the Action Level, WPM is the Weighted Peak Method.*

employer [17], as "the employer shall be in possession of an assessment of the risks to safety and health at work, including those facing groups of workers exposed to particular risks".

Conclusions

Assessing occupational EMF exposure still reveals difficulties. Many scientists estimate (usually past) EMF exposures, mainly for epidemiological studies; nevertheless, the various proposed (non-measuring) approaches suffer from inaccuracies and biases. The scientific approach is straightforward: reliable experiments and measurements need to be performed!

When it comes to measurements, the main lessons learnt from the occupational exposure assessment in Greece [2, 3] that can be related to the proposed flowcharts system, are summarised below:

- Most of the occupational exposures actually correspond to g.p. exposures (zone 0). Unfortunately, the misunderstandings already attributed to the g.p. have been also reported for workplaces; measurements by alleged "experts" have been reported to be carried out not in accordance with the relevant international standards and there are cases where the measured values are being compared to the "*limits of independent organisations*", that are up to three orders of magnitude lower than the legislated limits!
- The exposure assessment on the basis of: a) the low ALs and the exposure percentage for the low frequencies and b) the ALs and the exposure ratio for the high frequencies has proven sufficient to ensure compliance with the whole EMF exposure limiting system.
- In order for the occupational risk assessment study to be properly conducted, the workers are grouped as: i) those not at particular risk; ii) those at particular risk, i.e. pregnant workers; and iii) those carrying active implants. The category of the workers at particular risk (i.e. *pregnant* workers) is derived from the overall OHS protection framework [17], which is also valid for the EMF legislation. However, the current scientific knowledge does not confirm the concerns of the OHS protection framework, and there are suggestions for the pregnant workers to be treated

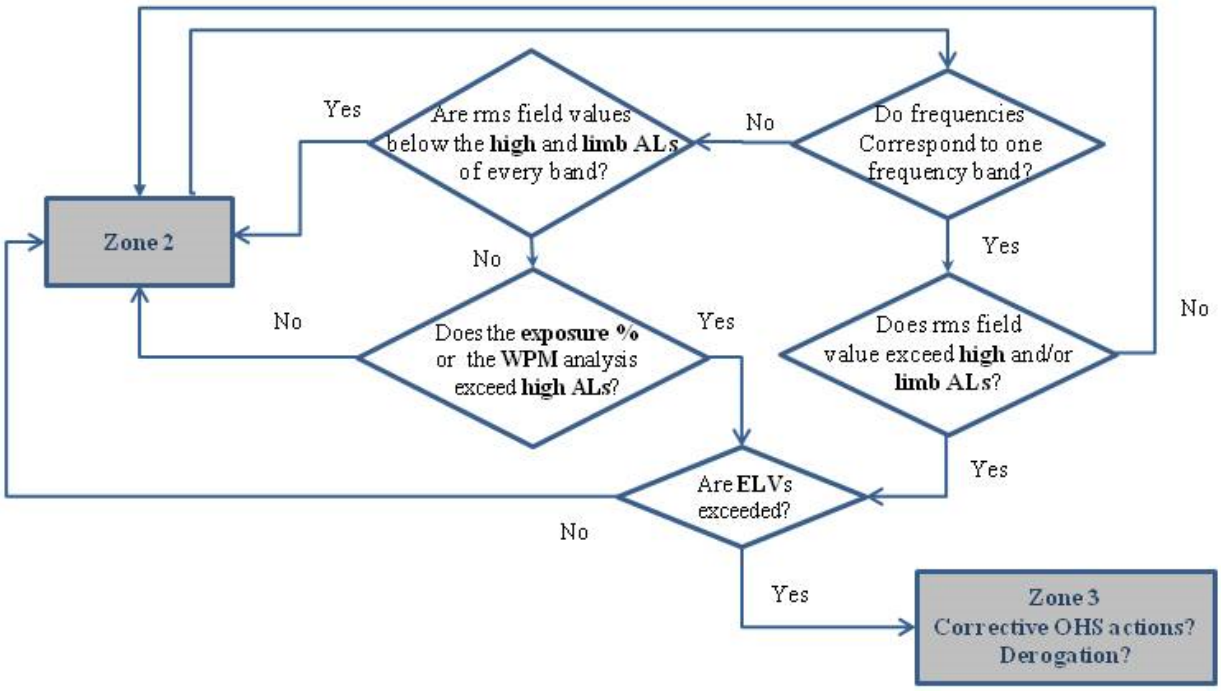

Fig. 3. *Flowchart for low frequency measurements (part 2). ELV is the Exposure Limit Value, OHS stands for Occupational Health and Safety.*

as general public [1]. Besides, the limiting system of ICNIRP yet provides significant safety margins to include people with (potential) health problems/issues [19, 20].

- The *indirect* effects of EMF (projectile, interference with active and passive implants, etc.) have been proven in practice (mainly at the MRI installations) much more dangerous than the direct biophysical ones (tissue heating and electrostimulation).
- Based on the above issues, it becomes obvious that providing information to the workers on EMFs is of vital importance and although in theory, it is a (compulsory) OHS demand, in practice, there is a substantial information gap.
- From the recorded data so far, it appears that there is no need for any further occupational derogation, implied by the Directive; even if the United Kingdom has already reported one [18]. This may be due to the fact that this country has a much more developed heavy industry compared to Greece.
- The need for an *increased health surveillance of the MRI workers*, as a result of the Directive's derogation (derogation from the ELVs and not from the ALs for indirect effects), has not been activated in practice; extremely few MRI risk assessments are available, while the need for relevant research, as it was described by SCENHIR [10], remains.
- A special case of occupational EMF exposure is related to certain *maintenance procedures*, where overexposures have been detected [2, 3]. The identification of those procedures, the exact measurement of the workers' exposure and the description of the appropriate corrective actions are highly important. Actually, these are the procedures that mainly lead to exposures that fall within zone 3.

The EMF protection framework, even if it's reasonable, is complicated and a handy system of flowcharts has been proposed in order to facilitate its implementation. The proposed flowcharts' system concerning the occupational EMF exposure assessment survey in Greece has proven to be a very useful tool and future case studies will further highlight it.

The proposed flowcharts' system is also directly applicable to healthcare professionals, both for low frequency applications (i.e. operating theater medical devices – **Figs. 2, 3**) and high frequency applications (i.e. phys-

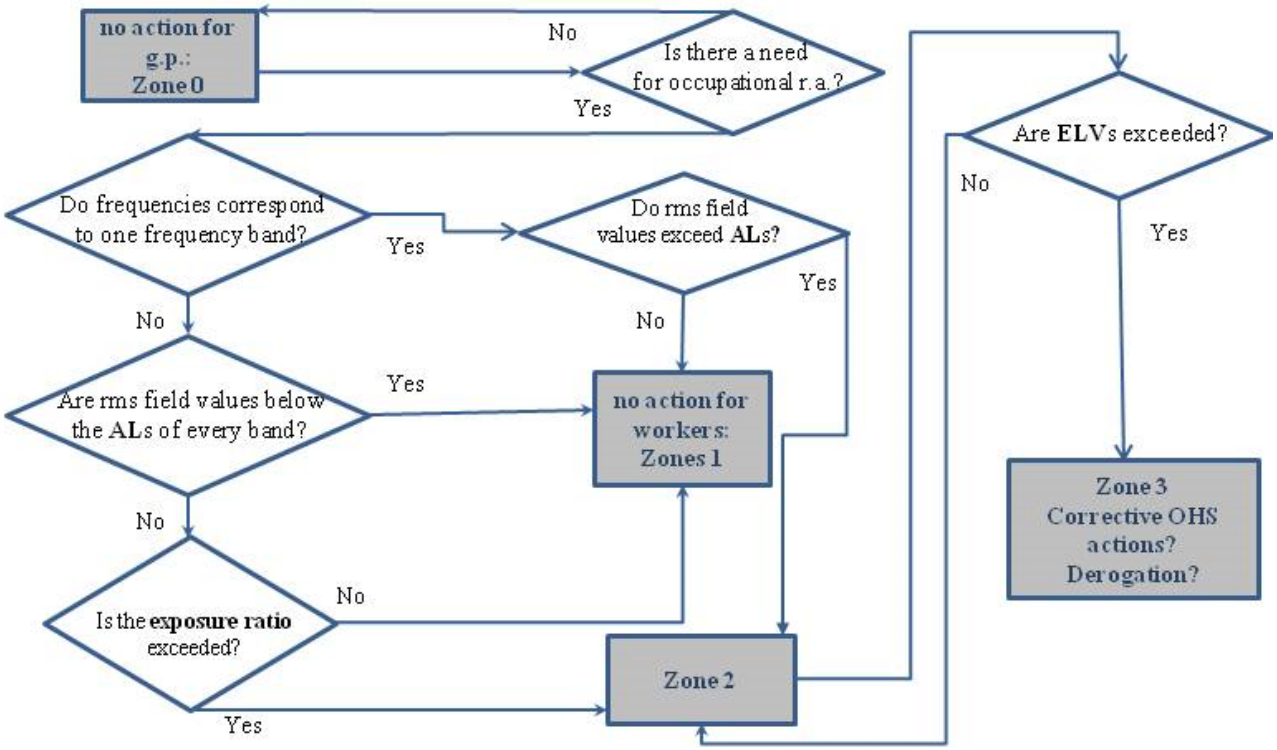

Fig. 4. *Flowchart for high frequency measurements. r.a. is the risk assessment study, g.p. is the general public, ELV is the Exposure Limit Value, OHS stands for Occupational Health and Safety, exposure ratio is the sum of the measured exposure parameters, at a specified location and for each operating frequency of a source, expressed as the sum of the fractions of the related Action Levels.*

iotherapy diathermies – **Fig. 4**). The MRI occupational environment, where increased health surveillance of the workers is demanded by the Directive, is the most challenging case. Future work can make use of the entire flowcharts' system **(Figs. 1-4)**, as all the EMF frequency ranges (static, low and high) are present [16]. **R**

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Conflict of interest

The authors declared no conflicts of interest.

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