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Final technical report on occupational EMF exposure

EMF-NET Main Task MT2 WORKEN

EMF exposure related risk in the working environment

[WP10, WP11, WP12, WP2.7]

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EMF exposure related risks in the working environment

1. Introduction

Main Task-2 (MT2) WORKEN is part of the European 6-th Framework Program co-ordination activity EMF-NET - *Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace*. The MT2 provides policy makers with basic scientific data on regulations or standards on electromagnetic fields (EMF) concerning occupational safety and health (OSH) on the national and European levels. MT2 focuses on analysis of on-going and completed studies conducted in different European countries in the area of measurement methods and computer simulations used for specific EMF exposure assessment for occupational risk evaluation.

The task involved exchange of information and good practices on occupational EMF exposure assessment. The integration of European research centers involved in studies on EMF occupational exposure is strengthening, in order to exchange experience and good practice obtained from national and international, current and completed activities. Studies and analyses performed under this task were focused on obtaining data concerning occupational EMF exposure problems and were disseminated among researchers and used in the reports and guidelines, as well as presented to the community. The aim of reporting activities (WP10) was exchanging information within the international team of researchers involved in the project, as well as compilation and publication of reports and guidelines.

The limits of external measures (environmental electric and magnetic fields) of EMF exposure (reference levels in the terminology of the International Commission on Non-Ionising Radiation Protection ICNIRP or action values established by EC Directive on workers' EMF exposure), are based on established effects related to the internal measures of exposure - induced current density and thermal heating in the exposed human body caused by exposure (ICNIRP's basic restrictions or exposure limits from EC EMF directive) [References Annex A, No 9, 13-15, 31, 34]. Measurement methods for the assessment of workers' exposure to EMF are considered for various exposure scenarios (WP11) and the applicable for assessment of EMF in various frequency ranges (WP11.1, WP11.2 and WP11.3) .

In addition to the measurement protocols, workers' EMF exposure conditions quite often require computational methods for the assessment of the exposure level in terms of internal quantities. The principles of computational methods for the risk assessment are considered in WP12, where an analysis is done of how to apply computer modeling and simulations of induced current density (WP12.1) or energy absorption (WP12.2) in an exposed body. Contact current and induced current leaving the body through legs and feet are considered for measurements, as well as for computational procedures. Practical possibilities of the application of computer simulations for the assessment of workers exposure to EMF in real conditions are analyzed.

The significant value of the MT2 execution originates from the gaps of knowledge in occupational exposure assessment and possible associated risks on the one hand, and on the other hand the EMF EU Directive [A9] on health and safety requirements for occupational exposure to EMF, which was issued during the course of the project realization. Article 12 imposes on the Member States that the provisions of the directive, considered as minimal requirements against occupational risks due to exposure to electromagnetic fields shall thus be mandatory and “operational” by April 2008 in all EC member countries.

The MT2 Working Group (MT2 WG) is working on above-mentioned subjects within Work Packages WP10, WP11, WP12 and WP2.7. The results of the work are related to the following deliverables from the EMF-NET work plan: D46, D47, D49, D50, D52, D53, D55, D56, D58, D59, D61, D62, D64, D66, D67, D69, D71, D72, D74, D76, D77.

2. MT2 Key issues

MT2 activities started with identification and definition of "Key issues" summarizing the general topics of the work. The key issues are focused on advice and guidance concerning the methods for measurement and computer simulations, which could be useful for occupational EMF exposure assessment, as well as for verification of the compliance with the provisions of the EU EMF Directive.

2.1. Exposure assessments (MT2-1)

The following key issues were identified for exposure assessment problems:

MT2-1A. Measurement procedures

MT2-1B. Calculation methods

MT2-1C. Reduction of exposure

Occupational use of various electrical devices expose a large population of workers to EMF - mainly industrial workers and health care staff. Their exposure characteristic is significantly different from that of the general public: workers can be exposed to higher levels than the general public, they are often closer to the sources, and the modulation (frequency composition) of EMF is more complex. Synergistic effects may occur due to simultaneous exposure to various biological, chemical and physical agents existing at workplace. This key issue takes these facts into account. Practical implementation of the EU EMF directive is the significant target of the key issues of MT2-1.

Various aspects of EMF exposure assessment in the workplace were discussed during MT2 Working Group Technical Meetings (WGTM) and scientific events were organised or co-organised by EMF-NET or regular EMF scientific conferences. Working documents have been prepared and specific examples were presented to the community; see for instance reference list in Annex B for publications from the MT2 group.

2.2. Provisions for health surveillance and examination (MT2-2)

Health surveillance of highly exposed workers and examination of workers that have been overexposed is one of significant requirements for the OSH practice, e.g. required by the European EMF directive 2004/40/EC. The practical implementation of these needs detailed advice to the occupational physicians. MT2 WG was working on developing these advices. Various aspects of health surveillance and examination were discussed during MT2 WGTM and scientific events in Prague, 2004 and in Helsinki, 2006. Documents and presentations have been produced. See also Ref.: A 1-3, 8, 10, 36-38.

2.3. Highly exposed workers and workers at particular risk (MT2-3)

Risk assessment of occupational exposure to EMF for highly exposed workers and workers at particular risk (pregnant workers; workers with metallic active or passive medical implants,; young workers and other vulnerable workers) need particular methods. These groups were also indicated in the EMF directive as groups for which occupational risk assessment should be made with special attention. Its practical implementation will need detailed advice for OSH engineers and employers.

Attention will be paid to exposure characteristics of various groups of workers and various categories of realistic exposure scenarios with respect to non-compliance or compliance of exposure level at the workplace:

(1) Highly exposed groups - Some technologies will require detailed investigation, and are the most likely situations of non-compliance with the exposure limitations, (see tab. 1). Internal measures of exposure assessment should be investigated for such workers, usually with the use of computational procedures. An important advice for the OSH practice is to consider only trained workers to participate in occupational activities in highly exposed workplaces. EMF exposure warning signs, labeling of EMF sources and informing the workers about possible EMF hazards should be also introduced. Suitable identification of such exposure situations is crucial for OSH practice. Further lack in OSH knowledge is the duration of time that even well trained workers can/may stay in an overexposed zone where source mitigation is difficult to apply. Although the EMF directive [A 9] states that protective actions should be taken, the details have been not specified yet.

(2) Possible exposed groups - Most technologies are likely to require assessment but include few cases of non-compliance (see tab. 1). In the most cases measurements of EMF exposure pattern is usually sufficient for the risk assessment. The practice of involving only trained workers for making occupational activities, EMF exposure warning signs, labeling of EMF sources and informing the workers about possible EMF hazards could be also considered in such workplace.

(3) Non-exposed groups - Many technologies will unlikely require further assessment with exposure levels being under the exposure guidelines, (see tab. 1). In such workplaces, detailed exposure assessment is usually not needed. The EMF emission assessment, e.g. product testing following requirements of European EN standards harmonized with low voltage (LV) or electromagnetic compatibility (EMC) European Directives, is enough for OSH practice. Usually there is no need for training and special informing workers about EMF hazards, but in some cases warning signs can be important to avoid indirect EMF hazards or risk for particular workers groups (e.g. hazard for cardiac pacemaker wearers from static magnetic fields or explosive hazards from the currents induced in metallic structures by shortwave EMF).

The above mentioned cases (1) and (2) of exposure to EMF can be called "occupational EMF exposure", the case (3) can be called "non-occupational EMF exposure", and it occurs usually in the workplace where the EMF exposure level is of the level typical for general public and open environment exposure.

The overall conclusions regarding the impact of the EMF directive are:

- There will be an on-going requirement to provide authoritative health and risk information to employees.

- The impact on access and working practices in most cases will be minimal, and no more than good practice would be called for - case (3) of exposure.
- The EMF emission testing already carried out for electrical appliances need careful interpretation to be applied for the workers' EMF exposure assessment.
- There will be requirements for further assessments if employees with pacemkers and other implanted medical devices have access to the areas of elevated EMF, like around the induction heaters, welding devices, or magnetic activators in libraries.
- There will be a requirement for access control close to some equipment, which will persist whether or not the EMF Directive is fully implemented (above mentioned cases (1) and (2) of exposure).
- Further standardization work (from CENELEC, ETSI, IEC, etc.) should consider significant differences among the technical and financial requirements for EMF emission testing in laboratory conditions and EMF exposure assessment *in situ* in the real workplace.

The detailed topics related to the EMF exposure level in various workplace were discussed during MT2 WGTM and in scientific events - organised or co-organised by EMF-NET or in regular EMF scientific conferences, see the Ref list in Annex B.

Notes for Table 1:

It is important to notice that various types of workers' activities in the vicinity of particular EMF sources can result in various exposure patterns, e.g.:

- EMF emission from mobile phones' base stations usually complies with the limitation of exposure for general public, but high level occupational exposure can occur when workers make technical activities in close vicinity to the antenna of base station.

- RADAR's beams are usually radiating far from human body locations, but serious non-compliance situations of exposure may exist during manufacturing and in the case of technical dysfunction of the device.

- High voltage power lines and transformer stations do not usually effect high level occupational exposure, because they are switched off before technical operations. However, very high exposure to magnetic field can occur during very specific type of the work, like repairing " live cable" .

- Electrosurgery scalpel and supplying cables produce high level electric field, which can be sufficiently assessed by measurements of the exposure level in the case of medical staff members who are not in direct contact with the EMF source. However, in the case of surgeon keeping the device by hand, internal measures of EMF exposure should usually be considered: induced/contact currents or local thermal effects

- handheld activator used in libraries to re-activate (magnetise) the security strips in the books produce high 50 Hz magnetic field on hand, arm at breast level of the operator, so that measurements/calculations of induced current are needed for compliance testing with basic restrictions.

The above mentioned examples show that there is a significant difference between EMF emission testing (which can be executed for the typical representative of each type of particular EMF sources) and the workers' EMF exposure assessment (which should be executed for any particular worker, taking into account the EMF sources affecting him as well as activities for which he has professional obligations). This important difference should be also presented in the standardised protocols for exposure assessment.

Table 1. EMF exposure at workplace - common applications resulting in EMF emission.

No	EMF source	EMF frequency related to application				Workers' EMF exposure		
		static	**ELF**	**IF**	**RF/MW**	**probably low level** - detailed exposure assessment not needed	**may be high** - external measures testing - environmental measurements use	**probably high level** - internal measures testing - computational assessment may be needed
1.	induction heating		**oo**	**o**			**xx**	**x**
2.	surgical and physiotherapeutic use of diathermy			**oo**	**oo**		**xx**	**x**
3.	dielectric heating (RF: glue drying and plastic welding & MW: heating and vulcanization applications)				**oo**		**xx**	**x**
4.	arc-welding (MIG, MAG, TIG, etc.)	**oo**	**oo**	**o**			**xx**	**xx**
5.	spot welding	**o**	**oo**	**o**			**xx**	**x**
6.	electrochemical installations or other using microwaves (e.g. chemical activation of processes)				**oo**	**NAD**		
7.	electrolytic installations	**o**	**oo**			**xx**	**x**	
8.	industrial microwave ovens				**oo**	**xx**	**x**	
9.	NMR/MRI medical diagnostic equipment	**oo**	**oo**		**oo**		**xx**	**x**
10.	NMR spectrometers	**oo**			**oo**	**x**	**x**	
11.	electric vehicles (trains, trams, metro)	**o**	**o**			**xx**	**x**	
12.	plasma discharge equipment					**NAD**		
13.	plasma polymerisation at RF				**o**	**NAD**		

14.	RADAR and other systems				**o**			**xx**
15.	broadcasting systems and devices (radio & TV: AM, VHF/UHF)		**o**	**o**	**o**	**xx**	**x**	**x**
16.	mobile telephony base stations				**oo**	**xx**	**x**	**x**
17.	military and research radiofrequency systems			**o**	**oo**	**x**	**xx**	**x**
18.	RFID/EAS and others anti-theft equipment	**o**	**o**	**o**	**o**	**xx**	**x**	**x**
19.	wireless local area networks (WLANs)				**oo**	**xx**		
20.	cordless phones				**o**	**xx**		**x**
21.	bluetooth devices and hands-free kits				**oo**	**xx**		**x**
22.	electricity supplying networks and electricity distribution and transmission equipment	**o**	**oo**			**xx**	**x**	
23.	electric handheld tools		**o**			**xx**	**x**	**x**
24.	industrial magnetizers/demagnetizers	**o**	**oo**				**x**	

oo – basic frequency range which is in the most common use for particular applications

o - other frequencies, which can be used for particular applications

xx – the most common situation in the work environment

x – possible situation in the work environment

NAD – no available data

3. Hypersensitivity

Electrical hypersensitivity (EHS) is a topic included in MT1, WP 2.2, deliverable report D5ter, but it is also an issue for MT2 (*workers at particular risk*). Report D5ter (authors Dr M Sandström, member of MT2 and MT1, Dr Z. Sienkiewicz, member of MT1) updated the ongoing and completed studies on the topic and gave a summary of the conclusions of the *WHO workshop on Electrical Hypersensitivity Prague, Czech Republic October 25-27, 2004,* (Prof. K Hansson Mild (member of MT2) was part of the organising committee and rapporteur). The report gave the following summary of the workshop:

- EHS is characterized by a variety of non-specific symptoms that differ from individual to individual. The symptoms are certainly real and can vary widely in their severity. For some individuals the symptoms have a substantial impact on their lifestyle.
- So far no causal relationship has been established between the reported symptoms and EMF therefore the term *Idiopathic Environmental Intolerance* (IEI) with attribution to EMF was proposed by the working group.
- Whatever its cause, EHS can be disabling for the affected individual. Treatment should focus on the symptoms and the clinical picture.
- Because EMF has not been established as a causative factor for the symptoms of EHS individuals, the focus of research should be the characterization of their physiological response.
- As a definition of an EHS individual is still lacking, at present it is not possible to design adequate EHS epidemiological studies.
- If provocation studies are to be considered, they should be properly designed and the protocol should be approved by an ethic committee.
- Although there is no scientific evidence of a causal link between symptoms and EMF exposure, governments should note that the symptoms of EHS patients are real.
- National authorities should not ignore the plight of EHS individuals.
- WHO issues a fact sheet that contains information on the symptoms of EHS individuals, indicating that, at present, these symptoms cannot be attributed to EMF.

Furthermore, the deliverable report summarises the provocation studies performed during 2004-2006. These studies have not been able to find a causal connection between exposure to EMF and symptoms or physiological measurements/cognitive responses.

Finally, the deliverable report points out the lack of an established definition of EHS, the need for a better characterization from a psychological point of view and a need for a bi-annual follow up of the ongoing studies in this area of research.

In summary, it is the lack of established definition of EHS/IEI and established links among EHS/IEI and EMF, but such symptoms can significantly influence on the ability of particular worker for performing professional activities with EMF sources and because of that it should be consider by occupational physicians.

See further Annex B, ref B 24, 25, 84, 108.

4. EMF exposure level estimators for occupational exposure assessment

(D46, D47/WP2.7)

The EMF exposure level estimators for a worker's exposure assessment should be harmonized with scientific knowledge on health effects of EMF exposure and on exposure pattern in the real workplace. Minimum safety requirements for EMF exposure are presented e.g. in ICNIRP's guidelines, international standards like IEC and IEEE or in European EMF directive, with the intention to avoid thermal effects or electric excitation of human body tissues. For radiofrequency fields, it means the use of root mean square (RMS) value of electric or magnetic field as the exposure estimator, which is correlated with the thermal effects. For human body exposure assessment, squared RMS value of field strength should be spatially averaged over the human body and time-averaged over the period harmonized with the dynamic characteristic of the heat rise in the exposed body caused by deposition of the energy of EMF of particular frequency (e.g. 6-minutes for 100 kHz – 10 GHz). In specific exposure conditions, there can be a need to determine the peak value of the field strength, e.g. spatial-peak for spatially heterogeneous exposure for assessment of localized thermal effect, or time-peak for pulse modulated field for assessment of the microwave hearing effect.

For electric excitation, it is necessary to use different exposure estimators. The most important is the time-peak value, which is non-proportional to RMS value in the case of non-sinusoidal fields. Gradients dB/dt or exposure factor calculated from sinusoidal components of various frequencies are also very useful exposure estimators for practical use.

For long-term exposures, the concept of so-called *dose* has been considered by researchers, but till today, no conclusion concerning the formula for dose calculation and detailed protocol for exposure assessment has been found. There are suggestions that the value of dose should be calculated taking into consideration the variability of exposure level and exposure duration (2-dimensional parameter), but no final conclusion concerning the formula for dose calculations with satisfactory correlation with possible dose-related health effects. For example, the risk of leukemia is usually analyzed on the base of its correlation with the dose estimated as EMF level averaged per year and multiplied by exposure duration (in years).

Recently, the possibility of using other estimators of exposure have been discussed (e.g. the application of genomics and proteomics methods). This work is at an early stage, currently without practical implementation.

The results of new research are permanently monitored by the new developed tool - a database for monitoring and evaluation of emerging scientific results concerning occupational EMF exposure. The structure of the database reflects the common structure of scientific articles. It has several data fields, ranging from the article title, authors and publication dates to more specific information on the study, such as frequency ranges, exposure determination methods, EMF sources and professions under study. The database will have internet data-form for article input to the database. Database will also have sophisticated and fast search functions which allow detailed database searches according to the different data fields.

The role of particular exposure estimators is important for epidemiological research and also sufficient interpretation of the provisions of the EMF directive. In carrying out the obligations of employer, the levels of EMF to which workers are exposed shall be assessed and, if necessary, measured and/or calculated. Assessment, measurement and calculation may, until harmonised European standards from CENELEC cover all relevant assessment, measurement and calculation situations, shall be carried out in accordance with the scientifically-based standards and guidelines.

EMF's have to be assessed in all work places. The assessment, measurement and/or calculations shall be planned and carried out by competent services or persons at suitable intervals. In the countries where EMF were not considered for OSH practice before, very few people have this competence and therefore education is needed. The majority of the work places can be assessed by a visual inspection by a person with the appropriate knowledge of EMF and its sources, but in many cases a measurement is needed. The proper identification of the exposure characteristics and the selection of harmonised exposure estimations play the crucial role in the process of exposure assessment.

By performing the assessment, special attention should be also given to any indirect effects, such as interference with medical electronic equipment and devices (including cardiac pacemakers and other implanted devices). The exposure estimators for the human body exposure assessment and indirect effects prediction can be different.

Ref [A 5,-7, 13-16, 18-21].

5. EMF occupational exposure assessment

EMF's exposure assessment adequate to the real exposure level is the crucial step towards appropriate risk assessment for occupational safety and health (OSH) engineering, epidemiological studies of EMF-exposed groups or environmental monitoring. The highest requirements concerning detailed EMF exposure assessment come from the legislations concerning mandatory control of occupational or environmental EMF exposure, e.g. European Directive on workers EMF exposure limitation 2004/40/EC [A9].

5.1. Measurements in various EMF frequency ranges

(D52, D53/WP11)

The need for occupational EMF exposure assessment usually occur because of epidemiological research, claiming about compensation for health-lost of worker operating EMF source or implementation of national EMF OSH legislation/occupational risk assessment. The most common measurements in real work places are executing because of the requirements of OSH legislation. Currently in Europe the most important discussion is focused on the national rules for workplace’s EMF exposure testing, which will be necessary for the implementation of EMF directive. The new EU directive [A9] on occupational exposure to EMF covers frequencies from static up to 300 GHz. For many years there have been recommendations and guidelines for radiofrequency fields and several nations have also had national limits for workers' exposure. Thus, there is a good experience for measurement of RF fields, but in the EC directive there are also limits put on induced and contact current for frequencies up to 100 MHz and this will need some special consideration. Very few countries have had limits for the low frequency range and therefore there is less practical experience and guidelines developed for these frequencies. In both frequency ranges it is crucial to apply the measurement’s protocol and devices harmonised with the frequency pattern of exposure limitation. Till today it is possible to find various frequency patterns of exposure limitation, e.g. IEEE and ICNIRP approaches to harmonics of power frequency.

To make a measurement to show compliance with the EMF directive's requirements, in the general case there is a need to use several different instruments: a broad band root-mean-square (RMS) field strength meter equipped with probes for both electric and magnetic field (of flat or frequency-shaped response), narrow-band field meter, dB/dt or peak sensitive meter, a frequency meter (because the exposure limits are frequency dependent), spectrum analyser, an instrument for induced current and one for contact current. EMF exposure assessment consist of the two basic stages of investigations, identification of the EMF affecting worker and testing the exposure level of identified fields. The instruments are rather expensive and needs expertise to handle in almost every cases, while measuring as well as interpreting the measurements results. The selection of the measurement devices for particular exposure patters and periodical calibration is also important. It is therefore necessary to discuss the question on who is authorized to take the measurement and make the exposure assessment according to the new directive and officially authorising the compliance with the EC directive's provisions.

Sufficient identification of parameters of the EMF taken into consideration is the one of the most important actions for the process. Any mistake at this step can totally destroy the EMF assessment process and results in many-fold over- or under-estimation of the exposure.

Practical guidelines concerning EMF exposure assessment for selected realistic problems are discussed in the following sections. Currently available standardisation is focused on EMF emission assessment, which is in many cases not relevant to worker's exposure assessment (see section 2.3). This difference of the needs and approaches should be mentioned very detailed within further work from standardisation bodies like CENELEC. For example, The TC26A committee is proposing now to measure EMF 20 cm away from the welding cable, whereas the welders put their cable right on to their bodies. Thus we have to deal with two situations: one according to product standard, and the other is real exposure assessment. The first method gives an idea of the different welding machines and processes but the other will give the real exposure that has to be evaluated according to the limits EU directive.

Physical field characterization - Good practice in EMF exposure assessment (EA) is impossible to perform without the knowledge of the basic physic for field characterization. Overview of the basic physics, the sources, polarisation, calculation, dosimetry, measurements, instruments, procedures and calibrations of the electric and magnetic fields respectively were discuss on the base of professional experience of the MT WG members and well documented publications, as e.g. published by ICNIRP, NIOSH or CENELEC [A 21, 27, 29, 30, 40, 42, B 13, 19, 27, 30, 32, 36, 41, 62]. ICNIRP also gives a short overview of the occupational EA related to the most important diseases of interest (leukaemia, brain cancer or neurodegenerative diseases [A 17, 27]). Such an EA is based on the job titles and job exposure matrices. Anyway such an EA is associated with the incompleteness of the source characterization and a lack of reliability and reproducibility.

Exposure Assessment - Though these publications contain the fundaments of a general EA, every working place and working environment has its specific characteristics that makes that no general EA protocol exists but that it has to be adapted or modified according the rules and the identity of the particular situation.

Therefore and on base of our own experience in the EA of low and high frequency EMF in the living and working environment [B 19] we want to enlighten some important points which should be taken into account in the framework of a good EA practice.

Every EMF EA should start with a well balanced experimental design including the following topics:

- Prospection and inspection of the workplace
- Inventory of the sources and the characteristic of the workplace of concern
- Is the workplace open to general public or not? If yes, compliance testing has also to be focused on exposure limits for general public.
- Development of an optimal work plan covering all the elements needed to perform the most realistic EA for compliance testing
- Selection of most suitable EMF meters/monitors:
  - are the instruments calibrated or at least verified on precision
  - is there a need to measure both, the electric, E, and the magnetic, H, field strength [flux density (B)]
  - how to avoid the shadow effect if the E-field has to be measured
  - is it necessary to record the individual exposure of the worker
  - is there a need for performing frequency analysis
- In situ measurements: stationary and personal EA
  - do we have to take into account field polarisation for complete or partly mitigation
  - do we gain enough inside in the real exposure situation by performing only spot measurement or is there a need to record the worker's individual exposure
  - do we want to classify the magnitude of the exposure by job or by source. In the latest case individual exposure is hardly needed. Anyway we have to test if the waveform is not too complex for performing individual exposure registration.
  - can the individual exposure be related to the stationary exposure by means of a relative exposure index
  - what with the EA of the handheld electrical devices, like welding, should e.g. the 20 cm recommendation CENELEC standard of the TC26A committee blindly be followed/accepted or do we have to modify the protocol in a more realistic way.
- EA by simulation technique:

  Are the following input data available for doing this job:
  - electrical parameters, wiring configuration, properties of the source shielding material
  - technical specification, design and installation or implantation plans of the source(s), workplace architecture
  - worker's positioning statistics: temporal and spatial averages about the position of the working relative to the source

- is the simulation engineering concept a reliable tool to be integrated in the development and architecture of the source and the working place respectively.

- Computational assessment
- Mitigation

  What are possible solutions for reducing the field at worker's level: active mitigation, passive mitigation, distance enlargement between source and subject, EMF protecting cloths or a combination of several or all the possibilities?
- Repeated measurements

  Is temporally variability involved in the production process and do measurement cycles have to be repeated till the data are coherent and reliable?
- Reproducibility of data

  Is the degree of reproducibility strong enough for deriving the best estimator of the real exposure?
- Variability and uncertainty

Variability and uncertainty - In contrast to the technical protocols which are in general well documented for all the frequency ranges, there is a real lack of knowledge about variability and uncertainty in the occupational exposure assessment of EMF. Therefore these topics will be a bit more extended than the others.

The occupational exposure assessment (EA) by measurements or calculation is a multi-step process starting with the experimental design (including the choice of instruments/models and corresponding protocols) and ending with data-analysis and reporting. Each step of the EA may be related in a more or less extend to variability and uncertainty. Variability is a property of nature that is related to the heterogeneity, homogeneity or consistency of the values over time, space and subjects. Uncertainty is generally defined as a lack of knowledge about the true value of the real exposure which might be due to the use of measurement errors or other factors. Since variability and uncertainty may have different implications for conclusions, recommendations and decisions one has to be careful not to interpret both concepts in the same way. With the exception of a few particular cases there is always a distinction between variability and uncertainty. Therefore the two concepts have to be handled separately. Tables 2 and 3 in Annex C summarise the main factors by which variability and uncertainty might be induced in occupational EA. Up till now, the variability and uncertainty were not quantified, but by taking into consideration the mentioned factors throughout the different steps of EA, variability and uncertainty might be reduced to a minimum.

All cases of EMF assessment can include the decision process considering the uncertainty and can need decision concerning the uncertainty analysis model, e.g. so-called "shared uncertainty" model of decision. The highest requirements for the uncertainty analysis come from the mandatory legislations of the "threshold type". In such case, if the EMF assessment is exceeding the EMF threshold (fixed by legislation) this will automatically lead to serious consequences as financial punishments or obligation for switch-off the EMF emitting devices. For such legislative model of EMF assessment protocol, there is a very strong need for detailed analysis of assessment uncertainty and also the arbitrary decision concerning the maximum acceptable uncertainty and decision model (e.g. shared uncertainty). On the contrary – the lowest requirements for the uncertainty analysis come from the "continuous quality improvement type” of legislations, standards or guidelines. In such case, the EMF assessment results should always be analyzed with consideration the possibility for EMF reduction, but the reduction should be stronger and should be initiated faster, when the EMF level is higher. In such model, the level of uncertainty can be accepted even of very high value and not calculated in details. The only important requirements are: it can be guaranteed that EMF identification, selection of the assessment criteria, measurement device and measurement protocol were executed properly.

5.1.1. Static magnetic fields

(D55/WP11.1)

High static magnetic field is associated with superconductive high currents installations, permanent magnets and DC/rectified AC high power supplying cables. There are only a few groups of workers with very high level of exposure, e.g. operating NMR (nuclear magnetic resonance) spectrometers, MRI (magnetic resonance imaging) scanners, scientists and maintenance technicians working with thermonuclear reactors and particle accelerators. Lower level of exposure can be found in the vicinity of all DC/rectified AC high currents cables, e.g. from electrolytic installations or DC engines supplying.

Workers operating the sources of high static magnetic field are usually exposed within the area of static magnetic field of significant spatial heterogeneity. In consequences the level of exposure varying significantly during the work. In the case of superconductive devices, as MRI scanners, static field is permanently switched on, and also non-professional staff as cleaners can be exposed to high fields. Occupational exposure assessment should be harmonised with time- and spatial- distribution of exposure to static magnetic field of particular worker and in the case of the use of rectified currents, consider also time-varying component of exposure.

In the case of very specific occupational situation of medical staff operating MRI scanners, additional attention should take notice on the occupational risk assessment. Further investigations and exposure assessment should cover the safety of patients and requirements for non-error work ability of medical staff and safety requirements preventing hazards from "flying metallic objects" and possible destroying of magnetic memories/cards. See also A 4, 18, 22, B 12, 62, 68, 75, 76.

5.1.2. Low frequency EMF

(D55, D56/WP11.1)

Low Frequency (LF) EMF induce currents in the body which might be hazardous for human health, and the LF EMF’s have to be measured and evaluated for compliance against national exposure limits if they already exist or in the case of their absence, against international. Anyway, according to the European directive 2004/40/EC [A9] every member state of the EC has to implement its own occupational exposure limits before 2012. In this respect the WP11.1 group has taken plenty of dissemination initiatives (participation in meetings, workshops etc. - see Ref in Annex B) in order to inform the safety staffs how to deal with the good practice for compliance measurements in the low frequency range. Since voltage facilities (AC power lines, substations, power stations) and almost all industrial electrical appliance, devices and machines produce fields of frequency roughly between 30 – 1000 Hz and because low frequency broadband meters operates mostly in the frequency range of 30 –

1000 Hz, we define LF EMF as fields of the frequency from the range between 30 and 1000 Hz.

Recommendation for occupational and policy decision makers - In order to come up in the final report with recommendations for decision makers EA tables are developed on which the recommendations of the WP11.1 will be based [B12]. Table 4 in Annex C gives an example of the structure of such tables for ELF EMF’s. Notice that these tables may be extended with other relevant topics and that they can be used for other frequency fields too.

5.1.3. Intermediate frequency EMF

(D58, D59/WP11.2)

The *Intermediate Frequency* (IF) range of EMF spectrum is specified by WHO as the band between the extremely low frequency (ELF) and radio frequency (RF) ranges, from 300 Hz to 10 MHz. Frequency characteristic of the exposure limitation in this frequency range is based on the extrapolation from low and high frequency ranges, because scientific data on health effects and tissue's electrical properties is very limited in the case of IF. Special attention is focused on the frequency range between 100 kHz and 10 MHz, where exposure limitation is based on both induced current density and thermal heating. Therefore measurements protocols for the EA are complicated. Spatial- and time- averaging procedures are not so clear as for the case of low frequency fields or high frequency field.

Many electrical devices produce EMF in the IF range. High exposure can be found for workers operating induction heaters (operating from 1 kHz to low MHz range), welding devices (common sources of ELF EMF but can be also a source of tens/hundreds kHz) and electrosurgical units (usually source of 300 kHz - 1.5 MHz). Usually, impedance of EMF in the workplace is high or low and in consequence, exposure assessment can be executed on the base of testing only one dominating component, e.g. magnetic in the case of induction heaters or electric in the case of electrosurgery.

According to the EMF EU Directive for workers' exposure [A9] assessment use measurements of root mean square (RMS) value of unperturbed electric and magnetic field strength averaged over the workers body position and averaged over time specified in the directive. Sometimes only assessment of internal measures of exposure can resolve the question concerning compliance of exposure conditions with limitations. For the IF range (100 kHz – 10 MHz) if the environmental exposure exceeds the limits, the exposure effects inside the body can be estimated with numerical calculations of current density or specific energy absorption rate.

Guidelines or recommendations for IF EA are still incomplete, e.g. it is a lack of detailed procedures for spatial and time averaging of EMF, which can be useful for *in situ* exposure assessment in real workplace or standardised protocol and equipment for measurement of contact/induced currents in real workplace, without any hazard for workers (it means for phantom measurements). The work on CENELEC standards for exposure assessment has begun (i.e. induction heating). It is still at an early stage because previous standardisation work was focused on the laboratory EMF emission control from electrical devices which is different than exposure assessment in the workplace (see section 2.3). The overall aim of this WP is to carry out the general guidelines for practical measurement protocols for IF with respect to physical parameters of complex EMF exposure characteristic: e.g. multifrequency content, spatial and time distribution of the field level, workers' activity characteristic.

Some countries have already established national regulations concerning exposure limitation for electric and magnetic fields in IF range (for example Poland - for 50 Hz - 1 kHz from 2001 and above 1 kHz from 1989). In consequences, national OSH experience can provide basic data on workers exposure characteristic.

Initial step in developing the practical guidelines for measurements in the IF range has recognized the existing problems, for example medical staff exposed to EMF produced by electrosurgery devices. The assessment can be performed on the results of the series of spot measurements of RMS value of unperturbed electric and magnetic field strength. First step of the assessment procedure can be based on searching for maximum over the worker's body position. If the results are above the limit of exposure then the next step in the assessment should be looking at the exposure averaged over any 6 minutes (see diagram proposed for RF in section 5.1.4). For the case when worker's body is in contact with the electric field sources, the above mentioned level of exposure should be established significantly below environmental limitation for unperturbed field (like action values from EMF directive) because spatial distribution of exposure is heterogeneous and it is a risk of exceeding of local thermal effect. The details should be discuss with the use of the results of numerical calculations and contact/induced currents measurements. The use of commercial broadband RMS electric and magnetic field strength meters should be very carefully considered in the case of highly modulated fields. Laboratory testing indicate, that correction factors for modulated fields can be established for typical wave shapes, but uncertainty of such procedure will significantly rise in comparison with measurements of sinusoidal waves.

In the case of hand operating strong electric field sources or contact of worker's body with their elements, the assessment of induced current resulting from coupling between workers body and element with high electric potential (active electrode or cable of electrosurgery unit) is problematic. The EMF directive's criteria for induced current in limbs are not given for frequency below 10 MHz, however local thermal effect in limbs (local SAR) was limited for frequencies exceeding 100 kHz. The assessment of these quantities may be carried out following the permissible values as specified in directive for contact current or permissible values for induced current in the feet specified in IEEE standard [A20]. Very few instruments measuring current flowing through limbs (clamp-on meter or stand-on meter) are currently available.

The following basic problems with EMF measurements and assessment of workers exposure were specified:

- heterogeneous distribution of EMF cause measurement's error in the result of field averaging over the EMF sensor
- measurements in direct proximity of the powered cables or other elements of EMF sources at high electric potential are connected with strong coupling between the meter's probe and EMF source what can influence on meter's sensitivity and lead to additional measurement error not covered by calibration of the device
- according to general rules, the assessment of workers exposure should base on unperturbed field. In the case of electrosurgical and many others devices, measurement of this field is impossible from technical reasons. Exposure assessment performed during simulated work of EMF sources doesn't take into account results of capacitive coupling and induced or contact current flowing through the workers body

- EMF measurements over the position of trunk not cover the hands' exposure, usually the most exposed part of body
- the use of meters calibrated in harmonic reference field for measurements of pulse modulated field may be a source of additional significant measurement's error.

Participants of MT2 (K. Gryz, J. Karpowicz, M. Hietanen) were also discussing IF problems participating in the work for EMF-NET Deliverable 7: Report on Evaluation of Relevant Results from Projects on the Effects IF Exposure, covered by WP2.3 activities.

See also [A 5, 19-21, 24-25].

5.1.4. Radiofrequency EMF

(D 61, D62/WP 11.3)

Measurement of field strength in air has for many years been made for *Radiofrequency* (RF) EMF. It can as an example is mentioned that Sweden has had law enforceable limits for electric and magnetic fields from 10 MHz to 300 GHz since 1976, or Poland from 1972 for 300 MHz - 300 GHz and from 1977 for 100 kHz - 300 MHz. Therefore, there are already several guidelines and recommendations publish on how to do these measurements. We have in this project been reviewing some of these [A 1, 20]; and this has resulted in a practical guideline on how to make the EMF exposure assessment for the RF range [B 27] and this will serve as a base for the practical guidelines and is published within EMF-NET activities.

It is well known that some devices making use of RF energy can lead to rather high exposure of the operators of the devices (see table in section 2.3). Concerning glue dryers and RF sealers there are several papers dealing with the exposure and how to do the measurements [B 35-37, A 40-42]. Information brochures are also available giving advice on how to work safely with these devices [B 80, 81].

Rooftop workers near base stations might be exposed to RF fields about 900-2000 MHz or near FM broadcasting antennas to RF fields of app. 100 MHz. Examples of possible exposed occupations are painters, sheet-metal workers, chimney-sweepers. In these cases the emission properties are well defined and informative simple instructions are more relevant than measurements (see identified problems in section 6), see fact sheet on Mobile Phone Base stations [B 110].

Before the start of an exposure assessment there are many things to consider in order to get the worst case situation, see further the practical guidance on RF assessment [B27].

Since the demand on making measurement on induced and contact current is new in the EMF directive, special attention has been devoted to this, and the background material and experience on this is limited [A 40-42] and further work on this is needed.

As a first step in developing the practical guideline we have the following diagram. After appropriate preparations and collected knowledge of the process to be measured, a first step can be to make the measurements of the electric and the magnetic field in air (so called unperturbed field) without time or spatial averaging. If the field strength measured at all points are below the action levels (taking into account any correction factors which sometimes have to be considered for modulated or pulsed fields when the used measurement devises were calibrated within reference CW sinusoidal fields), no further measurements of these parameters are needed. Then proceed with measurement of contact and induced current if this is needed for the device under test (frequency dependent).

However, if the field strength in air is higher than the action levels and reduction measures have failed to reduce the values, then there is a need to make measurements that are both time and spatially averaged. Note that we still are discussing the problem of spatial averaging procedure; some say that up to 100 MHz there should be made linear averaging, and then it should be made on the squared quantity, whereas other say it should be squared averaged from 10 MHz and up. The results of various spatial averaging following various protocols can in practical situations differ significantly. So for further implementation of the EC EMF Directive, spatial averaging protocol for the testing the directive compliance should be fixed by authorised standardisation body to avoid misinterpretation of measurements results. If the values still are too high and no reduction measures are possible, the next step is to make an evaluation if the basic restrictions also are exceeded. This can be done by computer simulations, but at the moment it is questionable if this is a practical way to go since the models and the techniques are still being developed and they are not standardised for workers exposure assessment needs.

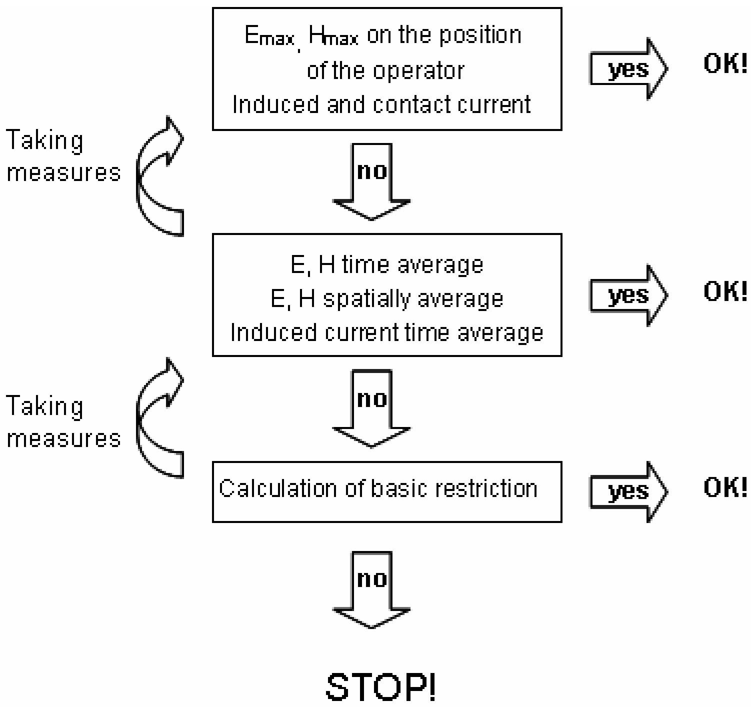

Fig. The EMF workers' exposure assessment against the Directive 2004/40/EC requirements [A9]

5.2. Calculations for workers' EMF exposure assessment

(D64, D66, D67, D69, D71, D72, D74, D76, D77/WP12)

Computational EMF EA has recently been investigated for mobile phones and laboratory studies. For the workers' exposure assessment, there is the different exposure pattern and as a consequence the use of available experience and calculations tools is very limited.

The main areas of the needs for computational EMF EA of workers are verification of thermal/non-thermal exposure level of workers selected for epidemiological studies and testing the compliance with the exposure limitation guidelines, standards or legislation. The European EMF directive [A9] on the protection of workers from exposure to EMF claims the employer to a specific risk assessment, and to verify the respect of limits of exposure that are expressed in terms of computational quantities, that is induced current density *J* (frequencies up to 10 MHz) and *SAR* - Specific Absorption Rate (frequency from 100 kHz to 10 GHz). The use of computational quantities for risk evaluation is achievable only by means of simulation methods based on the use of proper numerical algorithms able to solve Maxwell's equations, in combination with high resolution models of worker’s body, and satisfactory representation of sources and workplace environment. As information technology, numerical methods are increasing and developing very rapidly. Application to more and more complex problems is expectable, like multiple sources and complex environments, but the reliability of results critically depends on the representation of the real problem; any obtainable result refers in fact to the representation scenario, and not to the actual problem, otherwise than *in situ* field measurements. Numerical techniques adopt the following general approach:

- development of a set of differential or integral equations in order to model the electromagnetic problem (Maxwell equations)
- segmentation, that is the realization of a discrete model of the exposed subject and surrounding environment, subdivided into small homogeneous elements (pixels in 2D problems, voxels in 3D problems)
- assignment of dielectric properties (frequency dependent) to each element
- transformation of differential or integral equations into a set of algebraic ones
- resolution by means of standard computational algorithms.

Many of different calculations methods are listed in CENELEC standard EN 50392 [A 7]:

- BEM (boundary element method)
- FDFD (finite difference frequency domain)
- FDTD (finite difference time domain)
- FEM (finite element method)
- FIT (finite integration technique)
- MoM (method of moments).

Many of the available numerical methods are implemented on commercialSW packages mostly developed by research teams, provided with digital human body models and CAD tools able to realistically represent sources and environment. All simulation packages and components are affected by advantages and disadvantages, so that the proper choice in a given situation may not be easy. It must be remarked that the knowledge of dielectric properties of human tissues is still affected by gaps especially at low and intermediate frequencies range, and the available models refer to very simple postures (erected), even if in occupational exposures the actual posture of the workers may be very complex. In this sense, methods have been introduced for scaling and obtain different body postures [A 26, 28, 35], but results obtained with such models need to be carefully validated in a wide number of conditions.

Low-frequency applications of computational exposure assessment take advantage of quasi-static approximation (QSA), where the electric and magnetic field problems are decoupled and can be solved separately. QSA could be applied up to few hundreds of kHz, but applications up to a few tens of MHz have been reported. The available software packages dedicated to low frequencies is to date very limited, and they are employed for specific research purposes. Few commercial software are available on the market, and their performance is not so excellent in particular for complex scenarios and accuracy of algorithms. Some packages are based on *frequency scaling method,* so they solve Maxwell equations at RF range and scale results at lower frequencies with necessary lost of accuracy. Specific standards for calculations have been issued by CENELEC and IEC (i.e. for EAS devices), but extensive application to more complex occupational exposures has not been carried out yet.

In the last years the main effort in the development of computational exposure assessment methods was addressed to high frequency range due to the rapid dissemination of mobile communication systems. Most of the available numerical methods implemented on commercial SW packages concerns high frequency applications, and a lot of scientific work and applications have been developed to address computational exposure evaluation for mobile phones (head), as well base stations and broadcasting (whole body). Specific standards for calculations have been issued by CENELEC and IEC, but extensive application to more complex occupational exposures has not been carried out yet.

In both low and high frequency range the treatment of uncertainty is well far for having being addressed, and the accuracy of results can be very low for comparison with exposure limits, so that inclusion of uncertainties in the comparison with limit values could strongly modify the outcome of risk assessment.

As a matter of fact, occupational exposure assessments based on numerical methods are very complicated and require high level education, to-date available only in research centers or institutes. The possibility of practical use of numerical modeling by the employers for real cases in working environment, especially from small and medium enterprises, seems to be very limited, in contrast to the relatively effective use of such technique for large scale manufacturing in standardized condition, bearing in mind however that occupational exposure patterns are much more complicated than general public ones (e.g. SAR in the head with mobile phones), and standardization bodies should carefully consider it. It should be also considered that the common approach to define emission standards could not be reliable for exposure standard.

Simplified models could be useful for performing rough assessment on occupational EMF sources and workers' exposure levels. Worst-case models could be used as intermediate step between field measurements and refined computational exposure assessment. To such aim, extensive comparisons of standard case-studies should be carried out, analyzing the performance of simplified models compared to more sophisticated ones.

Moreover, manufacturers of commercial SW should be encouraged to optimize their products to the scope of occupational assessments.

The detailed topics related to calculations methods and their practical applications were discussed during MT2 WGTM and scientific events - organised or co-organised by EMF-NET and at regular EMF Conferences. In particular, a special session “Problems and perspectives for computational dosimetry of workers exposed to EMF” has been jointly co-organised by EMF-NET/MT2 in the frame of the international workshop “Electromagnetic fields in the workplace”, Warszawa, Poland, September 5-7, 2005.

5.3. Calculations needs in various EMF frequency ranges

(D65, D70, D75/WP12)

The provisions deriving from Directive 2004/40/CE pose the need to answer to some basic questions, and identify a logical pathway in order to correctly manage the computational problem. The first basic question is to address when numerical calculations must be invoked in EMF occupational risk assessment.

A general need for computational EMF exposure assessment occurs when action values established by EU EMF directive are exceeded and no reduction measure is possible. A condition where reference/action levels are exceeded but basic/exposure limits are probably not, may occur in the case of RF fields strictly confined close to the source, similarly to head exposure from a mobile phone. Numerical calculations represent a useful tools for analyzing near-field conditions, allowing at same time the consideration of inhomogeneous bodies, as much as the influences of parameter (e. g. tissue, geometry) variations in specific exposure situations.

A second case, to be carefully considered, deals with compliance with local basic restrictions. Guidelines of ICINIRP [A 13] clearly states that: "*the reference levels are intended to be spatially averaged values over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded"*. In other words, reference/action levels are able to guarantee compliance with body averaged SAR but don't assure compliance with restrictions on local SAR, which is however crucial when the source is very close to the worker and directly coupled to the body. In the frequency range 10 MHz - 110 MHz, where the electromagnetic energy is mostly absorbed inside legs and limbs, ICNIRP Guidelines [A 13] and Directive 2004/40/CE [A 9] provide a reference/action level for feet current that is helpful in order to verify compliance with local SAR limits in the limbs. On the opposite hand, in the "hot spot" frequency range (400 MHz - 3 GHz) localized peaks of energy absorption may concern internal organs, and in such condition the assessment of local SAR by means of numerical simulations should be recommended even when the exposure levels (as spatially averaged values over the body) approach the reference/action levels.

In any case, as reported in 5.2, for technical and economical reasons, numerical simulations seems to be reasonably applicable only for large scale manufacturing, in order to assess the general aspects of the exposure from a given source. The need of numerical simulations should not be intended as recommendable for single particular cases in real workplace, but as a general tool to get general and qualitative information on exposure from a given sources in standard and traceable condition.

The detailed topics related to needs of computational EMF exposure assessment were discussed during MT2 WGTM and scientific events organised or co-organised by EMF-NET and at regular EMF conferences. In particular, a special session “Problems and perspectives for computational dosimetry of workers exposed to EMF” has been jointly co-organised by EMF-NET/MT2 in the frame of the international workshop “Electromagnetic fields in the workplace”, Warszawa, Poland, September 5-7, 2005.

6. Identified problems and research needs

There is still significant lack of epidemiological and biomedical studies taking into consideration real complex parameters of exposure to EMFs. The "environmental" exposure pattern is so complicated that carrying out an experimental study of all possibilities of simultaneous exposure is impossible. The first step of such a study could be a good quality epidemiological study based on appropriate EMF exposure assessment, taking into consideration all exposure components and presenting new exposure estimators for complex exposure conditions. In addition, no information is available for combined exposure EMF and various chemicals. One example is the recently published the tamoxifen effect: magnetic field exposure inhibits the effect of the medication.

The groups of highly exposed workers as mentioned in section 2.3, should be considered as the basic target for further epidemiological studies on health consequences of EMF exposure. An adequate exposure assessment is critical in all cases of such studies. A poor exposure assessment or its surrogates, like job titles, used in some of previous studies were the most important reason of non-conclusive results of these studies. It is necessary to improve exposure assessment for further epidemiological investigations on EMF.

Health risks of static fields

Biological and health consequences of static magnetic fields are still under question, especially in case of chronic exposure of high level. The recent World Health Organization (WHO) monograph 232 [A41] concluded that there is not sufficient scientific data for establishing health risk of static magnetic field exposure.

This lack of information resulted in that the EU Directive 2004/40/EC provisions do not contain exposure limit value for static magnetic fields., Further investigations concerning health risk assessments for static magnetic field exposure have recently been identified by international bodies as being of high priority for the health risk assessment about static fields. The main areas identified for such research include among others:

- monitoring of occupational exposure, especially above 4 T, suitable to allow epidemiological studies

- epidemiological studies of possible long-term health effects in patients, volunteers, and staff with occupational exposure, particularly those with high levels of cumulative exposure

- epidemiological studies on pregnancy outcome, of high interest for patients as well as pregnant workers.

Exposure assessment procedures

Further studies should be more systematic and coordinated. Appropriate dosimetry is important for all kind of research. There is a need to investigate the importance of physical parameters of exposure such as:

- field intensity
- exposure duration
- field gradient on biological outcome.

It means in practice the need of the use of a specific investigation protocol, which allow the performance of the analysis of exposure level's distribution during the shift.

Reliable epidemiological studies are of primary importance in health risk assessment. The use of adequate estimates of exposure from all relevant sources and to establish real exposure pattern and its variability among various countries is essential for quantitative analysis of research results and exposure's risk. High quality epidemiological studies, not executed until now, should focus on workers involved in high exposure areas and address endpoints such as cancer and pregnancy outcomes in occupational situations.

Experience with other frequencies has shown that obtaining reliable estimates of exposure to EMF for use in epidemiological studies can be very difficult. Investigations concerning low frequency exposure shown that pocket-personal dosimeters would significantly improve exposure assessment for epidemiological studies and risk assessment. Adequate exposure assessment protocol for such method should be focused on:

- magnetic field strength
- magnetic field gradients
- exposure durations
- the rate of change of the magnetic due to motion.

Development of methods and tools for reliable assessment of human body exposure levels taking into account exposure metrics other than average field strength; criteria, improving exposure monitoring strategies both for static magnetic field and time-varying components, for complex and inhomogeneous exposure situations and for personal exposure assessment (personal dosimeters) is included in the high priority research needs crucial for investigations on exposure risk for MRI technology. Numerical and experimental validation of the dosimeters is required and should consider technical properties of dosimeter coming from EMF sensor, its calibration, dynamic and frequency respond, spatial respond, sensitivity to human body, motion speed, sampling, etc. For the possibility of the use of monitoring results for various kind of analysis, it is very important to develop standardized exposure assessment protocol.

In the case of very specific occupational situation of medical staff operating MRI scanners, additional attention should take notice of the occupational risk assessment. Further investigations and exposure assessment should include the safety of patients from non-error work ability of medical staff and safety requirements preventing hazards from "flying metallic objects" and possible destroying of magnetic memories/cards.

For the practical EMF exposure assessment (especially at workplace), first of all it should be discussed when it is acceptable to make the EMF exposure assessment by spot measurements with a broad-band RMS meter (i.e. the most convenient and less expensive method). For the other situations, it should be decided the use of more complicated (and more expensive) exposure assessment method: more detailed measurements or computational exposure assessment.

In the most of cases of high level exposure, it is caused by the need for hand operation of the EMF sources. For the exposure assessment of such cases the modeling of realistic posture of exposed body and possible simplifications of it to reduce the complication and costs of exposure assessment process is of high priority. For the wider use of numerical calculations for the assessment of workers EMF exposure, it is of high priority to obtained well verified scientific data concerning the possibility to use simplified numerical models of working places and EMF exposure conditions and the uncertainty of exposure assessment for checking the compliance with the regulations. The practical use of numerical calculations for the EMF exposure assessment is also problematic because it was not defined when various software packages can be use, and non of currently available software is specialized for workers exposure. Additionally, a few commercial human body models are applicable for selected specialized software only. Separate problem is the calculations of induced and contacts currents, which can be also measured. Realistic area covered by spot measurements in the vicinity of hand operated EMF source should be also consider for standardized procedures for measurements for workers exposure assessment.

These are reasons why, the possibility of practical use of numerical modeling by the particular employers, especially from SMEs is very limited in contrast to the relatively effective use of such technique for large series manufacturing (e.g. common use electrical devices, like mobile phones handsets). In this respect, the question arises if more simple models are powerful enough for performing roughly assessment of the occupational EMF sources and workers exposure level, while every day's occupational safety and health practice.

Implementation of the European EMF directive bring also new problems and questions from the "legal" interpretation of EMF exposure assessment. For example how to understand the provisions of the directive for power frequency electric fields. EMF directive now gives 10 kV/m as the highest value for working in a 50 Hz environment. However, the ICNIRP guideline (used as scientific base for the directive provisions) gives a possibility of increasing this with a factor 2 if not in contact with electrical grounds. Working in existing all over Europe many thousands of high voltage switchyard may be problematic with the low 10 kV/m limit. Since the limit for E field is based on avoiding spark discharges and not current density. This example show how detailed interpretation of the directive can be needed for its practical implementation and how significant financial consequences can it has got. Some next examples of "legislative" questions are the following:

- When is the action level exceeded? and How to express the uncertainty in the measurement?
- When is the limit of exposure exceeded? and How to express the uncertainty in computational exposure assessment?
- Lack of exposure limit of exposure to static magnetic field: how to treat with MR scanners worker's exposure? ICNIRP (1998) is referring to ICNIRP (1994)
- Compliance with the EMF directive provisions for welders
- How about worst case situation for time averaging? Can we take peak hold values and do the averaging.
- Averaging of the E field values not clear how to do. Intermediate frequencies: need to do both squared and linear averaging?
- Contact current: grasp or point contact?

- Time averaging for induced current density and the contact current
- Electrical properties and geometrical shape of standardized worker's body phantoms for numerical calculations
- How to determine the worst case of exposure of particular worker
- Time averaging for SAR
- Exposure assessment for complex frequency composition of exposure
- The assessment of the localized exposure of hands
- How to use a series of spot measurement for the averaging of the non-uniform field
- Assessment of the electric field - unperturbed field or in the vicinity of the workers body
- Induced and contact currents measurements protocol - with the phantom use or with the real body
- Professional requirements for people involved in risk assessment.

For some of above mentioned questions it is a need for arbitrary administrative decision but for others further research is necessary, e.g. :

- How to estimate the uncertainty in the measurement?
- How to make exposure assessment for exposure conditions in the vicinity of EMF source of dynamically-changed geometry and EMF emission level, as e.g. welding devices
- If limb current may be exceeded although E field value is below the action level
- The range of the needs for the use of spectrum analyzers.

Interference with medical devices should be monitored and research should be updated. It is a need to make a review of data on EMF and for instance pacemakers and other implantable devices to find answers on:

- the possible interference between the E- and B-field at the different frequency bands and pacemakers, ferromagnetic implants and other electronic implants
- what's the probability that an interference event occurs by exceeding the DC B-field threshold of 0.5 mT? Which is the modal event that occurs?
- are strong static E-fields produced by ESD (electrostatic discharge) able to trigger such interference ?
- what's the interference threshold for ELF B-field, is it 200 μT and what's the probability of an interference event?
- does there exists well defined interference thresholds for IF and RF fields ?

For the cases of overexposure in the workplace, these are also important questions on effectiveness of mitigation in the occupational high exposure technology (and even for occupational and general public in the public transport sector: metro, tram and perhaps trains).

Final report will present among others detailed recommendations on base of these questions and answers, among others for workers, authorities, decision makers, OP's, designers, safety engineers etc.

7. Abbreviations

CENELEC - European Committee for Electrotechnical Standardization

EA - Exposure Assessment

ELF - Extremely Low Frequency

EHS - Electrical Hypersensitivity

EMF - Electromagnetic Fields

EMF Directive - Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC), O.J. nr L-184 of 24 May 2004.

EMF-NET - Effects of the Exposure to Electromagnetic Fields: From Science to Public Health and Safer Workplace - European 6-th Framework Programme Coordination Action

ICNIRP - International Commission on Non-Ionising Radiation Protection

IEC - International Electrotechnical Commission

IEEE - Institute of Electrical and Electronics Engineers

IEI - Idiopathic Environmental Intolerance

IF - Intermediate Frequency

MT2 - EMF-NET Main Task 2 - WORKEN - EMF Exposure Related risk in the Working Environment

OSH - Occupational Safety and Health

RF - Radio Frequency

SAR - Specific Absorption Rate

WGTM - Working Group Technical Meetings

WHO - World Health Organization

WP - EMF-NET Work Package

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ANNEX A

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ANNEX B

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ANNEX C

Table 2: Factors influencing variability and uncertainty in the exposure assessment by measurement

Influencing steps/factors	**Variability**	**Uncertainty about:**
Measurement instrument	- within certain limits	- precision
Measurement protocol	- between protocols	- use of correct protocol
Experimental design		- optimal coverage of all the EA steps for making powerful statistics & conclusions
Man made bias in personal exposure assessment	- might induce variation and unrealistic exposure statistics	- application of the correct protocol by subject under test
Sampling methodology	- in repeated measurements	- best estimator of real exposure
Sampling over time	- temporal variation often occurs	- duration of field registration (what is the optimal sampling time)
Spatial sampling of B-field in home	- exposure often varies from location to location even in the same work place	- the most representative location for defining the real exposure in the place under test
Individual/subjects	- inter-individual variation for EMF-risks may exist	
Data-analysis		- correct frequency or probability distribution - best estimator of real exposure - use of the most powerful statistical test - outliers: are extreme data outliers or data generated by seldom occurring events

Table 3: Factors influencing variability and uncertainty in the exposure assessment by modelling

Influencing steps/factors	**Variability**	**Uncertainty about:**
Source specifications and configurations	- there are a lot of different specifications and configurations which might produce variation	- exact specifications and configurations
Effective voltage and current load of source	- variation within the same type and between different types of sources	
Current direction		- same or opposite direction
Configuration of work place	- in architecture	
Distance between source and exposed subject	- big variations may occur	

Table 4: Structure of EA recommendation tables

ELF EMF: frequency range 25 – 820 Hz
Action Level of the directive 2004/40/EC: - Electric field (E) in V/m: 500/f - Magnetic field (H) in A/m: 20/f - Magnetic flux density (B) in µT: 25/f
Applications summary: Are mostly based on energy distribution systems

Application	**Availability of data from measurement , simulation or numerical calculations**			
	Y/N	If Y which type (M, S, C) and which field E-, B- or E&B	Reference if Yes	Advised Meas. /sim. /calc. protocol if No
Electrode welding				
Resistence welding				
Other welding systems				
Energy distribution systems				
Switchboards (see subtable ELF1)				
In substations				
In offices round transformers				
Resistence welding				
Energy distribution systems				
In transformer cabins				
Magnetic pumps				
Induction heaters (Arc ovens)				
Other hand tool devices than welding equipment				
Deck wires of airplans				
Deck wires of boats				
Magnetic Activators (library)				
Anti-theft systems				
Deck wires of boats				
Other ELF sources				

<table>
<tr><th rowspan="3">Application</th><th colspan="2">Safety diagram/specifications (scatter diagram with interference contours) delivered by constructor (Y/N</th></tr>
<tr><th>IF Yes: conform with regulations? (Y/N)</th><th>If No: is it needed? (Y/No)</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Electrode welding</td><td></td><td></td></tr>
<tr><td>Resistence welding</td><td></td><td></td></tr>
<tr><td>Other welding systems</td><td></td><td></td></tr>
<tr><td>Energy distribution systems</td><td></td><td></td></tr>
<tr><td>Switchboards (see subtable ELF1)</td><td></td><td></td></tr>
<tr><td>In substations</td><td></td><td></td></tr>
<tr><td>In transformer cabines</td><td></td><td></td></tr>
<tr><td>In offices round transformers</td><td></td><td></td></tr>
<tr><td>Resistence welding</td><td></td><td></td></tr>
<tr><td>Energy distribution systems</td><td></td><td></td></tr>
<tr><td>Magnetic pumps</td><td></td><td></td></tr>
<tr><td>Induction heaters (Arc ovens)</td><td></td><td></td></tr>
<tr><td>Other hand tool devices than welding equipment</td><td></td><td></td></tr>
<tr><td>Deck wires of airplans</td><td></td><td></td></tr>
<tr><td>Deck wires of boats</td><td></td><td></td></tr>
<tr><td>Magnetic Activators (library)</td><td></td><td></td></tr>
<tr><td>Anti-theft systems</td><td></td><td></td></tr>
<tr><td>Deck wires of boats</td><td></td><td></td></tr>
<tr><td>Other ELF sources</td><td></td><td></td></tr>
</table>

Application	Risks according to the interpretation of the directive 2004/40/EC and ICNIRP						
	Normal worker	Groups at partical risk					
		Pregnant women	Young workers	Pace-makers	Metallic Prosthe-ses	Defibri-llators	Other imp-lants
Electrode welding							
Resistence welding							
Other welding systems							
Energy distribution systems							
Switchboards (see subtable ELF1)							
In substations							
In transformer cabins							
In offices round transformers							
Resistence welding							
Energy distribution systems							
Magnetic pumps							
Induction heaters (Arc ovens)							
Other hand tool devices than welding equipment							
Deck wires of airplans							
Deck wires of boats							
Magnetic Activators (library)							
Anti-theft systems							
Deck wires of boats							
Other ELF sources							

Application	**Advise for:**		**Comments**
	Occupational safety staff	**Policy makers**	
Electrode welding			
Resistence welding			
Other welding systems			
Energy distribution systems			
Switchboards (see subtable ELF1)			
In substations			
In transformer cabins			
In offices round transformers			
Resistence welding			
Energy distribution systems			
Magnetic pumps			
Induction heaters (Arc ovens)			
Other hand tool devices than welding equipment			
Deck wires of airplans			
Deck wires of boats			
Magnetic Activators (library)			
Anti-theft systems			
Deck wires of boats			
Other ELF sources			

Policy advice in general and/or concerning particular applications