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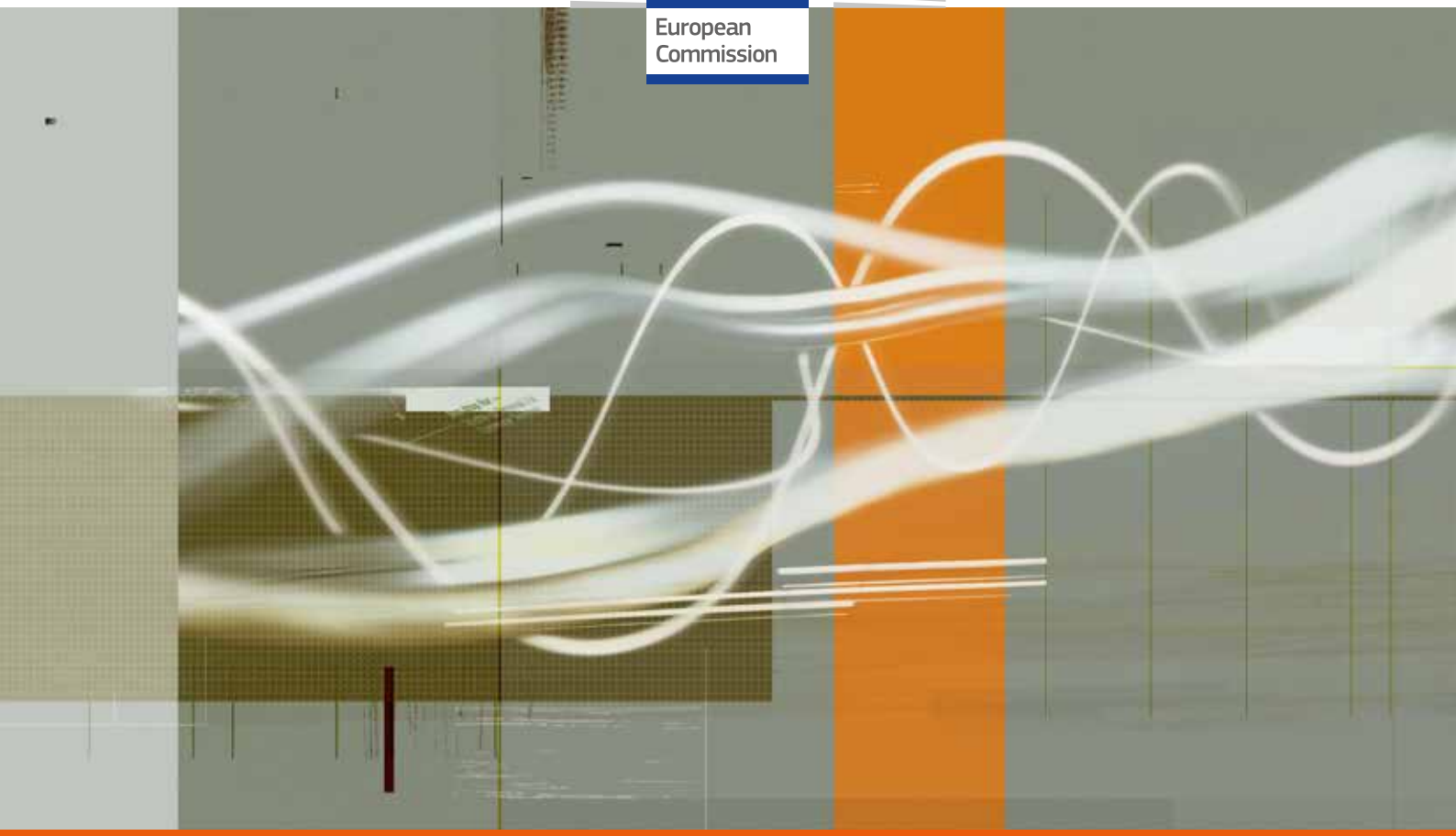

Non-binding guide
to good practice
for implementing
Directive 2013/35/EU

Electromagnetic Fields

Volume 1: Practical Guide

Social Europe

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Electromagnetic Fields

Volume 1: Practical Guide

European Commission
Directorate-General
for Employment, Social Affairs and Inclusion
Unit B3

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EXECUTIVE SUMMARY

A practical guide has been prepared to assist employers, particularly small to medium sized enterprises, to understand what they will need to do to comply with the Electromagnetic Fields (EMF) Directive (2013/35/EU). Within the European Union, the general arrangements for ensuring the health and safety of workers are set out in the Framework Directive (89/391/EEC). The EMF Directive essentially gives additional detail on how to achieve the objectives of the Framework Directive for the specific situation of work with electromagnetic fields.

Many of the activities carried out in modern workplaces give rise to electromagnetic fields, including use of electrical equipment and many common communications devices. Nevertheless, in the majority of workplaces, the levels of exposure are very low and will not give rise to risks to workers. Even where strong fields are generated, these will normally reduce rapidly with distance, so that if workers do not have to approach close to equipment, there will be no risk. Also, as most fields are electrically generated, they will disappear when the power is switched off.

Risks to workers may result from both direct effects of the field on the body, and indirect effects, which result from the presence of objects in the field. The direct effects may be either non-thermal or thermal in nature. Some workers may be at particular risk from electromagnetic fields. These workers include those wearing active implanted medical devices, those wearing passive medical devices, those using body-worn medical devices, and pregnant workers.

To assist employers to carry out an initial assessment of their workplace, the guide presents a table of common work situations. Three columns indicate situations requiring specific assessments for workers with active implants, other workers at particular risk, and all workers. This table should help the majority of employers to establish that there are no risks from EMF in their workplaces.

Even for workers wearing active implanted medical devices it will normally be sufficient to ensure that they follow the sensible instructions provided to them by the medical team responsible for their care. An appendix is provided that will assist employers who need to assess the risk to workers at particular risk.

The final column in the table identifies work situations that are expected to give rise to strong fields and for these it will normally be necessary for employers to follow a more detailed assessment procedure. Often the fields will only present a risk to workers at particular risk, but in a few cases there may be risks from direct or indirect effects of EMF for all workers. In these cases it will be necessary for the employer to consider implementing additional protective or preventive measures.

The practical guide provides advice on carrying out risk assessment that should be consistent with a number of widely used risk assessment procedures including the OiRA tool provided by the European Agency for Safety and Health at Work.

During the assessment of risks it may sometimes be necessary for employers to compare information on the fields present in the workplace with the action levels and exposure limit values specified in the EMF Directive. Where fields in the workplace are low, such comparisons will not normally be necessary and the guide advises employers to instead rely on generic information such as the tables mentioned above.

Where it is necessary to make comparisons with action levels or exposure limit values, employers are encouraged to make use of information available from manufacturers or databases and to avoid carrying out their own assessments where possible. For those employers who do have to carry out their own assessments, the guide provides advice on methods and gives guidance on specific issues such as dealing with non-uniform fields, multifrequency summation and application of the weighted peak approach.

Where employers need to implement additional protective or preventive measures, the guide provides further advice on the options that may be available. It is important to stress that there is no single solution to all EMF risks and employers should consider all available options so that they select those most appropriate for their situation.

It has been recognised for some time that the use of magnetic resonance imaging in healthcare can result in worker exposures that exceed the exposure limit values specified in the EMF Directive. Magnetic resonance imaging is an important medical technology that is essential to the diagnosis and treatment of disease. Hence the EMF Directive grants a conditional derogation from the requirement to comply with the exposure limit values. An appendix to the guide prepared in consultation with relevant stakeholders provides practical guidance to employers on achieving compliance with the conditions of the derogation.

Volume 2 presents twelve case studies that show employers how to approach assessments and illustrate some of the preventive and protective measures that might be selected and implemented. The case studies are presented in the context of generic workplaces, but were compiled from real work situations. Many of the situations assessed in the case studies gave rise to strong fields. In some cases the risk was only to workers at particular risk who could be excluded from the strong field area. In other cases there were potential risks to all workers, but it was not necessary for them to be present in the area whilst the strong field was being generated.

In addition to magnetic resonance imaging (discussed above), two further situations were identified that could routinely give rise to worker exposures in excess of the exposure limit values.

The most widely used of these was resistance welding. This process relies on very high currents and frequently gives rise to magnetic flux densities close to or exceeding the action levels specified in the EMF Directive. For manual welding processes the operator is necessarily close to the source of the field. For situations examined in the case studies and elsewhere, the low action levels were sometimes exceeded temporarily. However, in all cases, either the high action level was not exceeded, or modelling showed that the exposure limit values were not exceeded. Hence in most cases risks can be managed by simple measures such as provision of information and training to workers so that they understand the risks and how to minimise exposures by using the equipment as intended. Nevertheless, it is possible that a minority of manual resistance welding operations may result in exposures in excess of the exposure limit values specified in the EMF Directive. It is likely that representatives of sectors employing these technologies will need to approach the government of each Member State to seek a derogation for the continued use of this equipment on a temporary basis to allow time for re-tooling.

The second situation giving rise to high exposure was the use of transcranial magnetic stimulation in medicine. This procedure is less common than magnetic resonance imaging, but is still an important and widely used technique in both therapy and diagnosis. During therapy the applicator is normally supported above the patient's head in a suitable mount. As the therapist need not be in close proximity during operation of the equipment it should be simple to limit worker exposures. In contrast, diagnostic applications currently employ manual manipulation of the applicator and so inevitably give rise to high worker exposures. The development of suitable remote manipulation equipment would allow worker exposures to be reduced.

In conclusion, the guide has been developed with a modular design to minimise the burden on the majority of employers, who should only have to read the first section. Some employers will need to consider workers at particular risk and these employers will also need to read the second section. Employers with strong fields will need to read as far as the third section, and those with fields that present risks will also need to consider the final section. The emphasis throughout is on simple approaches, both for assessments and for preventive and protective measures.

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SECTION 1 — ALL EMPLOYERS

SECTION 2 — DECIDING WHETHER TO DO MORE

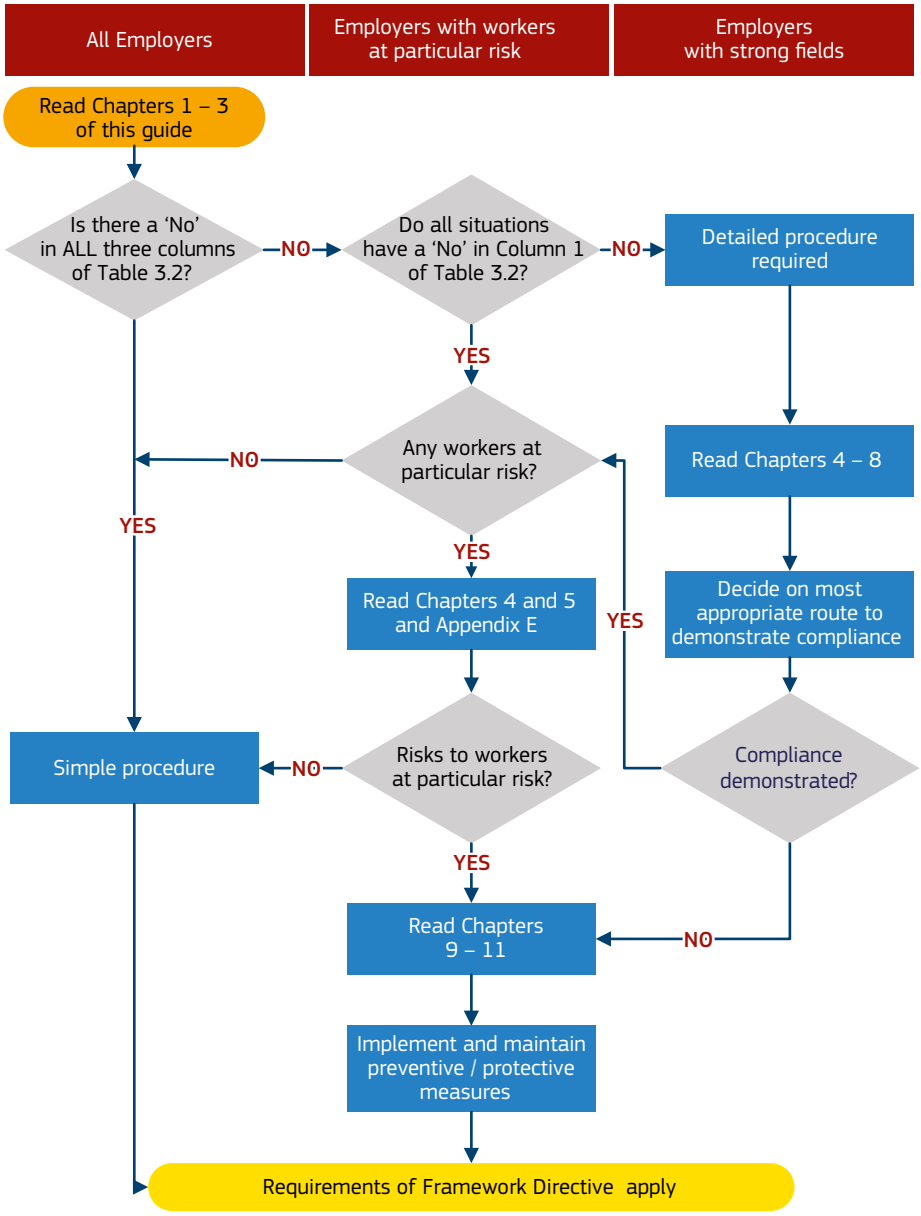
Section 1

ALL EMPLOYERS

1. INTRODUCTION AND PURPOSE OF THIS GUIDE

The presence of electromagnetic fields (EMF) covered by the EMF Directive (Directive 2013/35/EU) is a fact of life in the developed world as they are generated whenever electricity is used. For most workers field strengths are at a level that will not cause any adverse effects. However, in some workplaces field strengths may present a risk and the EMF Directive exists to ensure the safety and health of workers in these situations. One of the main difficulties facing employers is how to recognise whether they need to take further specific action, or not.

Figure 1.1 — Overview of how to use this guide



1.1 How to Use This Guide

This guide is aimed primarily at employers and in particular small and medium-sized enterprises. However, it may also be useful for workers, worker representatives and regulatory authorities in Member States.

It will assist you to carry out an initial assessment of the risks from EMF in your workplace. Based on the outcome of this assessment, it will help you decide whether you need to take any further action as a result of the EMF Directive. If you do, it will provide practical advice on measures you can take.

This guide is designed to help you understand how the work you carry out may be affected by the EMF Directive. It is not legally binding and does not provide an interpretation of specific legal requirements that you may have to comply with. It should therefore be read in conjunction with the EMF Directive (see Appendix L), the Framework Directive (89/391/EEC) and relevant national legislation.

The EMF Directive lays down the minimum safety requirements regarding the exposure of workers to risks arising from electromagnetic fields. However, few employers will need to calculate or measure the levels of EMF in their workplace. In most cases the nature of the work carried out is such that risks will be low and this can be established fairly simply. The structure of this guide is designed so that employers who are already compliant will be able to establish that quickly and without having to read the entire guide.

The process of using this guide is illustrated in the flow chart in Figure 1.1. This guide naturally falls into four sections.

1. The first section (Chapters 1 to 3) is aimed at all readers and provides a general introduction, instructions on how to use this guide, an outline of the main safety and health effects and an explanation of sources of EMF. Importantly, Chapter 3 includes a list of generic equipment, activities and situations where the EMFs are expected to be so weak that employers will not need to take any further action. For most employers, provided they are already complying with the requirements of the Framework Directive, this table should enable them to decide that they have already met their obligations. For these employers this guide will have served its purpose and they need go no further.

2. The second section (Chapters 4 and 5) is aimed at those employers who have not been able to conclude that they have nothing more to do. These employers will need a better understanding of the requirements of the EMF Directive and will need to carry out a specific EMF risk assessment. For some this will be because they employ workers who are at particular risk from EMF. Depending on the outcome of the assessment, these employers may be referred directly to the fourth section. For other employers the EMF may be strong enough to present risks to all workers. These employers will also need to consider the third section.

3. The third section (Chapters 6, 7, and 8) is aimed at employers who need to establish whether action levels (ALs), and in some cases exposure limit values (ELVs), will be exceeded. Often it will be possible to demonstrate that this is not the case and existing work practices are acceptable. However, these employers will still need a more detailed risk assessment and a better estimate of exposures. For many it will be sufficient to read as far as Chapter 7, but some employers may also find it helpful to read Chapter 8.

4. The fourth section (Chapters 9, 10 and 11) is aimed at the small minority of employers who identify exposures above an ELV or other risks that need to be reduced. These employers will need to implement changes to protect workers. These employers should already have read earlier chapters of this guide.

This guide aims to lead you through a logical path for assessing the risk from exposure of workers to electromagnetic fields.

Table 1.1 — Path for the assessment of risks from electromagnetic fields using this guide

If all risks from electromagnetic fields in the workplace are low then no further action is required. Employers will wish to record that they have reviewed their workplace and reached this conclusion.
If risks from electromagnetic fields are not low, or the risk is unknown, employers should follow a process to assess the risk and implement appropriate precautions, if necessary.
Chapter 4 describes the requirements of the EMF Directive, whilst Chapter 5 explains a suggested methodology for assessing risks from EMF. It is possible that the conclusion is that there is no significant risk. In this case the assessment should be recorded and the process stops here.
Chapter 6 explains the use of exposure limit values and action levels. It also discusses the derogations.
To assist with the risk assessment generally and specifically to assess compliance with action levels or exposure limit values, employers may need information on the level of EMF. This may be available from databases or manufacturers (Chapter 7) or it may be necessary to perform calculations or measurements (Chapter 8).
Chapter 9 details preventive and protective measures where it is necessary to reduce the risk.
Chapter 10 provides guidance on emergency preparedness, whilst Chapter 11 gives advice on risks, symptoms and health surveillance.

The chapters of this guide have been kept as brief as possible to minimise the burden on employers using them. The appendices to this guide provide further information for employers and others who may be involved with the risk assessment process (Table1.2):

Table 1.2 — Appendices to this guide

A — Nature of EMF
B — Health effects of EMF
C — EMF quantities and units
D — Exposure assessment
E — Indirect effects and workers at particular risk
F — Guidance on MRI
G — Requirements of other European texts
H — European and international standards
I — Resources
J — Glossary, abbreviations and flow chart symbols
K — Bibliography
L — Directive 2013/35/EU

1.2 Introduction to the EMF Directive

All employers have a duty to assess the risks arising from the work they undertake and to put in place protective or preventive measures to reduce the risks they identify. These duties are a requirement of the Framework Directive. The EMF Directive was introduced to help employers to comply with their general duties under the Framework Directive for the specific case of EMF in the workplace. As employers will already be complying with the requirements of the Framework Directive, most will find that they already fully comply with the EMF Directive and have nothing more to do.

Electromagnetic fields are defined within the EMF Directive as static electric, static magnetic and time-varying electric, magnetic and electromagnetic fields with frequencies up to 300GHz. This terminology is only used in this guide where there is a clear benefit in doing so.

Electromagnetic fields are produced by a wide range of sources that workers may encounter in the workplace. They are generated and used in many work activities, including manufacturing processes, research, communication, medical applications, power generation, transmission and distribution, broadcasting, aeronautical and marine navigation, and security. Electromagnetic fields may also be incidental, such as the fields that are generated near to cables distributing electrical power within buildings, or resulting from the use of electrically powered equipment and appliances. As most fields are electrically generated, they will disappear when the power is switched off.

The EMF Directive addresses established direct and indirect effects caused by electromagnetic fields; it does not cover suggested long-term health effects (see Section 2.2).The direct effects are separated into; non-thermal effects, such as the stimulation of nerves, muscles and sensory organs and thermal effects, such as tissue heating (see Section 2.1). Indirect effects occur where the presence of an object within an electromagnetic field may become the cause of a safety or health hazard (see Section 2.3).

1.3 Scope of This Guide

This guide is intended to provide practical advice to help employers comply with the EMF Directive. It is aimed at all undertakings where workers may encounter electromagnetic fields. Although the EMF Directive does not specifically exclude any particular type of work or technologies, the fields in many workplaces will be so weak that there is no risk. This guide provides a list of generic work activities, equipment and workplaces where fields are expected to be so weak that employers will not need to take any further action. This guide does not consider electromagnetic compatibility issues, which are discussed elsewhere.

The EMF Directive requires employers to consider workers who are likely to be at particular risk, including workers who wear active or passive implanted medical devices, such as cardiac pacemakers, workers with medical devices worn on the body, such as insulin pumps, and pregnant workers. This guide provides advice in these situations.

There will be some potential exposure scenarios that are highly specific or very complex and therefore beyond the scope of this guide. Some industries with particular exposure scenarios may develop their own guidance in relation to the EMF Directive and this should be consulted where appropriate (see Appendix I). Employers with complex exposure scenarios should seek further advice on assessment (see Chapter 8 and Appendix I).

1.4 Correspondence with Directive 2013/35/EU

This guide has been produced to satisfy Article 14 of the EMF Directive. Table 1.3 shows how the Articles of the EMF Directive map to the chapters of this guide.

Table 1.3 — Correspondence between articles of the EMF Directive and sections of this guide

Articles and guidance	Guide Section
Article 2: Definitions	
Background information	Appendices A, B
Quantities and units used in the EMF Directive	Appendix C
Terms and abbreviations	Appendix J
Article 3: Exposure limit values and action levels	
Limitation of exposure	Section 6.3
Application of action levels	Sections 6.1, 6.2
Required actions	Sections 9.4, 9.5
Article 4: Assessment of risks and determination of exposure	
Risk assessment	Chapter 5
Indirect effects and workers at particular risk	Sections 5.3, 5.4, and Appendix E
Assessment of exposure using available information	Chapter7
Assessment of exposure by measurement or calculation	Chapter 8 and Appendix D
Article 5: Provisions aimed at avoiding or reducing risks	
Principles of prevention	Section 9.1
Technical measures	Section 9.4
Organisational measures	Section 9.5
Personal protective equipment	Section 9.6
Article 6: Worker information and training	
Worker information	Section 9.5 and Appendix E
Worker training	Section 9.5 and Appendices A, B
Article 7: Consultation and participation of workers	
Worker consultation and participation	Chapter 4
Article 8: Health surveillance	
Symptoms	Section 11.1
Health surveillance	Section 11.2
Medical examination	Section 11.3
Article 10:Derogations	
Derogations	Section 6.4 and Appendix F

1.5 National Regulations and Sources of Further Information

Use of this guide does not necessarily ensure compliance with statutory electromagnetic fields protection requirements in the various EU Member States. The rules of law by which the Member States have transposed Directive 2013/35/EU always take precedence. These may go beyond the minimum requirements of the EMF Directive, on which this guide is based. Further information may be available from the national regulatory authorities given in Appendix I.

As a further aid to implementing the requirements of the EMF Directive, manufacturers may design their products to minimise accessible EMF. They may also provide information on the fields and risks associated with equipment in normal use. The use of manufacturer's information is discussed further in Chapter 7.

Sources of additional information are given in the appendices to this guide. In particular, Appendix I gives details of national organisations and trade associations, whilst Appendix J contains a glossary, a list of abbreviations and an explanation of the flow chart symbols used in this guide. Appendix K provides a bibliography of useful publications.

2. HEALTH EFFECTS AND SAFETY RISKS FROM ELECTROMAGNETIC FIELDS

The type of effect that electromagnetic fields have in people depends primarily on the frequency and intensity: other factors such as the shape of the waveform may also be important in some situations. Some fields cause stimulation of sensory organs, nerves and muscle, while others cause heating. The effects caused by heating are termed *thermal effects* by the EMF Directive, while all other effects are termed *non-thermal effects.* Further details about health effects of exposure to electromagnetic fields are given in Appendix B.

Importantly, all these effects show a threshold below which there is no risk, and exposures below the threshold are not cumulative in any way. The effects caused by exposure are transient being limited to the duration of exposure, and they will stop or decrease once exposure ceases. This means that there can be no further risk to health once exposure has ended.

2.1 Direct Effects

Direct effects are changes that occur in a person as a result of being exposed to an electromagnetic field. The EMF Directive only considers well-understood effects that are based on known mechanisms. It distinguishes between sensory effects and health effects, which are considered to be more serious.

The direct effects are:

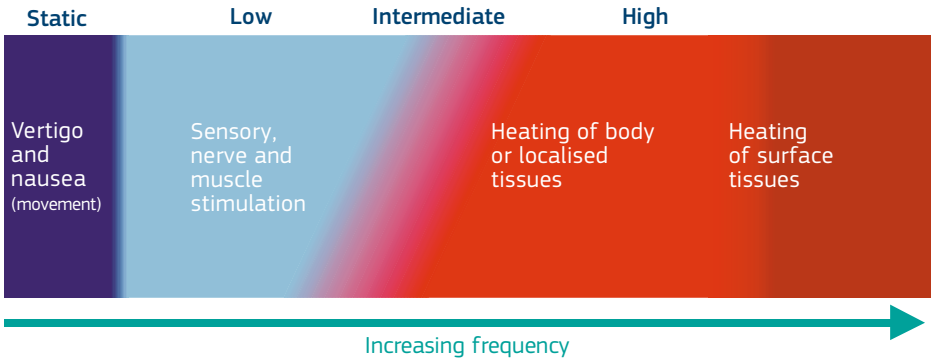
- vertigo and nausea from static magnetic fields (typically associated with movement, but may also occur when stationary)
- effects on sense organs, nerves and muscles from low frequency fields (up to 100 kHz)
- heating of the whole body or parts of it from high frequency fields (10 MHz and above); above a few GHz heating is increasingly limited to the surface of the body
- effects on nerves, muscles and heating from intermediate frequencies (100 kHz — 10 MHz)

These concepts are illustrated in Figure 2.1. See Appendix B for more information about direct effects.

2.2 Long-term Effects

The EMF Directive does not address suggested long-term effects of exposure to electromagnetic fields, since there is currently no well-established scientific evidence of a causal relationship. However, if such well-established scientific evidence emerges, the European Commission will consider the most appropriate means for addressing such effects.

Figure 2.1 — The effects of EMF in different frequency ranges (frequency intervals are not to scale)



2.3 Indirect Effects

Undesirable effects may occur due to the presence of objects in the field resulting in a safety or health hazard. Contact with a live conductor is not within the scope of the EMF Directive.

The indirect effects are:

- interference with medical electronic equipment and other devices
- interference with active implanted medical devices or equipment, such as cardiac pacemakers or defibrillators
- interference with medical devices worn on the body, such as insulin pumps
- interference with passive implants (artificial joints, pins, wires or plates made of metal)
- effects on shrapnel, body piercings, tattoos and body art
- projectile risk from loose ferromagnetic objects in a static magnetic field
- unintentional initiation of detonators
- fires or explosions from ignition of flammable or explosive material
- electric shocks or burns from contact currents when a person touches a conductive object in an electromagnetic field and one of them is grounded whilst the other is not

Chapter 5 and Appendix E provide further information about indirect effects and how these risks may be managed in the workplace.

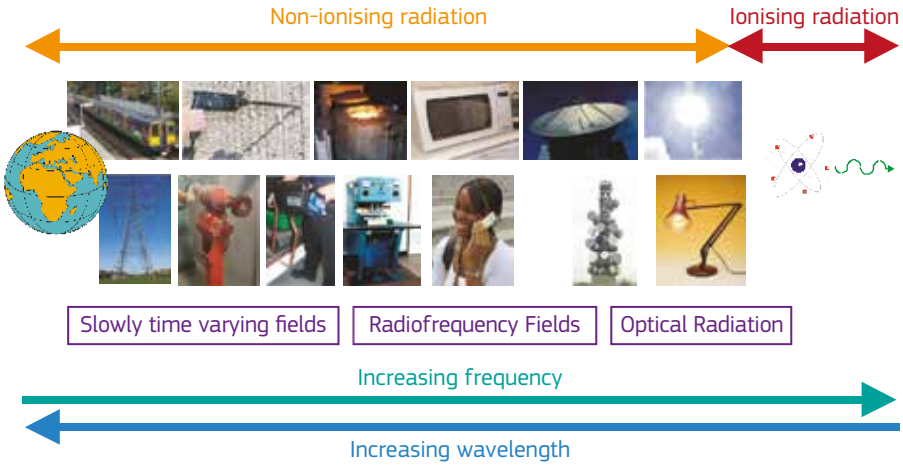
Key message: effects of EMF

EMF in the workplace may cause direct or indirect effects. Direct effects are those arising from an interaction of the fields with the body and may be either non-thermal or thermal in nature. Indirect effects result from the presence of an object in the field resulting in a safety or health hazard.

3. SOURCES OF ELECTROMAGNETIC FIELDS

Everyone in our modern society is exposed to electric and magnetic fields from many sources including electrical equipment, broadcast transmissions and communications devices (Figure 3.1). Appendix A provides further information on the nature of electromagnetic fields. The majority of sources of electromagnetic fields found both at home and in the workplace produce extremely low levels of exposure and as such most common work activities are unlikely to give rise to exposures in excess of the action levels or the exposure limit values established by the EMF Directive.

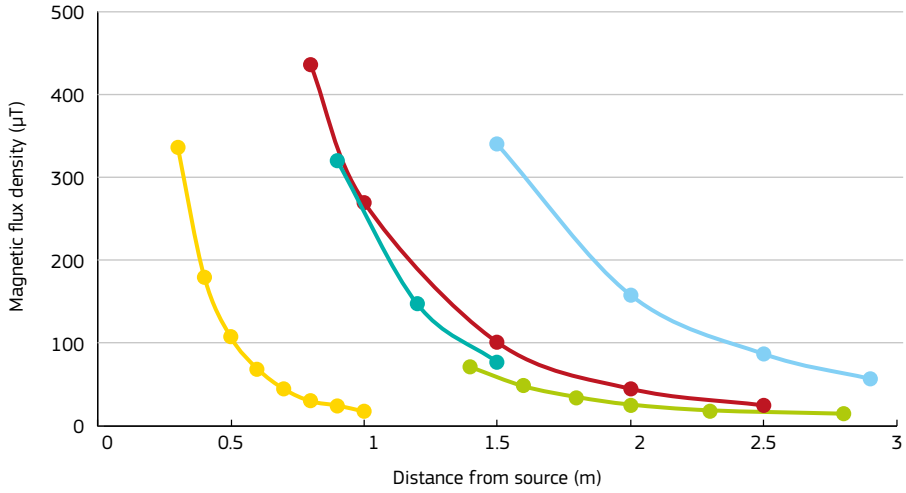
Figure 3.1 — Schematic representation of electromagnetic spectrum showing some typical sources



The aim of this chapter is to provide employers with information on the sources of EMF found within the work environment to help them decide whether further assessment of the risks from EMF is required. The extent and magnitude of electromagnetic fields produced will depend on the voltages, currents and frequencies that the equipment operates at or generates, along with the design of the equipment. Some equipment may be designed to intentionally generate external electromagnetic fields. In this case, small low-powered equipment may give rise to significant external electromagnetic fields. Generally equipment that uses high currents, high voltages or that is designed to emit electromagnetic radiation will require further assessment. Appendix C provides more information on common quantities and units used to evaluate electromagnetic fields. Advice on risk assessment in the context of the EMF Directive can be found in Chapter 5.

The magnitude of an electromagnetic field will decrease rapidly with distance from its source (Figure 3.2). Worker exposure can be reduced if it is possible to restrict access to areas close to the equipment when the equipment is in operation. It is also worth remembering that electromagnetic fields, unless generated by a permanent magnet or superconducting magnet, will normally disappear when the power is removed from the equipment.

Figure 3.2 — Decrease in magnetic flux density with distance for a variety of power frequency sources: spot welder (●—●); 0.5 m demagnetising coil (●—●); 180 kW induction furnace (●—●); 100kVA seam welder (●—●); 1 m demagnetising coil (●—●)



The remainder of this chapter aims to help employers distinguish between, equipment, activities and situations that are unlikely to present a hazard and those where protective or preventive measures may be needed to protect employees.

3.1 Workers at Particular Risk

Some groups of workers (see Table 3.1) are considered to be at particular risk from electromagnetic fields. These workers may not be adequately protected by the ALs specified in the EMF Directive and so it is necessary for employers to consider their exposure separately to that of other workers.

Workers at particular risk will normally be adequately protected by compliance with the reference levels specified in Council Recommendation 1999/519/EC (see Appendix E). However, for a very small minority even these reference levels may not provide adequate protection. These individuals will have received appropriate advice from the medical practitioner responsible for their care, and this should assist the employer to establish whether the individual is at risk in the workplace.

Table 3.1 — Workers at particular risk as identified in the EMF Directive

Workers at particular risk	Examples
Workers wearing active implanted medical devices (AIMD)	Cardiac pacemakers, cardiac defibrillators, cochlear implants, brainstem implants, inner ear prostheses, neurostimulators, retinal encoders, implanted drug infusion pumps
Workers wearing passive implanted medical devices containing metal	Artificial joints, pins, plates, screws, surgical clips, aneurism clips, stents, heart valve prostheses, annuloplasty rings, metallic contraceptive implants, and cases of AIMD
Workers wearing body-worn medical devices	External hormone infusion pumps
Pregnant workers	

NB: In considering whether workers may be at particular risk, employers should give consideration to the frequency, level and duration of exposure.

3.1.1 Workers wearing active implanted medical devices (AIMD)

One group of workers at particular risk are those wearing active implanted medical devices (AIMD). This is because strong electromagnetic fields may interfere with the normal operation of these active implants. There is a legal requirement for device manufacturers to ensure that their products have reasonable immunity to interference and they are routinely tested for field strengths that might be encountered in the public environment. As a result field strengths up to the reference levels specified in Council Recommendation 1999/519/EC should not adversely affect the operation of these devices. However, field strengths above these reference levels *at the position of the device or its sensing leads* (when present) may result in a malfunction, which would present a risk to those wearing them.

Although some of the work situations discussed in this chapter may give rise to strong fields, in many cases these will be highly localised. The risk can therefore be managed by ensuring that the strong field is not generated in the immediate vicinity of the implant. For example, the field produced by a mobile phone could interfere with a cardiac pacemaker if the phone was held close to the device. Nevertheless, people wearing cardiac pacemakers can still use mobile phones without being at risk. They simply have to be careful to keep the phone away from the chest.

Column 3 of Table 3.2 identifies those situations where a specific assessment is required for workers wearing active implants due to the possibility that strong fields could be generated in the immediate vicinity of the device or its sensing leads (when present). Often the outcome of this assessment will be that the worker should simply follow the instructions given to them by their medical team when the implant was fitted.

Where workers or others fitted with active implants have access to a workplace, the employer will need to consider whether a more detailed assessment is required. In this context it should be noted that for a number of work situations listed in Table 3.2, a distinction is made between someone personally carrying out an activity and the activity occurring in the workplace. The latter situation is unlikely to result in a strong field in the immediate vicinity of the implant and so an assessment is not normally required.

A few situations (such as induction melting) generate very strong fields. In these cases, the region over which the reference levels in Council Recommendation 1999/519/EC may be exceeded will generally be much larger. Consequently the assessment is likely to be more complex (see Appendix E) and there may be a requirement to implement access restrictions.

3.1.2 Other workers at particular risk

For the other groups of workers at particular risk (see Table 3.1) highly localised strong fields will not normally present a risk. Instead, these workers will be at risk where work activities are likely to generate fields that exceed the reference levels in Council Recommendation 1999/519/EC over regions that are more generally accessible. Common situations where this is likely are identified in Column 2 of Table 3.2 and will require specific assessments.

Where an assessment is required for workers at particular risk, employers should consult Appendix E.

Key message: workers at particular risk

Workers with active implants may be at risk from strong fields in the workplace. These fields are often highly localised and risks can usually be adequately managed by following a few simple precautions based on advice from the worker's care team.

Although strong fields may present particular risks to other groups of workers (those with passive implants, body-worn medical devices and pregnant workers) this is only likely in a limited number of situations (see Table 3.2).

3.2 Assessment Requirements for Common Work Activities, Equipment and Workplaces

Table 3.2 lists many common work activities, equipment and workplaces, and provides an indication of whether assessments are likely to be required for:

- workers with active implants
- other workers at particular risk
- workers not at particular risk.

The entries in this table are based on whether a situation is likely to give rise to field strengths in excess of the reference levels in Council Recommendation 1999/519/EC, and if so, whether those fields are likely to be highly localised or not.

Table 3.2 is based on the use of equipment conforming to recent standards that has been correctly maintained and is being used as intended by the manufacturer. Where work involves the use of very old, non-standard or poorly maintained equipment, the guidance in Table 3.2 may not be applicable.

Where every activity in a workplace has a 'No' in all three columns, it should not be necessary to carry out a specific assessment in relation to the EMF Directive as there is expected to be no risk from EMF. In these situations further actions will not normally by required. It will, however, be necessary to make a general risk assessment meeting the requirements of the Framework Directive. Employers should remain alert to changing circumstances as required by the Framework Directive and should review the need for a specific EMF assessment in the light of any changes identified.

Similarly, for workplaces where there is no access for workers with active implants or other workers at particular risk, provided every activity has a 'No' in all *relevant* columns, it should not be necessary to carry out a specific assessment in relation to the EMF Directive. It will still be necessary to make a general risk assessment as required by the Framework Directive. Employers should also remain alert to changing circumstances and in particular the possibility of access to premises by workers at particular risk.

Key message: EMF assessments

Where the workplace contains only situations listed in Table 3.2 that have a 'No' in all relevant columns it will not normally be necessary to make a specific EMF assessment. A general risk assessment meeting the requirements of the Framework Directive will still be required and employers should remain alert to changing circumstances.

Table 3.2 — Requirements for specific EMF assessments in respect of common work activities, equipment and workplaces

Type of equipment or workplace	Assessment required for		
	Workers not at particular risk* (1)	Workers at particular risk (excluding those with active implants)** (2)	Workers with active implants*** (3)
Wireless communications			
Phones, cordless (including base stations for DECT cordless phones) — use of	No	No	Yes
Phones, cordless (including base stations for DECT cordless phones) — workplaces containing	No	No	No
Phones, mobile — use of	No	No	Yes
Phones, mobile — workplaces containing	No	No	No
Wireless Communication Devices (e.g. Wi-Fi or Bluetooth) including access points for WLAN — use of	No	No	Yes
Wireless Communication Devices (e.g. Wi-Fi or Bluetooth) including access points for WLAN — workplaces containing	No	No	No
Office			
Audio-visual equipment (e.g. televisions, DVD players)	No	No	No
Audio-visual equipment containing radiofrequency transmitters	No	No	Yes
Communication equipment and networks, wired	No	No	No
Computer and IT equipment	No	No	No
Fan heaters, electric	No	No	No
Fans, electric	No	No	No
Office equipment (e.g. photocopiers, paper shredders, electrically operated staplers)	No	No	No
Phones (landline) and fax machines	No	No	No
Infrastructure (buildings and grounds)			
Alarm systems	No	No	No
Base station antennas, inside operator's designated exclusion zone	Yes	Yes	Yes
Base station antennas, outside operator's designated exclusion zone	No	No	No
Garden appliances (electric operated) — use of	No	No	Yes
Garden appliances (electric) — workplaces containing	No	No	No
Heating equipment (electrical) for room heating	No	No	No
Household and professional appliances, e.g. refrigerator, washing machine, dryer, dishwasher, oven, toaster, microwave oven, iron, provided it does not contain transmission equipment such as WLAN, Bluetooth or mobile phones	No	No	No
Lighting equipment, e.g. area lighting and desk lamps	No	No	No
Lighting equipment, RF or microwave energised	Yes	Yes	Yes
Work places accessible to the general public which meet the reference levels specified in Council Recommendation 1999/519/EC	No	No	No

Security			
Article surveillance systems and RFID (radio frequency identification)	No	No	Yes
Erasers, Tape or Hard Drive	No	No	Yes
Metal detectors	No	No	Yes
Electrical supply			
Electrical circuit where the conductors are close together and having a net current of 100 A or less — includes wiring, switchgear, transformers, etc. — exposure to magnetic fields	No	No	No
Electrical circuit where the conductors are close together and having a net current of greater than 100 A — includes wiring, switchgear, transformers, etc. — exposure to magnetic fields	Yes	Yes	Yes
Electrical circuits within an installation, with a phase current rating of 100 A or less for the individual circuit — includes wiring, switchgear, transformers, etc. — exposure to magnetic fields	No	No	No
Electrical circuits within an installation, with a phase current rating of greater than 100 A for the individual circuit — includes wiring, switchgear, transformers, etc. — exposure to magnetic fields	Yes	Yes	Yes
Electrical installations with a phase current rating of greater than 100A — includes wiring, switchgear, transformers, etc. — exposure to magnetic fields	Yes	Yes	Yes
Electrical installations with a phase current rating of 100A or less — includes wiring, switchgear, transformers, etc. — exposure to magnetic fields	No	No	No
Generators and emergency generators — work on	No	No	Yes
Inverters, including those on photovoltaic systems	No	No	Yes
Overhead bare conductor rated at a voltage up to 100 kV, or overhead line up to 150 kV, above the workplace — exposure to electric fields	No	No	No
Overhead bare conductor rated at a voltage greater than 100 kV, or overhead line greater than 150 kV [1], above the workplace — exposure to electric fields	Yes	Yes	Yes
Overhead bare conductors of any voltage — exposure to magnetic fields	No	No	No
Underground or insulated cable circuit, rated at any voltage — exposure to electric fields	No	No	No
Wind turbines, work on	No	Yes	Yes
Light industry			
Arc welding processes, manual (including MIG, MAG, TIG) when following good practice and not supporting cable on body	No	No	Yes
Battery chargers, industrial	No	No	Yes
Battery chargers, large professional	No	No	Yes
Coating and painting equipment	No	No	No
Control equipment not containing radio transmitters	No	No	No
Corona surface treatment equipment	No	No	Yes
Dielectric heating	Yes	Yes	Yes

[1] For overhead lines above 150kV the electric field strength will usually, but not always, be lower than the reference level specified in Council Recommendation 1999/519/EC.

Dielectric welding	Yes	Yes	Yes
Electrostatic painting equipment	No	Yes	Yes
Furnaces, resistively heated	No	No	Yes
Glue guns (portable) — workplaces containing	No	No	No
Glue guns — use of	No	No	Yes
Heat guns (portable) — workplaces containing	No	No	No
Heat guns — use of	No	No	Yes
Hydraulic ramps	No	No	No
Induction heating	Yes	Yes	Yes
Induction heating systems, automated, fault-finding and repair involving close proximity to the EMF source	No	Yes	Yes
Induction sealing equipment	No	No	Yes
Induction soldering	Yes	Yes	Yes
Machine tools (for example pedestal drills, grinders, lathes, milling machines, saws)	No	No	Yes
Magnetic particle inspection (crack detection)	Yes	Yes	Yes
Magnetizer/demagnetizers, industrial (including tape erasers)	Yes	Yes	Yes
Measuring equipment and instrumentation not containing radio transmitters	No	No	No
Microwave heating and drying, in woodworking industries (wood drying, wood forming, wood gluing)	Yes	Yes	Yes
RF plasma devices including vacuum deposition and sputtering	Yes	Yes	Yes
Tools (electric handheld and transportable e.g. drills, sanders, circular saws, and angle grinders) — use of	No	No	Yes
Tools (electric handheld and transportable) — workplaces containing	No	No	No
Welding systems, automated, fault-finding, repair and teaching involving close proximity to the EMF source	No	Yes	Yes
Welding, manual resistance (spot welding, seam welding)	Yes	Yes	Yes
Heavy industry			
Electrolysis, industrial	Yes	Yes	Yes
Furnaces, arc melting	Yes	Yes	Yes
Furnaces, induction melting (smaller furnaces normally have higher accessible fields than larger furnaces)	Yes	Yes	Yes
Construction			
Construction equipment (e.g. concrete mixers, vibrators, cranes, etc) — work in close proximity	No	No	Yes
Microwave drying, in construction industry	Yes	Yes	Yes
Medical			
Medical equipment not employing EMF for diagnosis or treatment	No	No	No
Medical equipment using EMF for diagnosis and treatment (for example, short wave diathermy, transcranial magnetic stimulation)	Yes	Yes	Yes
Transport			
Motor vehicles and plant — work in close proximity to starter, alternator, ignition systems	No	No	Yes

Radar, air traffic control, military, weather and long range	Yes	Yes	Yes
Trains and trams, electrically driven	Yes	Yes	Yes
Miscellaneous			
Battery chargers, inductive or proximity coupling	No	No	Yes
Battery chargers, non-inductive coupling designed for household use	No	No	No
Broadcasting systems and devices (radio and TV: LF, MF, HF, VHF, UHF)	Yes	Yes	Yes
Equipment generating static magnetic fields > 0.5 millitesla, whether generated electrically or from permanent magnets (for example, magnetic chucks, tables and conveyors, lifting magnets, magnetic brackets, nameplates, badges)	No	No	Yes
Equipment placed on the European market as compliant with Council Recommendation 1999/519/EC or harmonised EMF standards	No	No	No
Headphones producing strong magnetic fields	No	No	Yes
Inductive cooking equipment, professional	No	No	Yes
Non-electrical equipment of all types except those containing permanent magnets	No	No	No
Portable equipment (battery powered) not containing radiofrequency transmitters	No	No	No
Radios, two-way (for example walkie-talkies, vehicle radios)	No	No	Yes
Transmitters, battery driven	No	No	Yes

NB: * Assessment required against applicable ALs or ELVs (see Chapter 6).
** Assess against Council Recommendation reference levels (see Section 5.4.1.3 and Appendix E).
*** Localised personal exposure may exceed reference levels in Council Recommendation — this will need to be considered in the risk assessment, which should be informed by information supplied by the healthcare team responsible for implanting device and/or subsequent care (see Section 5.4.1.3 and Appendix E).

3.2.1 Work Activities, Equipment and Workplaces Likely to Require Specific Assessment

Workplaces containing or close to equipment operating at high currents or high voltages may have regions of strong electromagnetic fields. This is also likely to be the case for equipment designed to deliberately transmit electromagnetic radiation at high power. These strong fields may exceed the ALs or ELVs contained within the EMF Directive or may present unacceptable risks through indirect effects.

Column 1 of Table 3.2 identifies situations that may give rise to strong fields that will normally require a specific EMF assessment. This table was compiled on the basis that existing measurement data for examples of these situations indicates that fields may be strong enough to approach and in some cases exceed relevant ALs. Hence a 'Yes' in Column 1 does not mean that the accessible field will definitely exceed an ELV. Rather, it means that it is not possible to be confident that the ELV will always be complied with, bearing in mind the range of variation likely to be encountered in the workplace. It is therefore advisable to make an assessment that is specific for each workplace.

It must be stressed that Table 3.2 gives examples of situations commonly encountered in the workplace. It cannot be regarded as an exhaustive list and other specialist equipment or unusual processes may exist that have not been included. However, the list should help employers to identify types of situation that are likely to require further detailed assessment.

3.3 Work Activities, Equipment and Workplaces Not Listed in this Chapter

Where employers identify situations in their workplaces that do not appear to be covered by entries in Table 3.2, the first step will be to gather as much information as they can from manuals and other documents in their possession. The next step will be to investigate if information is available from external sources such as equipment manufacturers and trade associations (see Chapter 7 of this guide).

If it is not possible to obtain information on EMF from anywhere else, then it may be necessary to carry out an assessment by means of measurement or calculation (see Chapter 8).

Section 2

DECIDING WHETHER TO DO MORE

4. STRUCTURE OF THE EMF DIRECTIVE

The full text of the EMF Directive (2013/35/EU) is included in Appendix L of this guide. This chapter explains how and why the EMF Directive has been introduced, and provides a summary of its key requirements.

The Treaty of Rome (now the Treaty on the Functioning of the European Union) sets an objective to encourage improvements in the working environment regarding the health and safety of workers. To help achieve this objective it allows for the introduction of directives to set minimum requirements. In 1989 the Framework Directive (89/391/EEC) was introduced as an overarching directive in this area. The Framework Directive sets out general requirements for assessing and reducing risks, emergency preparedness, worker information, participation and training, worker obligations, and health surveillance. It also provides for the introduction of individual directives, which essentially give additional detail on how to achieve the objectives of the Framework Directive in specific situations. The EMF Directive is the twentieth such individual directive. Figure 4.1 illustrates how it fits into the broader legislative landscape.

Figure 4.1 — Schematic representation of legislative setting for EMF Directive

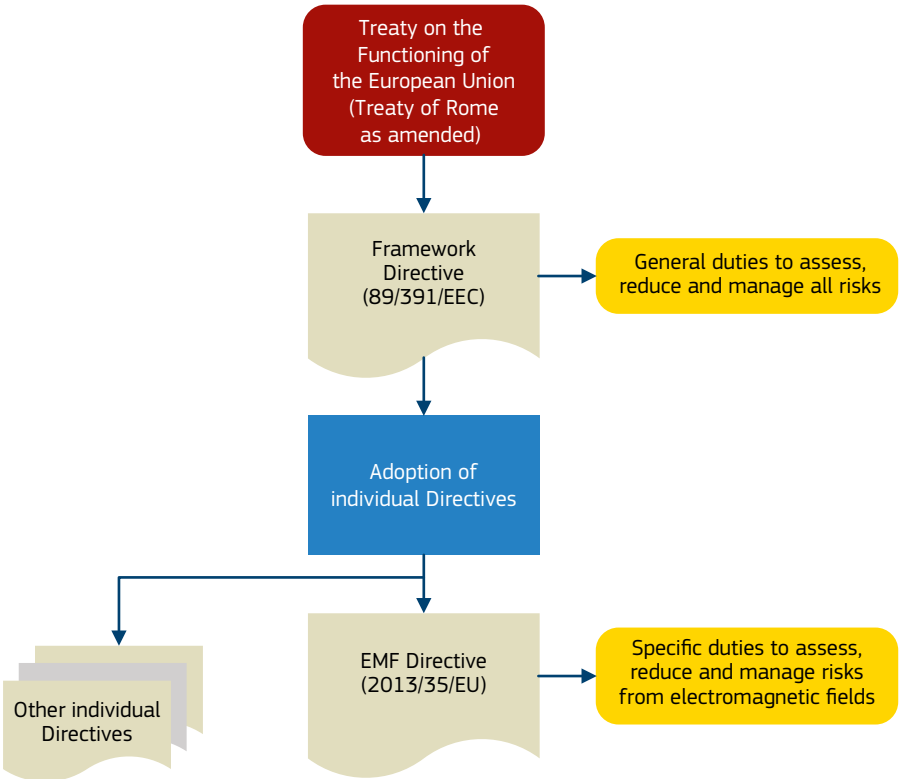
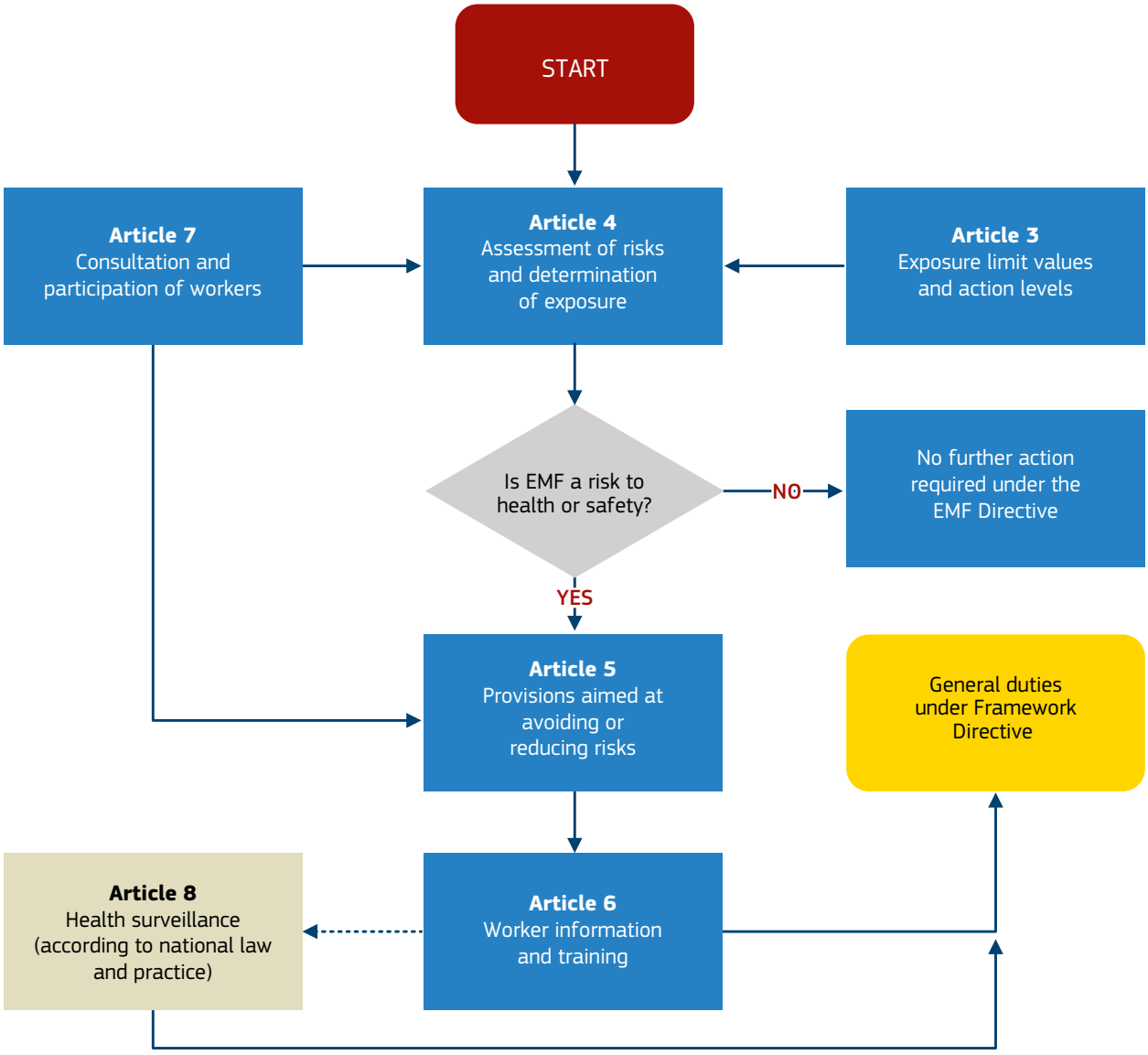


Figure 4.2 illustrates an overview of the main articles of the EMF Directive that are relevant to employers and how they interact with each other.

Figure 4.2 — Schematic showing interaction between articles of the EMF Directive



As explained above, the EMF Directive is intended to help employers achieve compliance with their obligations under the Framework Directive for the specific situation of work that involves exposure to EMF. It follows that many of the requirements of the EMF Directive mirror those in the more general Framework Directive and hence the two Directives should be used together. The main emphasis of the EMF Directive is to assess risks arising from electromagnetic fields in the workplace and then, if necessary, put in place measures to reduce them. However, one result of the linkage between the two Directives is that most employers who are already meeting their obligations under the Framework Directive should find that they have little more to do in order to achieve compliance with the EMF Directive.

The EMF Directive seeks to introduce *minimum* requirements for health and safety in relation to work with EMF. In line with the Treaty on the Functioning of the European Union, individual Member States may choose to maintain existing legislation or introduce new legislation with requirements that are more stringent than those in the EMF Directive.

4.1 Article 3 — Exposure Limit Values and Action Levels

Article 3 limits maximum exposures by setting exposure limit values (ELVs) for sensory and health effects. These are defined in Annexes II (non-thermal effects) and III (thermal effects) of the EMF Directive. The health effects ELVs must always be complied with. However, it is acceptable to temporarily exceed the sensory effects ELVs provided workers are provided with information and other measures are implemented as specified in Article 3.

Key message: Definitions

Many terms used in the EMF Directive are defined in Article 2. However, some terms such as 'temporarily' and 'justified' are not defined and may be used differently depending on the context. Where terms are not explicitly defined in the EMF Directive, Member States will define them during implementation, either in legislation or by other means.

In most cases the ELVs are specified in terms of internal body quantities that cannot be directly measured or simply calculated. For this reason Article 3 introduces action levels (ALs), which are set in terms of external field quantities that can be more easily found by measurement or calculation. The ALs are defined in Annexes II and III to the EMF Directive. Provided the ALs are not exceeded then it can be assumed that exposures will comply with the ELVs and further assessment is not needed. Under some circumstances it may be acceptable to exceed some ALs and rules for this are given in Article 3.

The practical application of ALs and ELVs is complicated and is discussed further in Chapter 6 of this guide.

4.2 Article 4 — Assessment of Risks and Determination of Exposure

The first step to creating a safer workplace is to assess the risks that are present. Chapter 5 of this guide gives further information about assessing risks from EMF in the workplace. This includes a discussion of the matters that must be considered in order to satisfy Article 4. It is important to note that it is not sufficient to simply demonstrate compliance with ALs or ELVs as this may not be sufficient to adequately protect workers at particular risk or avoid safety risks from indirect effects.

When assessing risks from EMF in the workplace it is necessary to understand the nature of the fields that are present. Hence Article 4 also requires employers to identify and assess EMF in the workplace. However, it allows employers to take account of information provided by others and only requires them to assess fields themselves where it is not possible to demonstrate compliance by any other means.

The acceptability of using data provided by manufacturers or published in databases of generic assessments is important because for most employers this will be by far the simplest means of assessing EMF in the workplace. The use of information provided by others is discussed further in Chapter 7 of this guide and illustrated in some case studies in Volume 2.

Even where it is necessary for employers to assess fields themselves, Article 4 permits them the choice of whether to do this by measurement or calculation. This flexibility will allow employers to select the simplest approach for their particular situation. There are many factors that influence the approach to be taken and these are discussed further in Chapter 8 of this guide, whilst additional guidance is available in Appendix D.

4.3 Article 5 — Provisions Aimed at Avoiding or Reducing Risks

Provided the ALs are not exceeded and other effects can be excluded, employers do not need to take any further action other than to ensure they continue to meet their duties under the Framework Directive. This will include periodic review of the risk assessment to ensure that it remains relevant.

Where ALs are exceeded, the employer may wish to try and demonstrate compliance with the ELVs and the absence of other safety risks from EMF if this is possible. However, in many cases it may be easier and cheaper to implement measures to prevent the risks than to demonstrate compliance with the ELV. As for other aspects of the EMF Directive, the general approaches to risk avoidance and reduction should follow those of the Framework Directive. Most employers will have a number of possible options and the most appropriate will depend on their particular situation. Common approaches are discussed in Chapter 9 of this guide and this includes some measures that are specific to risks from EMF.

As mentioned in Section 4.1 above, Article 3 allows low ALs or sensory ELVs to be temporarily exceeded subject to conditions. Article 5 specifies precautions that must be implemented in these situations.

Even where ALs are not exceeded, the employer will need to consider that this may not provide adequate protection for workers at particular risk or avoid safety risks from indirect effects. Again a variety of options are often available to manage these risks and these are also discussed further in Chapter 9.

4.4 Article 6 — Worker Information and Training

As with other aspects of the EMF Directive, the requirements of Article 6 are broadly similar to corresponding articles in the Framework Directive. Where risks have been identified then appropriate information and training should be provided. However, it is recognised that many workers may be unfamiliar with the nature of the hazards associated with EMF, possible symptoms or concepts such as ELVs and ALs and so these should be specifically covered in any training. Employees will also need to be given specific information about the results of assessments for their specific workplace.

It is equally important that the risks are put in perspective. Workers should be aware that many of the sources of electromagnetic fields in the workplace do not present a risk to their health or safety. Indeed many, such as mobile phones or lifting equipment may contribute to their welfare or make their work much easier. Provision of information and training is discussed further in Chapter 9 of this guide.

4.5 Article 7 — Consultation and Participation of Workers

Article 7 of the EMF Directive refers directly to Article11 of the Framework Directive.

4.6 Article 8 — Health Surveillance

Article 8 of the EMF Directive builds on the requirements of Article14 of the Framework Directive. Member States are specifically allowed to adapt these requirements to the systems they already have in place and so the practical implementation of this article is likely to vary from country to country. Some guidance on health surveillance is provided in Chapter 11 of this guide.

4.7 Article 10 — Derogations

Article10 grants one non-discretionary and two discretionary derogations. A derogation is a relaxation in a legislative requirement. In this case, it means that under specific circumstances employers do not have to meet some requirements of the EMF Directive, provided workers are still adequately protected.

The non-discretionary derogation relates to the installation, testing, use, development, maintenance of, or research related to the use of magnetic resonance imaging (MRI) equipment in the healthcare sector. The derogation allows exposures to exceed the ELVs providing certain conditions are satisfied. These conditions are discussed further in Appendix F to this guide, along with guidance to employers on how to demonstrate compliance.

The first discretionary derogation permits Member States to allow the use of an alternative system of protection for personnel working in military installations, involved in military activities, or taking part in joint international military exercises. This derogation is subject to the condition that adverse health effects and safety risks are prevented.

The second discretionary derogation is a general derogation that permits Member States to allow ELVs to be temporarily exceeded in specific sectors or for specific activities subject to certain conditions.

The derogations are discussed further in Section 6.4 of this guide.

4.8 Summary

The EMF Directive is intended to help employers achieve compliance with the requirements of the Framework Directive in respect of the specific risks associated with EMF. Most employers will already be meeting their obligations under the Framework Directive and in doing so will have discharged their responsibilities under the EMF Directive. However, for some workplaces where fields are stronger, employers may need to carry out more detailed assessments and introduce additional precautions to avoid or reduce the risks. Employers will also need to provide information and training to their staff, involve workers in the management of risks and follow national practice in relation to health surveillance.

Magnetic resonance imaging in the healthcare sector is subject to a non-discretionary derogation. Further derogations permit Member States to adopt an alternative system of protection for military activities and to allow ELVs to be temporarily exceeded in other sectors subject to conditions.

5. RISK ASSESSMENT IN THE CONTEXT OF THE EMF DIRECTIVE

Risk assessment is a fundamental requirement of the Framework Directive and this is reflected in Article 4 of the EMF Directive. This introduces a number of specific matters that must be considered when assessing risks from EMF. This chapter provides guidance on how to approach the assessment of risks from electromagnetic fields. The advice may be adapted by individual employers to fit in with their existing risk assessment systems.

In general there are no fixed rules about how to undertake a risk assessment, although it is always worth checking with national authorities in case there are specific national requirements. Structured approaches to risk assessment will normally be the most effective as they allow hazards and workers at risk to be identified systematically. This will help to ensure that risks are not inadvertently missed. The complexity of the assessment will vary depending on the nature of the tasks to be assessed, but experience suggests that in most situations it is best to keep it as simple as possible.

Just as there are no fixed rules about undertaking risk assessments, so the terminology used can vary. This chapter uses the terms and definitions recommended by the European Agency for Safety and Health at Work (Table 5.1).

Table 5.1 — Terms and definitions used in this guide in relation to risk assessment

Hazard	The intrinsic property or ability of something with the potential to do harm
Risk	The likelihood that the potential for harm will be attained under the conditions of use and/or exposure, and the possible extent of the harm
Risk assessment	The process of evaluating the risk to health and safety of workers while at work arising from the circumstances of the occurrence of a hazard at the workplace

A full risk assessment will need to consider all of the hazards associated with the work activity. However, for the purposes of this guidance only the EMF hazard will be discussed. Some examples of EMF-specific risk assessment are given in the case studies in Volume 2 of this guide. For some applications, adequate information will be supplied by the product manufacturer to conclude that the risk is adequately managed. Therefore, the risk assessment process need not be particularly onerous. The assessment must be preserved according to national law and practice.

Risk assessment is the responsibility of management, but should be undertaken in consultation with workers, who should be given information about the outcome of the assessment.

5.1 Online Interactive Risk Assessment (OiRA) Platform

In an initiative to assist micro and small enterprises, the European Agency for Safety and Health at Work has developed the Online Interactive Risk Assessment (OiRA) platform. This is hosted on a dedicated website (www.oiraproject.EU) that gives access to OiRA tools. These are provided free and are designed to help employers to put in place a step-by-step risk assessment process. As the tools are sector-specific, they help employers identify the most common hazards in their sectors.

There are four main stages to the OiRA process as shown in Table 5.2 below.

Table 5.2 — Stages of the OiRA process

Preparation	This gives you an overview of the particular assessment you are about to begin and can allow you to further customise the assessment to the specific nature of your business.
Identification	OiRA will present a series of potential health and safety hazards or problems that could exist in your workplace. By answering the statements/questions with either yes or no, you state if such hazards or problems are present. You can also decide to leave a question unanswered and thus put it on hold to be answered at a later stage.
Evaluation	Here you will be able to determine the level of risk attached to each of the items you identified as 'need to be addressed' in the 'Identification' stage.
Action Plan	In the fourth stage of the assessment you can decide what steps you will take to address the risks you have identified previously and what resources this might require. Based on this, a report will be automatically produced in the next step.

The guidance described below is consistent with the OiRA process and should be useful to those using OiRA tools. However, it is recognised that not all employers will want to use the OiRA tools. Some may have risk assessment systems already in place, whilst others may be following health and safety management systems such as OHSAS 18001. The advice given in this chapter is therefore intended to be relevant in all these situations.

5.2 Step 1 — Preparation

The first step in any risk assessment is to gather information about the work activities including:

- description of the work tasks
- who carries out the work
- how the work is carried out
- what equipment is used to perform the work tasks

Consultation with workers and observation of work activities are particularly important at this stage. How a work activity is carried out in practice may be different to how it is carried out in theory.

It is also important to ensure that the assessment addresses both routine operations and those that are non-routine or intermittent. These might include:

- cleaning
- maintenance
- servicing
- repair
- new installations
- commissioning
- decommissioning

5.3 Step 2 — Identification of Hazards and Those at Risk

5.3.1 Identification of hazards

The first step towards the identification of EMF hazards is to identify activities and equipment giving rise to electromagnetic fields in the workplace. It will be helpful to compare this list with Table 3.2 in Chapter 3 as in many cases the nature of an activity or the design of equipment will be such that only weak fields are produced. Such weak fields will not be hazardous, even if multiple activities or items of equipment are in close proximity.

The EMF Directive recognises that some workplaces that are open to the public may already have been assessed in relation to the Council Recommendation on limiting public exposure to EMF (1999/519/EC). Provided such workplaces comply with Council Recommendation 1999/519/EC and health and safety risks can be excluded, there is no requirement for any further exposure assessment to be carried out. These conditions are deemed to have been met where:

- equipment intended for public use is used as intended
- equipment complies with product directives that establish stricter safety levels than those provided in the EMF Directive
- no other equipment is used.

Table3.2 in Chapter 3 will also be helpful for identifying activities and equipment that are likely to require detailed assessment.

Some sources will give rise to stronger fields that are not accessible in normal use due to the equipment housing or guarding of work areas. In these situations it will be important to consider if workers could access strong fields during maintenance, servicing or repair.

Manufacturers and installers of equipment will need to consider that testing of partially constructed equipment may allow workers to access to strong fields that would not normally be accessible.

5.3.2 Identification of existing preventive and precautionary measures

In most workplaces there will already be a range of preventive and precautionary measures in place to eliminate or reduce workplace risks. Such measures may have been implemented specifically in relation to electromagnetic fields. In other cases they may have been put in place in relation to other hazards, but will also serve to restrict access to EMF.

It is therefore important to identify existing preventive and precautionary measures as an input to the risk assessment process.

5.3.3 Identification of those at risk

It is necessary to identify who could be harmed by the hazards under consideration. In doing this, it is important to consider all the workers in the workplace. Those carrying out work activities or using equipment generating strong fields should be straightforward to identify. However, it is important to take account of those carrying out other tasks or working with other equipment, but who might also be exposed to the fields. For example, the assessment of fields from the bench-top spot welder in the fabrication workshop case study (Volume 2 of this guide) shows that the field is not strongest at the operator position, but rather alongside the equipment. If the welder was adjacent to a designated walkway then other workers walking past may be exposed to stronger fields than the operator.

It is also important to consider risks to those who are not direct employees but who may nevertheless be present in the workplace. This could include visitors, service engineers, other contractors, and delivery workers.

5.3.4 Workers at particular risk

There is a requirement to consider workers who may be at particular risk and the EMF Directive specifically identifies four groups of workers who fall into this category (see Table 3.1 for further details):

- workers who wear active implanted medical devices
- workers with passive implanted medical devices
- workers with medical devices worn on the body
- pregnant workers

Workers falling into any of these groups may be at greater risk from electromagnetic fields than the general working population and should be subject to a specific risk assessment (see Section 5.4.1.3 below). Sometimes this may show that the risk remains tolerable, but in other cases it may be necessary to make adjustments to their working conditions to reduce the risk.

5.4 Step 3 — Evaluating and Prioritising Risks

5.4.1 Evaluation of risk

Risk evaluation can involve varying degrees of complexity from a simple judgement of whether a risk is low, medium or high to a highly quantitative analysis. The simple evaluation will normally be appropriate where fields are all at a low level, such as where all the activities and equipment have a 'No' in *all* Columns of Table 3.2. However, where fields are expected to be stronger, the evaluation is likely to be more complex and may involve an element of quantitative assessment to establish the magnitude of any hazard.

The risk evaluation should take account of both the severity of a hazardous event and the likelihood of that event occurring.

The severity rating assigned should reflect the expected outcome from the hazardous event. A range of possible outcomes of varying seriousness is possible from interactions of electromagnetic fields in the workplace. Examples of some possible outcomes and severities are given below. In practice the assignment of severity will be a matter for the judgement of the assessor and will be influenced by the strength of the accessible field and other local circumstances.

Table 5.3 — Examples of possible outcomes and severities resulting from interactions of EMF in the workplace

Outcome	Severity
Feelings of vertigo and nausea Perceived light flashes (phosphenes) Tingling feeling or pain (nerve stimulation) Small increases in tissue temperature Microwave hearing	Minor
Movement of ferromagnetic projectiles in static magnetic fields Interference with implanted medical devices Large increases in tissue temperature	Serious
Ignition of flammable atmospheres Initiation of detonators	Fatal

The assessment of likelihood will need to take account of a number of factors including access to the field and the nature of the work tasks undertaken. Often access to strong fields is restricted for other reasons, such as mechanical or electrical hazards. In these circumstances it will not be necessary to implement further restrictions. Equally, the assessment of likelihood should take account of the work process. For example, an induction furnace may operate at full power during the initial heating phase, but workers may not normally be in close proximity to the furnace during this part of the cycle. Later, once the charge is melted, the furnace may operate at reduced power, so the fields will be much lower.

The evaluation of risk will need to take account of any existing preventive or precautionary measures that are already in place (see Section 5.3.2).

Electromagnetic fields may give rise to risks by both direct and indirect interactions and these risks should be evaluated separately. In addition, some workers may be at particular risk (see Section 5.3.4 above) and risks to these workers will need to be specifically evaluated.

Key message: risk evaluation

Risk evaluation need not be complex and employers may use Table 3.2 to help them decide on the level of detail required. The assessment should take into account both severity of the hazardous event and the likelihood of the event occurring.

5.4.1.1 Direct effects

The assessment of risks resulting from direct interactions of electromagnetic fields with workers will need to take account of the characteristics of accessible fields. The principal factors affecting the magnitude of any hazard will be the frequency (or frequencies) present and the field strength. However, other factors such as waveform, spatial uniformity, and changes in field strength over time may also be important.

The key to this aspect of the assessment is to determine whether workers could be exposed in excess of the ELVs(see Chapter 6). Where exposure limit values cannot be exceeded there will be no direct effects hazard.

In general, for time varying fields with frequencies between 1 Hz and 6 GHz, ELVs cannot easily be measured or calculated and most employers will find it more convenient to assess whether accessible fields exceed the direct effects action levels (ALs). Where the action levels are not exceeded the ELVs cannot be exceeded.

The EMF Directive does not require employers to undertake calculations or measurements in order to establish that action levels are not exceeded unless this information is not available from anywhere else. Many employers will find that for all their activities and equipment there is a 'No' in all three columns of Table 3.2. If this is the case then the action levels will not be exceeded, even if multiple activities or items of equipment occur in close proximity. Even where activities or equipment are not listed in Table 3.2, information confirming that action levels are not exceeded may be available elsewhere (see Chapter 7).

Where employers cannot demonstrate compliance with either ALs or ELVs from readily available information, they can either pursue a more detailed assessment (see Chapter 8), or they can consider whether they could introduce measures to restrict access to the fields (see Chapter 9).

5.4.1.2 Indirect effects

Electromagnetic fields can give rise to risks to safety and health through interaction with objects present in the field. The EMF Directive requires that these risks are also assessed, and they should be assessed separately from the risks from direct effects.

The EMF Directive identifies a number of indirect effects that may need to be assessed:

- interference with medical electronic equipment and devices including cardiac pacemakers and other implants or medical devices worn on the body
- projectile risk from ferromagnetic objects in static magnetic fields
- initiation of electro-explosive devices (detonators)
- fires and explosions resulting from ignition of flammable materials by sparks caused by induced fields, contact currents or spark discharges
- contact currents

Many of these indirect effects will only occur in specific situations and hence for most employers the first step will be to consider if these risks are likely to occur at all in their workplace.

The EMF Directive specifies ALs to assist employers in assessing risks for two of these indirect effects: projectile risk from ferromagnetic objects in static magnetic fields; and contact currents. If the AL is not exceeded, the risk is low and no further preventive or precautionary measures are required.

For the remaining indirect effects, there are no ALs, but European standards provide additional guidance on the assessment of risks. This is discussed further in Appendix E of this guide.

5.4.1.3 Workers at particular risk

For workers at particular risk (see Table 3.1) the assessment is generally more complicated. The ALs for direct effects may not provide adequate protection for these workers and a separate assessment is required.

Workers with medical implants or body-worn medical devices may have been given specific information on safe field strengths. If this is the case then this information will provide assessment criteria and should take precedence over any more general information that may be available. For example, the assessment in relation to a pacemaker wearer in the RF plasma devices case study (Volume 2) makes use of manufacturer's data.

Where specific information is not available in relation to medical implants or body-worn medical devices and for pregnant workers, employers should refer to the guidance in Appendix E of this guide.

Key message: matters to be considered

In making an assessment of risks from EMF, employers should consider risks from both direct and indirect effects. Some workers may be at particular risk from EMF (see Table 3.1) and this should also be taken into account.

5.5 Step 4 — Deciding on Preventive Action

If risks are identified then the first step is to ask if they can be eliminated. Would it be possible to reduce the field strength to a level that does not present a risk or is it possible to prevent access to the field?

Where possible, decisions on preventive action should be taken at the design or purchasing stages for new processes or equipment.

Chapter 9 of this guide provides guidance on the preventive and protective measures that may be used to minimise the risks from electromagnetic fields. Collective protection should always take priority over personal protection.

5.6 Step 5 — Taking Action

If it is necessary to take action, it is important to prioritise the implementation of preventive or protective measures. Priority should normally be assigned on the basis of magnitude of the risk and the severity of the outcome should a hazardous event occur. It may be that it is not practicable to put all new measures in place immediately. In this situation a judgement will need to be made on whether some temporary measures may be put in place that will allow work to continue until the permanent preventive measures are in place. Alternatively, it may be decided that the work should stop until the new measures are in place.

5.7 Documenting the Risk Assessment

It is important to record the results of the risk assessment. This should identify the key elements of the risk assessment, including the hazards identified, the workers potentially at risk and the outcome of the assessment. Where workers at particular risk have been identified, this should also be recorded. Requirements for any new preventive or precautionary measures should be documented, along with arrangements for subsequent review of the assessment.

5.8 Monitoring and Reviewing the Risk Assessment

It is important to periodically review the risk assessment to determine if it was suitable and the preventive or protective measures were effective. This review should take account of the results of any routine checks on the condition of the equipment as any deterioration might affect the conclusions of the risk assessment. It is also essential to review the risk assessment if the equipment in use changes or work practices are modified.

Employers should also remember that the status of workers may change. For example, a worker may be fitted with a medical implant or become pregnant. Such a change should trigger a review of the risk assessment to determine if it is still suitable.

Where workers are temporarily exposed in excess of the low AL for magnetic fields (Table B2 of Annex II of the EMF Directive) or any of the sensory ELVs they may experience transient symptoms. These symptoms may include:

- vertigo or nausea from exposure to static and low frequency magnetic fields
- sensory perception such as light flashes (phosphenes) or minor changes in brain function from exposure to low frequency EMF
- sensory perception such as ‘microwave hearing’ from exposure to pulsed radiofrequency fields under specific conditions (see Section B5)

Where workers report such symptoms, the employer should review and, if necessary, update the risk assessment. This may lead to the selection of additional preventive or protective measures.

Section 3

COMPLIANCE ASSESSMENTS

6. USE OF EXPOSURE LIMIT VALUES AND ACTION LEVELS

As discussed in Chapter 2, exposure to electromagnetic fields can produce different effects depending on the frequency. As a result the EMF Directive provides exposure limit values (ELVs) for:

- Non-thermal effects (0 — 10MHz) in Annex II
- Thermal effects (100kHz — 300GHz) in Annex III

It follows from this that it is generally necessary to know the frequency (or frequencies) of the electromagnetic field before the correct ELV can be selected. It can be seen that the two ranges overlap. Hence in the intermediate frequency range (100 kHz — 10 MHz) both thermal and non-thermal effects can occur and so both ELVs need to be considered.

For frequencies between 1 Hz and 6 GHz, ELVs are defined in terms of quantities within the body that cannot be easily measured or calculated. The EMF Directive therefore also provides actions levels (ALs) that are set in terms of external field quantities that can be measured or calculated relatively simply. These ALs are derived from the ELVs using conservative assumptions and so compliance with the relevant AL will always ensure compliance with the corresponding ELV. However, it is possible to exceed an AL and yet still comply with the ELV. This is discussed further in Section 6.1. Figure 6.1 illustrates the process for deciding whether to assess compliance with ALs or ELVs.

The comparison with ALs or ELVs forms an input into the risk assessment process. If compliance with ALs cannot be demonstrated then employers may decide to assess against the ELVs instead. However, such an assessment is likely to be more complex and consequently more expensive. In many cases it may be possible to implement additional measures in order to achieve compliance with either ALs or ELVs. Once the employer has either demonstrated compliance or exhausted all practicable options for additional measures, they should continue with the risk assessment process (see Chapter 5).

Full assessment of worker exposure and comparison with the ELVs can be complex and beyond the scope of this guide. Some further information on assessments is given in Appendix D to this guide. However, the main purpose of the information presented in this chapter is to explain how the system of ELVs and ALs operate in practice so that employers can decide whether to undertake these themselves or seek specialist assistance.

The Directive defines a number of different ALs, more than one of which can apply simultaneously. The ALs either relate to direct or indirect effects. At low frequencies, electric and magnetic fields can be regarded as independent (the so-called quasi-static approximation) and both will induce electric fields in the body. Hence at low frequencies there are ALs for electric and magnetic fields. There are also ALs for contact current.

As frequency increases, the fields become more closely coupled and the interaction with the body changes, resulting in energy deposition leading to thermal effects. For these frequencies there are ALs for electric and magnetic fields. At frequencies above 6 GHz, there is an additional AL for power density, which is related to both the electric and magnetic field strengths. There are also ALs for induced limb currents, which also relate to thermal effects, and for contact currents. The system of ALs is illustrated in Figure 6.2.

Figure 6.1 — Process for deciding whether to assess compliance with ALs or ELVs

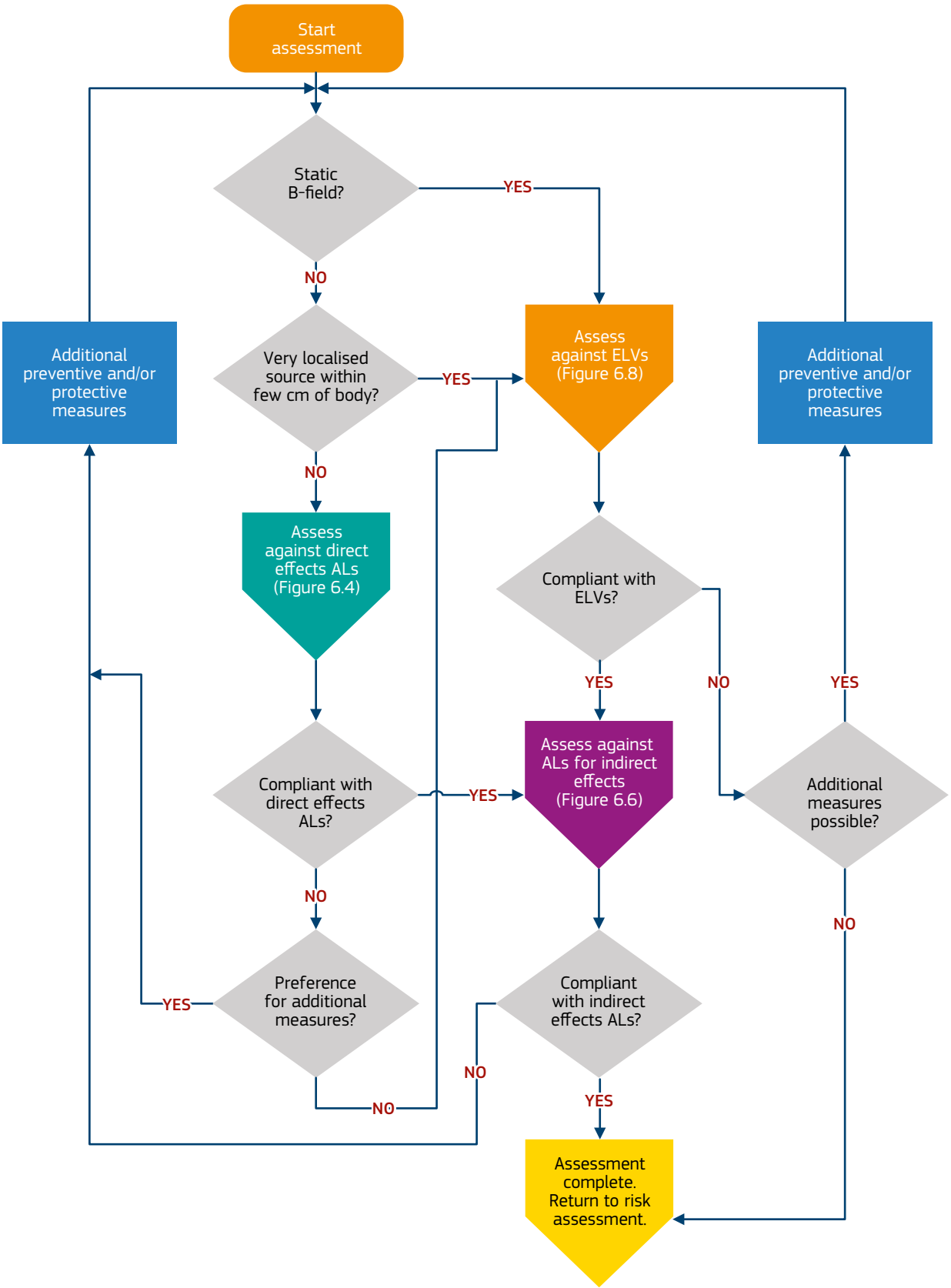
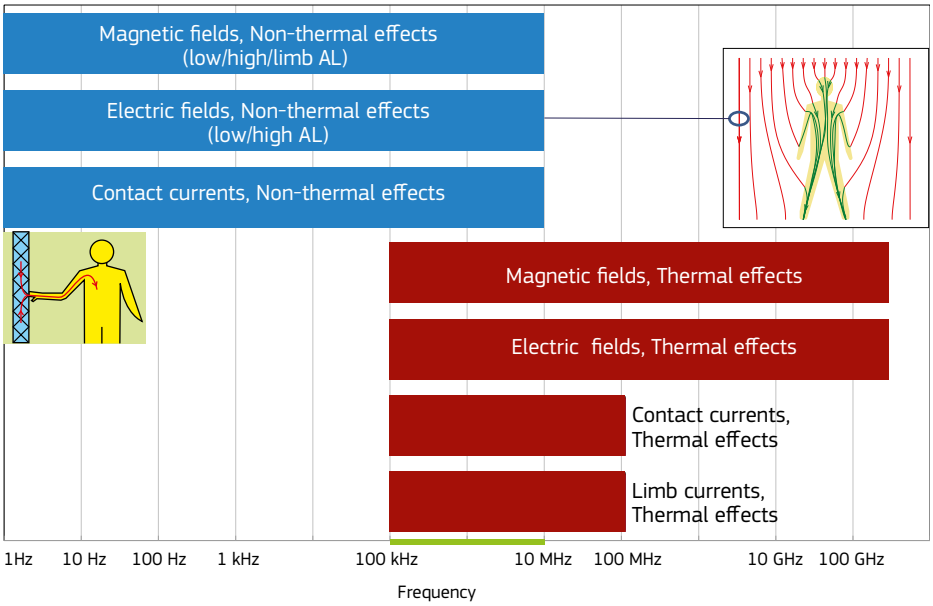


Figure 6.2 — Range of frequencies over which different ALs are applicable.



Blue bars indicate non-thermal effects and red bars thermal effects. Where the frequency range is highlighted in green both compliance with non-thermal effects (electric field, magnetic field and contact currents) and with thermal effects (electric and magnetic field) is required.

The ELVs and the related ALs are based on the guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Further information on the underlying rationale can be found in these guidelines, which are available from www.icnirp.org (see Resources in Appendix I).

The EMF Directive requires Member States to implement the ELVs into their national legislation and hence employers are legally bound to comply with them. The EMF Directive contains provisions to allow the ALs to be revised by the Commission should the need arise.

Key message: action levels and exposure limit values

For most employers it will be simpler to demonstrate compliance with action levels than exposure limit values, although compliance distances may well be larger for the former than the latter. Action levels are also provided for some, but not all, indirect effects. Action levels and exposure limit values will not normally provide sufficient protection for workers at particular risk.

6.1 Direct Effects Action Levels

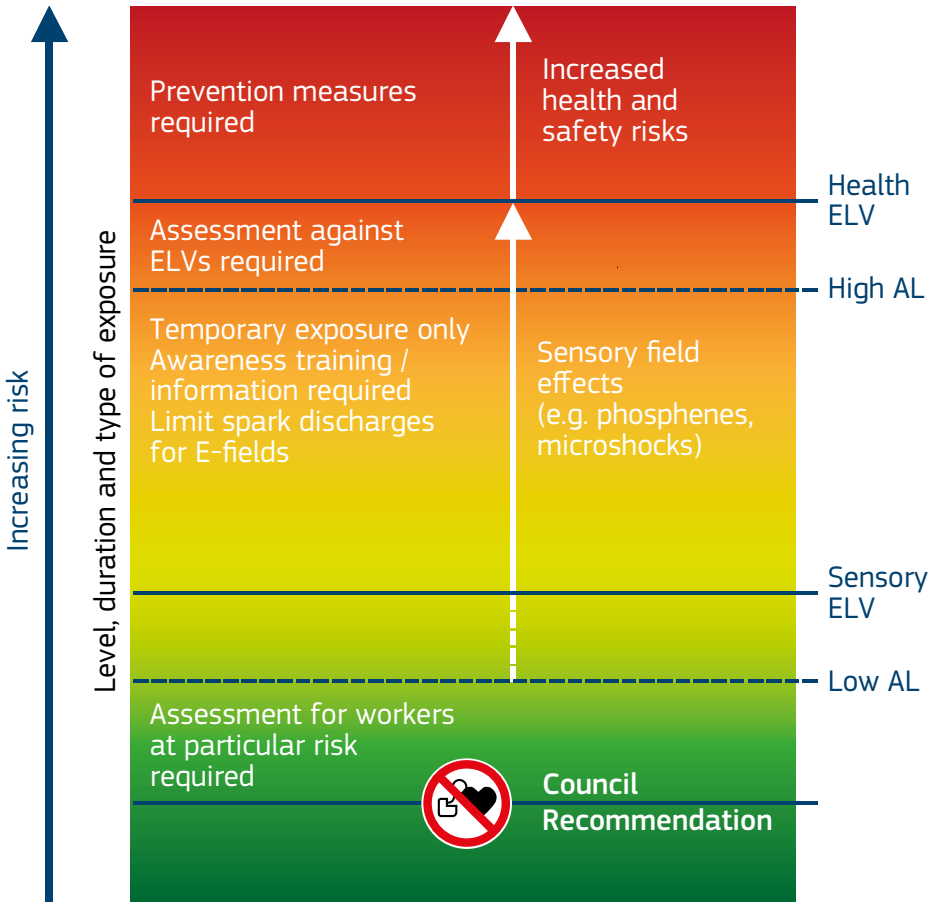
As indicated above, the direct effects ALs have been derived from the corresponding ELVs using computer modelling and assuming worst case interactions. This means that compliance with the AL will guarantee compliance with the corresponding ELV. However, in many situations it will be possible to exceed the AL and still comply with the corresponding ELV. The relationship between the AL and ELV is illustrated in Figure 6.3. For most employers and most situations, the direct effects ALs offer a relatively simple route to demonstrating compliance with the underlying ELVs.

All ALs are specified for fields that are unperturbed by the presence of the worker's body.

If it is not possible to demonstrate compliance with the ALs, then employers have a choice to either implement protective and preventive measures or to assess compliance with the ELV directly. In making this decision, employers will need to consider that the outcome of assessment against the ELV may still be a requirement to implement protective and preventive measures.

The process for the selection of direct effects action levels is illustrated in the flow chart in Figure 6.4.

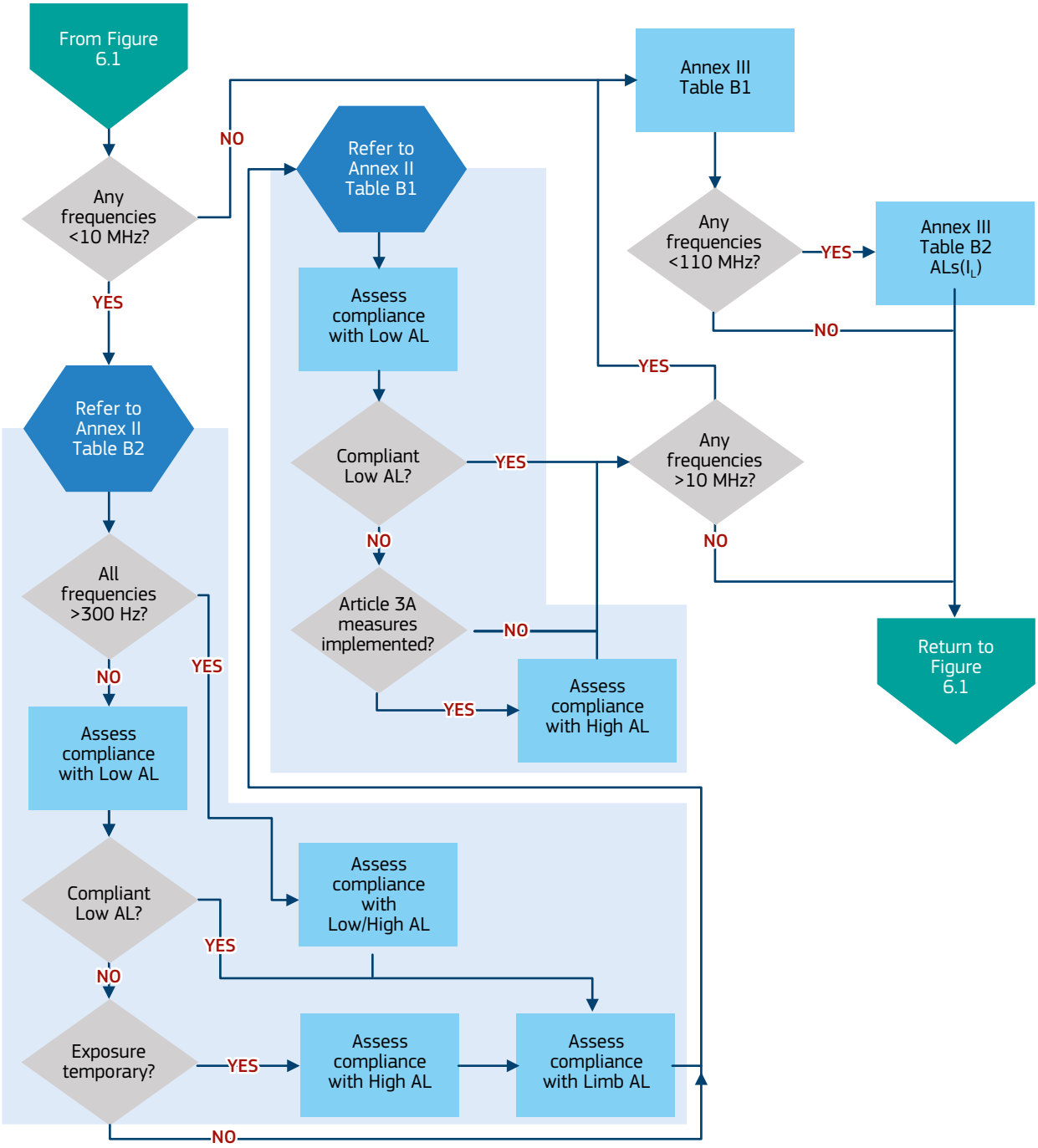
Figure 6.3 Schematic showing relationship between exposure limit values and action levels



6.1.1 Electric field Action Levels (1 Hz — 10 MHz)

The EMF Directive defines two ALs for low frequency electric fields, low and high. The concept of low and high ALs is illustrated in Figure 6.3 above. Compliance with the low AL will ensure that neither of the applicable ELVs will be exceeded and will also prevent annoying spark discharges in the work environment.

Figure 6.4 — Flow chart for selection of direct effects ALs ("Annex" refers to the Annexes of the EMF Directive)



Provided that electric field strengths do not exceed the low AL, neither of the applicable ELVs will be exceeded. However, if electric field strengths exceed the low AL, compliance with the high AL will not, on its own, be sufficient to prevent annoying spark discharges. Hence in this situation it is necessary to implement additional technical, organisational and, if appropriate, personal protective measures to limit spark discharges.

6.1.2 Magnetic field Action Levels (1 Hz — 10 MHz)

The EMF Directive defines three ALs for low frequency magnetic fields, low, high and limb.

The low ALs are derived from the sensory effects ELVs (see Section 6.3.1) such that compliance guarantees compliance with both sensory effects and health effects ELVs. Low ALs have the same value as high ALs for frequencies above 300 Hz.

Compliance with the high ALs will guarantee compliance with the health effects ELVs, from which they are derived, but will not ensure compliance with the sensory effects ELVs at frequencies below 300 Hz. The EMF Directive allows the low ALs to be exceeded, provided it can be shown either that the sensory effects ELVs are not exceeded, or if they are exceeded, that this occurs only temporarily. Nevertheless, the health effects ELVs must not be exceeded. Moreover, workers must be informed about possible transient symptoms and sensations. Where transient symptoms are reported the employer shall, if necessary, take action to update the risk assessment and prevention measures.

Compliance with the limb ALs will ensure compliance with the health effects ELVs, from which they are derived. The limb ALs take account of weaker coupling of the field into the limbs and are consequently less restrictive than the high ALs. Use of the limb ALs would only be justified where body exposure at the same field strength is unlikely. So their use would be justified in the case of a worker holding a tool generating EMF, but not if the tool was being held next to the body when in use (Figure 6.5). Where assessment of limb exposure against the limb action level is carried out, it would be normal practice to also assess body exposure against the low or high AL as appropriate.

Figure 6.5 — Worker with a power tool held close to the body. In this situation exposure of the body and limbs will be similar and compliance with the low/high ALs will be limiting

6.1.3 Electric and magnetic field Action Levels (100 kHz — 300 GHz)

For frequencies between 100 kHz and 6 GHz, the EMF Directive defines ALs for electric field strength and magnetic flux density, which are derived from the health effects ELV. As the underlying ELVs are time averaged values, the square of the AL should be averaged over any six minute period.

For frequencies above 6 GHz, the EMF Directive defines ALs for electric field strength, magnetic flux density and power density. The power density AL should be averaged over any 20 cm^2 of exposed area, subject to the condition that spatial maximum averaged of any 1 cm^2 should not exceed 20 times the AL(S). Power density ALs are also time averaged, over any six minute period for frequencies up to 10 GHz, and over any $68/f^{1.05}$ minute period for higher frequencies (where f is the frequency in GHz). Beyond this the averaging time decreases with increasing frequency reflecting decreasing penetration depth.

For frequencies above 6 GHz, the ALs for electric field strength and magnetic flux density are derived from the power density ELV. Hence, although not explicitly stated in the EMF Directive, for consistency the spatial and time averaging conditions for AL(S) should also apply to $[AL(E)]^2$ and $[AL(B)]^2$ at frequencies above 6 GHz.

6.1.4 Induced limb current Action Levels (10 — 110 MHz)

The EMF Directive specifies ALs for the magnitude of the radiofrequency current induced in the limbs of a worker exposed to a radiofrequency field. As this AL relates to heating of tissues, the square of the AL should be averaged over any six minute period.

6.2 Indirect Effects Action Levels

The EMF Directive specifies ALs to provide protection from some indirect effects associated with EMF. The process for the selection of indirect effects action levels is illustrated in the flow chart in Figure 6.6.

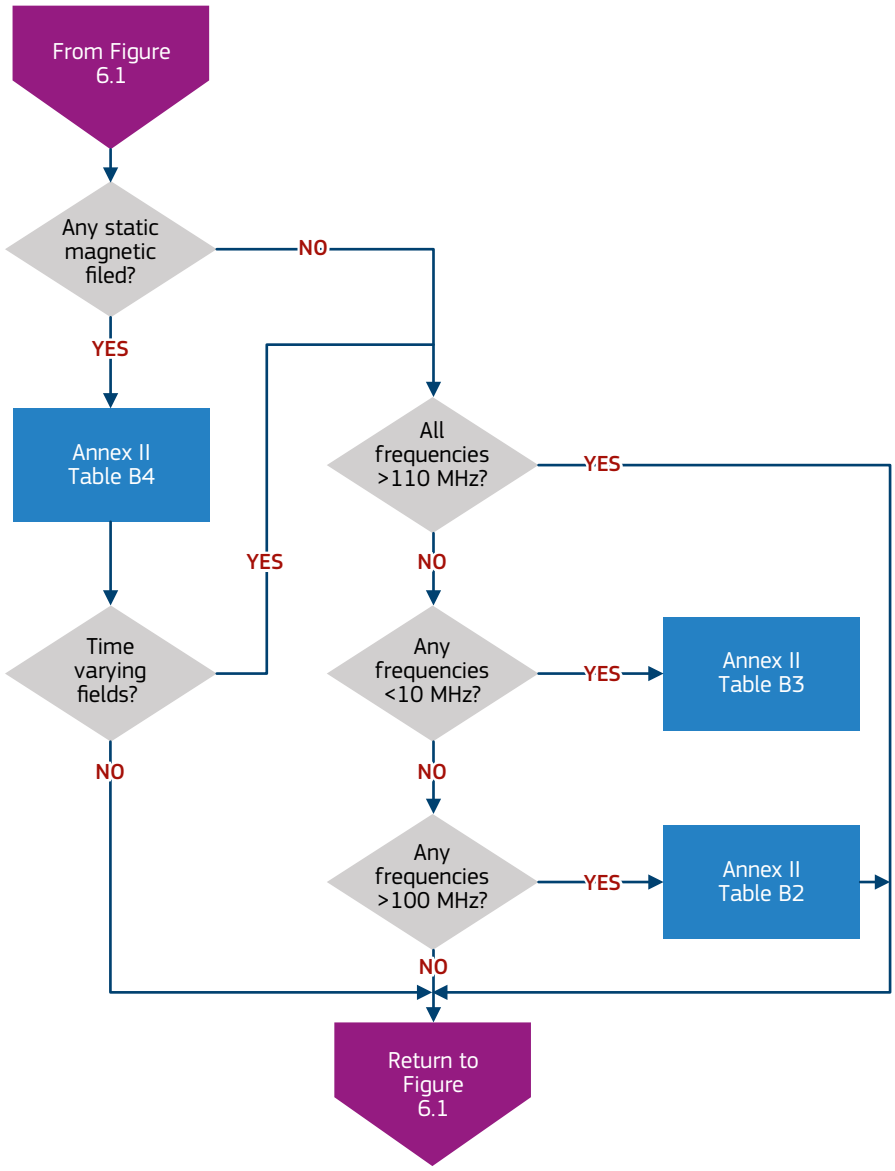
6.2.1 Static magnetic field Action Levels

An AL of 0.5 mT is specified to limit interference with the function of active implanted medical devices. The EMF Directive also provides an AL of 3 mT to limit the projectile risk in the fringe field from strong sources (> 100 mT).

6.2.2 Contact current Action Levels (up to 110 MHz)

The EMF Directive specifies ALs for steady state contact current to limit the risk of shock and burn when a person touches a conducting object in a field and one of them is grounded whilst the other is not.

Figure 6.6 — Flow chart for selection of indirect effects ALs ("Annex" refers to the Annexes of the EMF Directive)

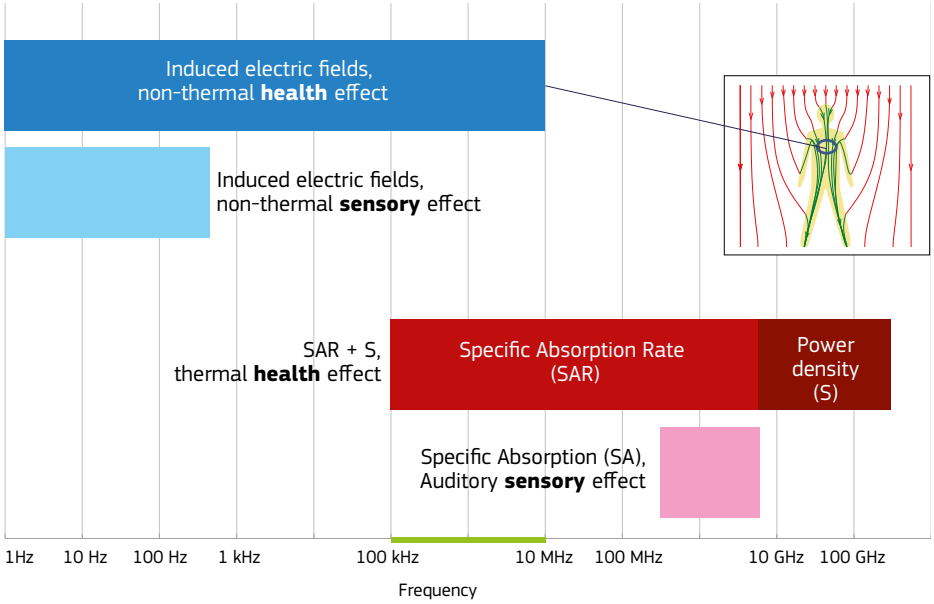


6.3 Exposure Limit Values

6.3.1 Sensory and health effects Exposure Limit Values

The EMF Directive defines separate ELVs for sensory and health effects (Figure 6.7). The sensory effects ELVs only apply to specific frequency ranges (0 — 400 Hz and 0.3 — 6 GHz). For low frequencies, perception of the field occurs at exposure levels lower than those producing health effects. The thermal effects sensory ELV is based on the avoidance of the 'microwave hearing' effect, which only occurs under specific conditions (see Appendix B). In contrast, health effects ELVs apply to all frequencies. In general, it is permissible to temporarily exceed the sensory effects ELVs for short periods providing certain conditions are met.

Figure 6.7 — Range of frequencies over which different ELVs are used.



Blue bars indicate non-thermal effects and red bars thermal effects.

6.3.2 Exposure Limit Values (0 — 1 Hz)

ELVs for the frequency range of 0 — 1 Hz are defined in terms of external magnetic flux density (Table A1 of Annex II of the EMF Directive). The sensory effects ELVs are set to prevent vertigo and other perceptual effects. These mainly result from electric fields induced in tissues when the body moves in a strong static magnetic field, although there is now some evidence that they can occur in the absence of movement. Hence for a controlled working environment where movement in the field is limited and workers are provided with information, it may be permissible to temporarily exceed the sensory effects ELVs provided this is justified by the practice or process. In this case exposures must not exceed the health effects ELV.

6.3.3 Exposure Limit Values (1 Hz — 10 MHz)

The ELVs in the frequency range of 1 Hz — 10 MHz are defined in terms of internal electric fields induced in the body (Table A2 and Table A3 of Annex II of the EMF Directive).

For frequencies up to 400 Hz, there are both sensory effects ELVs and health effects ELVs. The sensory effects ELVs are intended to prevent retinal phosphenes and minor transient changes in brain function. Consequently they only apply to the central nervous system (cns) tissues within the head of the exposed worker.

The health effects ELVs apply to all frequencies between 1 Hz and 10 MHz and are intended to prevent stimulation of peripheral and central nerves. Hence these ELVs apply to all tissues throughout the body of an exposed worker.

6.3.4 Exposure Limit Values (100 kHz — 300 GHz)

For frequencies in the range 100 kHz — 6 GHz, the degree of heating resulting from exposure depends on the rate at which energy is absorbed in tissues. This is defined by the specific energy absorption rate (SAR), which is used to specify the health effects ELVs, with separate values for whole body and localised exposures (Table A1 of Annex III of the EMF Directive). The whole body values protect from heat stress and heat stroke and are applied to the SAR averaged over the entire body. The localised values protect from thermal injury to specific tissues and are applied to the SAR averaged over any 10 g of contiguous (or connected) tissue. Both whole body and localised SAR are averaged over a six minute period.

For frequencies in the range 300 MHz — 6 GHz there are also sensory effects ELVs that are intended to prevent the 'microwave hearing' phenomena resulting from exposure to pulsed fields (Table A2 of Annex III of the EMF Directive). These are specified in terms of specific absorption (SA) averaged over 10 g in the head.

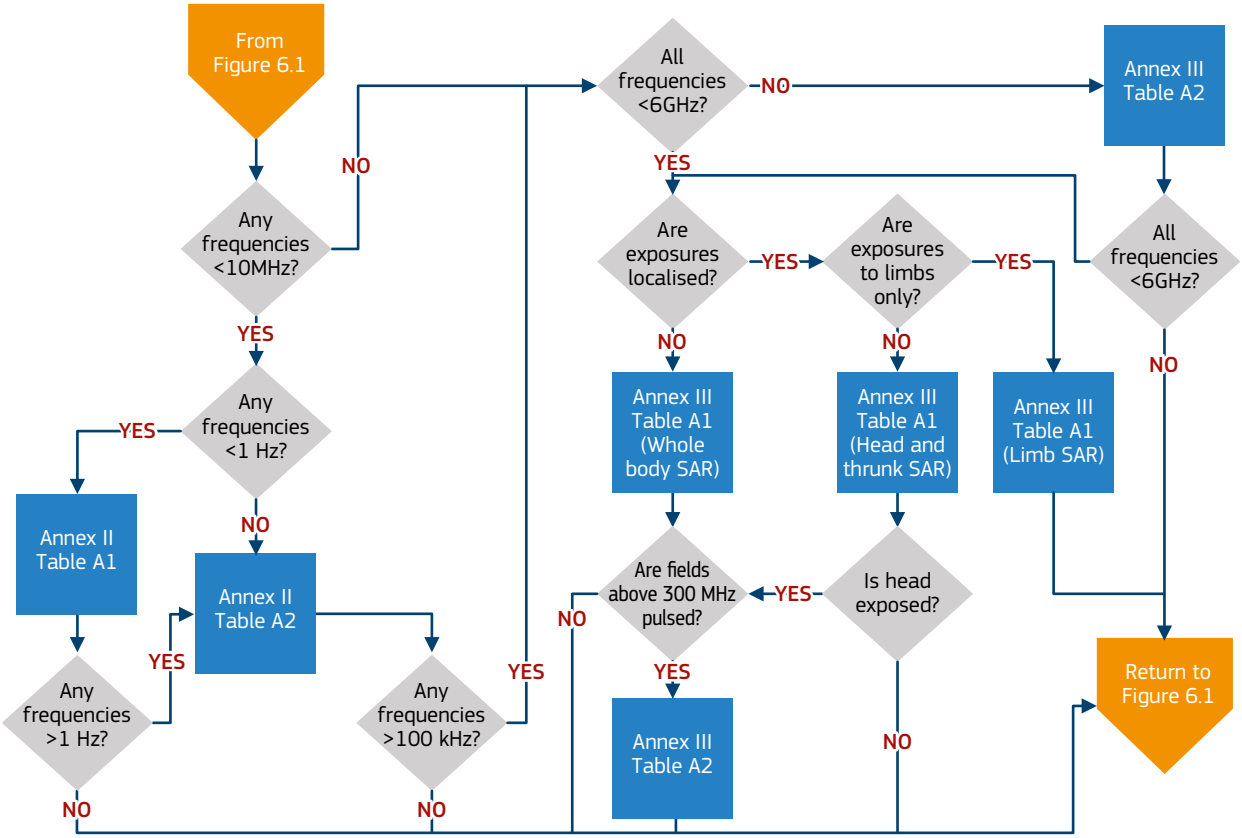
Penetration of EMF into the body decreases with frequency in the radiofrequency range, so that for frequencies above 6 GHz the field is absorbed mostly on the surface of the body. This means that for these frequencies it is much more relevant to limit power density incident on the body surface than the rate at which energy is absorbed into a mass of tissue. The power density is averaged over 20 cm^2, subject to a limit on the maximum averaged over any 1 cm^2. For frequencies in the range 6 — 10 GHz the power density is averaged over any six minute period. Beyond this the averaging time decreases with increasing frequency reflecting decreasing penetration depth (Table A3 of Annex III of the EMF Directive).

6.4 Derogations

Article 10 of the EMF Directive grants a conditional derogation from Article 3 (ELVs and ALs) for three situations. Article 10 does not affect the general duty of employers under Article 5(1) to ensure that risks from EMF in the workplace are eliminated or reduced to a minimum.

The first derogation, relating to the use of magnetic resonance imaging (MRI) in healthcare is non-discretionary. The remaining derogations are at the discretion of Member States.

Figure 6.8 — Flow chart for selection of ELVs



6.4.1 MRI derogation

Exposures relating to installation, testing, use, development, maintenance of, or research related to MRI for patients in the healthcare sector may exceed the ELVs subject to the following conditions:

(i) the risk assessment has demonstrated that the ELVs are exceeded

(ii) given the state of the art, all technical and/or organisational measures have been applied

(iii) the circumstances duly justify exceeding the ELVs

(iv) the characteristics of the workplace, work equipment, or work practices have been taken into account

(v) the employer demonstrates that workers are still protected against adverse health effects and safety risks, including ensuring that instructions for safe use provided by the manufacturer are followed.

Further guidance for employers on compliance with the MRI derogation is given in Appendix F of this guide.

6.4.2 Military derogation

Member States may allow for the implementation of equivalent protection systems for workers in operational military installations or involved in military activities. This derogation is subject to the condition that adverse health effects and safety risks are prevented.

6.4.3 General derogation

Member States may allow ELVs to be temporarily exceeded in specific sectors and for specific activities outside the scope of the other two derogations, provided the circumstances are duly justified. In order for circumstances to be duly justified, the following conditions must be met:

(i) the risk assessment has shown that the ELVs are exceeded

(ii) given the state of the art, all technical and/or organisational measures have been applied

(iii) the specific characteristics of the workplace, work equipment, or work practices have been taken into account

(iv) the employer demonstrates that workers are still protected against adverse health effects and safety risks, including using comparable, more specific and internationally recognised standards and guidelines.

7. USE OF DATABASES AND MANUFACTURER'S EMISSION DATA

Information on exposures may be available from manufacturers of equipment. In addition, government institutes, professional bodies or trade associations may develop and maintain databases of generic exposure assessments. If this type of information is available and relevant, it will provide employers with the simplest means of demonstrating compliance with the EMF Directive. It follows that most employers will want to explore this option prior to considering assessment of exposures by measurement or calculation.

7.1 Using Information Provided by Manufacturers

It is important for employers to recognise that their responsibilities under the EMF Directive relate to the total exposure of the worker rather than exposure from a particular item of equipment. The assessment will therefore need to take account of exposure arising from all sources in the working environment. In contrast, where manufacturers provide information, this will be for the particular item of equipment they produce.

For most types of equipment field strengths fall very rapidly with distance from the source (see Figure 3.2. This means that in many cases worker exposure will be dominated by one, or at worst, a few items of equipment in the immediate vicinity of the workstation. Consequently, employers will often want information on the way that fields fall off with distance from the equipment. When considering contributions to worker exposure from multiple sources, employers should not forget fields generated by ancillary installations such as supply cables, power supplies and switchgear.

Whilst information from manufacturers has the potential to offer a simple solution to the problem of assessing exposure, employers do need to exercise some caution in its use. There are many reasons why manufacturers provide information about EMF associated with their equipment. For example a manufacturer may provide information about the field strength generated by equipment, because this is important to its function and consequently part of the specification. Information may also be provided to demonstrate compliance with electromagnetic compatibility requirements of European product directives (see Appendix G). Whilst this information may be of relevance to safety issues from interference, it will not be helpful for the purposes of exposure assessment.

The most helpful information from the employer's perspective would be an assessment of typical worker exposures during normal use of the equipment together with an indication of the way fields fall off with distance. Alternatively an indication of field strengths relative to the action levels at various accessible positions around the equipment would enable employers to make their own assessment of compliance during use.

Key message: information from databases and manufacturers

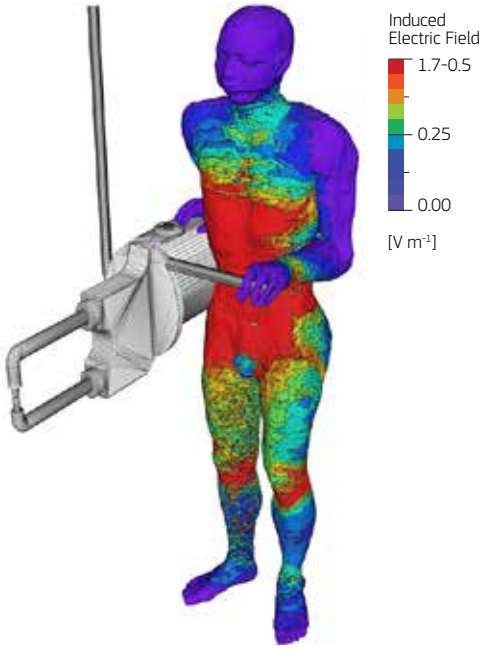
Where information from databases and manufacturers is available this will offer employers a much simpler route to demonstrating compliance than undertaking a specific assessment. Suppliers of machinery have a legal obligation to ensure emissions are not hazardous to people (see Appendix H). They are also required to provide information on residual risks and likely emissions that may cause harm to people, including those wearing implanted medical devices.

7.1.1 Basis for Manufacturer's Assessment

Some manufacturers may publish assessments of their equipment undertaken using standardised procedures. However, many measurement standards are produced from an emission rather than a human exposure point of view. These emission standards are developed to provide standardised procedures for laboratory testing of the level of EMF produced by specific types of electrical devices. They are focused on the field value at a certain point in space and are useful in comparing different devices or appliances. However, they may be of limited value in assessing exposure relative to ALs or ELVs in normal use.

For example the currently harmonised standard for compliance testing of welding equipment recommends measuring fields at 20 cm from the welding cable as this results in a more reproducible measurement. However, in everyday use the cable may be in contact with the worker's body and may be close to sensitive tissues in the worker's head. Figure 7.1 illustrates a spot welding gun held close to a workers body and well within the specified 20 cm. It is understood that this weakness will be addressed in future editions of the standard.

Figure 7.1 — Induced electric field distribution in a human model from exposure to a portable spot welding or PSW gun. This is an example in which the electromagnetic field source is significantly less than 20 cm away from the body



Note: The example in this figure is provided for illustrative purposes only and should not be extrapolated to any specific situation

This illustrates that before making use of data published by manufacturers it is important to understand which standard was applied and for what purpose the data was generated.

7.2 Assessment Databases

Databases of generic assessments for particular industry sectors may be very helpful. These might be produced by government institutions, professional bodies or trade associations. In all cases a prime consideration would be to save individual employers from the time and expense of carrying out specific assessments. Where equipment and work practices are fairly standard this is a pragmatic cost-effective approach.

When considering the use of information obtained from databases, employers should check that the equipment is being used as intended in both the database assessment and their own workplace. In addition, the assessment data may not be relevant if the equipment is of a very different age or has not been properly maintained.

The European Commission has supported work to develop a software package that is intended to assist employers in carrying out assessment of welding and allied processes. Further information on this project is available through the EMF weld website (www.emfweld.com).

7.3 Provision of Information by Manufacturers

Manufacturers that supply equipment falling within the scope of the Machinery Directive (see Appendix G) have specific obligations in respect of the provision of information. In particular, in order to satisfy the essential requirements, manufacturers have to provide information on any residual risks and any protective measures to be implemented by the user.

More specifically, where machinery is likely to emit non-ionising radiation that may cause harm, particularly to those with medical implants, the manufacturer is required to provide information on the emission in respect of both the operator and anyone else exposed.

7.3.1 Assessment standards

Standards committees are actively developing standards to guide manufacturers through the process of assessing emissions in relation to the ALs and ELVs specified in the EMF Directive. In some cases these standards also specify how the assessment results should be reported to purchasers of equipment.

Hence the first step for any manufacturer should be to check whether a relevant standard has been published and relates to the current EMF Directive. If a relevant standard exists and provides advice on the reporting of assessment results, then the manufacturer should follow it.

Manufacturers may also decide to provide additional information not specified in the standard where they feel this would be helpful to a purchaser.

7.3.2 If there is no relevant standard

Where there is no relevant standard to guide the manufacturer, the following assessment information should enable purchasers to carry out adequate assessments in their own workplaces.

The first three items of information should provide the purchaser with some background information about the types of effect expected and how the assessment was carried out. In particular, it will be important for the purchaser to know if the operating conditions for the assessment will reflect the way they will use the equipment.

The next two items of information will be helpful in understanding likely operator exposures and whether they will need to implement restrictions or provide staff training.

The final two items of information can be used for a simple assessment of the effect of placing multiple items of equipment in the same area. Employers can use the contours showing percentage of the AL or percentage of the reference levels given in Council Recommendation 1999/519/EC to make a simple assessment of the cumulative effect of positioning equipment in close proximity.

This approach will often produce an overestimation of the resulting field strengths. This is because sources may not all operate at the same time and often there will cancellation of fields due to phase differences. Nevertheless, the approach is simple to apply and will make it easy for most purchasers to demonstrate compliance.

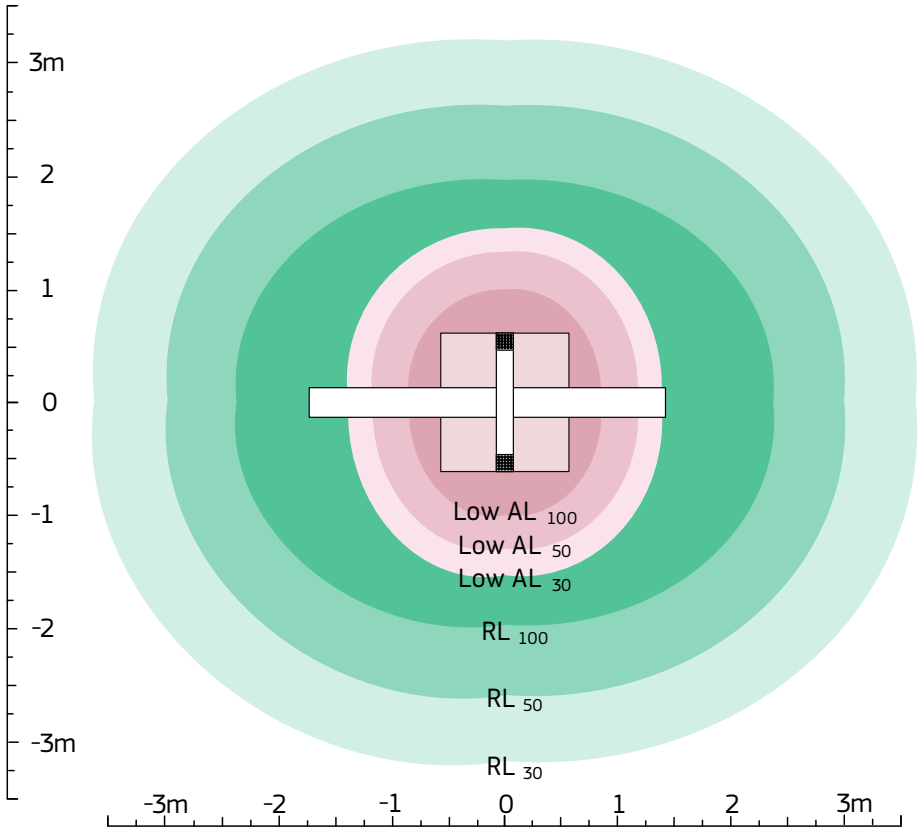
Table 7.1 — Suggested information to be provided by manufacturers

Matters to be considered in a workplace assessment:	• non-thermal effects • thermal effects • indirect effects (specify)
Operating conditions under which assessment carried out:	• maximum power source capability • worst case settings (specify) • typical settings (specify)
Averaging applied to assessment result • spatial • time	
When used as intended, does exposure at the normal operator position exceed: • low AL, • high, • limb — OR — • sensory effects ELV, • health effects ELV	
When used as intended, does exposure at the normal operator position exceed the relevant values from Council Recommendation 1999/519/EC for: • reference level OR • basic restriction	
Where field strengths may exceed one or more ALs, provide maximum distances, or preferably a contour plan, for the following fractions of the AL: • 100 % • 50 % • 30 %	
Where field strengths may exceed one or more reference levels, provide maximum distances, or preferably a contour plan, for the following fractions of the reference level: • 100 % • 50 % • 30 %	

In general physical considerations will constrain the number of units that can be placed in close proximity. As fields typically fall rapidly with distance (see Chapter 3), more distant equipment is not likely to make a significant contribution to exposure.

Figure 7.2 illustrates contour plans that could be provided for equipment.

Figure 7.2 — Illustration of contour maps that could be provided by manufacturers to assist users in ensuring that the cumulative effect of multiple items of equipment in the workplace does not cause ALs to be exceeded.



The example shows a generic piece of equipment with contours showing the distances at which the field is equal to 100 %, 50 % and 30 % (indicated by subscripts) of the relevant AL. Equivalent contours are given for the reference levels in Council Recommendation 1999/519/EC (indicated by RL) to aid assessment for workers at particular risk.

8. CALCULATION OR MEASUREMENT OF EXPOSURE

The assessment of EMF exposures is a specialist subject and few employers will have the expertise to carry out these assessments themselves. However, the alternative of using an external contractor may well be costly. In general employers will need to weigh this cost against that of implementing simple protective or preventive measures (see Chapter 9). When considering the available options, it is important to bear in mind that the outcome of any assessment might be a requirement to implement protective or preventive measures anyway. As discussed earlier in this guide, fields often fall rapidly with distance so that restricting access to the immediate vicinity of equipment may be a cheap and effective measure.

8.1 Requirements of the EMF Directive

The EMF Directive includes a clear requirement for employers to assess the risks to their employees arising from electromagnetic fields in the workplace. As part of the risk assessment, employers are required to identify and assess EMF in the workplace. However, this need not involve calculation or measurement as employers are entitled to take into account emission and other safety-related data provided by manufacturers or distributors. It is only if compliance with ELVs cannot be reliably demonstrated by other means that employers are required to undertake calculations or measurements.

Where manufacturers have provided exposure data or assessments of risks, this will generally offer a simpler and cheaper route to demonstrating compliance. Similarly, where relevant generic assessment data is available from government institutions, professional bodies and trade associations, employers will normally find it easier to use this than to pursue exposure assessments. Both of these options are discussed further in Chapter 7.

8.2 Workplace Assessments

Where employers decide that there is a need to undertake exposure assessment within the workplace there are often a variety of options available. The first decision will be whether to assess the exposure by calculation or by measurement. Both are acceptable approaches to demonstrate compliance with the EMF Directive and both may offer a number of different options varying in complexity.

Simple assessment methods are often based on assumptions or approximations that will result in exposure being overestimated. As a result, more complex assessment methods are likely to result in smaller compliance distances but will almost certainly cost more in terms of time or money. It follows that the final choice will be determined by the particular circumstances of the work and workplace. However, for many employers a relatively simple assessment will be perfectly adequate.

Assessments of EMF exposure are often complex. Consequently employers proposing to assess exposures themselves will need to consider the competence of those undertaking the work. A few employers will have the necessary knowledge and skills in-house, but for most acquiring these skills will require a significant investment.

For measurement-based assessments, there will be additional investment in acquiring the necessary instruments and keeping these calibrated. Those carrying out the

assessment will need an understanding of the technical performance required from instruments so that they ensure they acquire suitable equipment. They also need to know how to use the instrument 'in the field' and be aware of the pitfalls. They must be able to recognise that measurements represent a 'snapshot' that is dependent on the operating parameters of the equipment at the time of the survey. Where assessments are infrequent, employers may find that hiring instruments from a reputable supplier is a more cost-effective option.

Finally, it is important to recognise that carrying out an assessment is not simply a matter of measuring fields. It is important to assess the nature of the work carried out so that the locations of workers can be determined. For frequencies where time averaging is permitted it is also essential to record duty cycles of equipment and to estimate the duration of occupancy of areas.

8.3 Special Cases

There are a number of situations where exposures may be unusually complex. Some of these are discussed further in Appendix D, as indicated in Table 8.1.

Table 8.1 — Further guidance on complex exposure assessments

Assessment scenario	Appendix
Non-uniform exposure	D2
Exposure to fields with frequencies between 100 kHz and 10 MHz	D3
Simultaneous exposure to multiple frequency components	D3
Exposure to non-sinusoidal fields	D3
Assessment of fields with frequencies from 0 — 1 Hz	D4

8.4 Seeking Further Assistance

Where employers do not already possess the expertise and, in the case of measurements, the instruments, needed to undertake assessments, a significant investment will be needed to develop this. For some employers this may be worthwhile, but for most it will not.

Employers seeking external assistance should bear in mind that this may be available from a number of different providers. The following types of organisation may have the necessary expertise and instruments to be able to help:

- national health and safety establishments
- some local or national authorities offer inexpensive assessment services to employers in their areas
- research establishments (such as universities)
- manufacturers of measurement instruments or their agents
- specialist commercial consultancies

When approaching any external provider for assistance the employer will want to be assured that it is competent to provide the service required. Employers should seek evidence that the service provider will:

- provide staff who are knowledgeable and experienced in the application of relevant ELVs and ALs, and any calculation methods required
- provide staff who are knowledgeable and experienced in the type of assessment required
- use instruments capable of measuring the fields of interest, bearing in mind factors such as frequency components, pulse characteristics and waveforms
- be able to demonstrate traceability of calibration to an appropriate national standard
- be able to estimate the uncertainty on any measurements made

The employer is dependent on the external provider to select appropriate ALs or ELVs and to generate data that is appropriate for comparison. Providers will need a system of quality assurance to ensure that data are reliable. They will also need to provide a written report that explains to the employer what the assessment means and provides clear conclusions. If appropriate, the report should also make recommendations for further actions.

Key message: measurement or calculation of exposure

Assessment of exposure by measurement or calculation is generally complex and should be avoided where information is available from other sources such as manufacturers or databases. If it is necessary to undertake an assessment, employers should consider carefully whether they have the capability to undertake this themselves

For many employers it may be more cost-effective to obtain external assistance, but in these cases they will want to assure themselves that the service providers have the appropriate instrumentation, competence and experience to undertake the assessment.

Section 4

NEED TO DO MORE?

9. PROTECTIVE AND PREVENTIVE MEASURES

The selection of appropriate protective or preventive measures for any specific situation should be guided by the outcome of the risk assessment. This will provide information about how hazardous exposures could occur. The selection of the measures to control risks will also need to take account of the nature of the work to be undertaken.

As discussed in Chapter 6, if it can be established that action levels (ALs) or exposure limit values (ELVs) will not be exceeded and there are no significant risks from indirect effects or to workers at particular risk then no further measures will be necessary.

For areas where there is a risk of exceeding ALs or ELVs, or of indirect effects occurring, then the employer will need to consider if the area is accessible whilst fields are present. If access to the area is already adequately restricted for other reasons (due to high voltages, for example) then additional measures will not normally be needed. If this is not the case then the employer will usually need to implement additional measures.

If additional protective or preventive measures are introduced then the related aspects of the risk assessment should be reviewed to determine if all risks have now been eliminated or reduced to a minimum.

In general the introduction of protective or preventive measures during design and installation of workplaces or equipment can offer significant advantages in safety and operation. Implementation at a later time may have significant cost implications.

9.1 Principles of Prevention

Where protective and preventive measures are required, Article 6 of the Framework Directive specifies principles of prevention that should be applied to all risks (see Table 9.1)

Table 9.1 — Principles of prevention specified in the Framework Directive

Principles of prevention:
Avoiding risks
Evaluating risks that cannot be avoided
Combating risks at source
Adapting work to the individual, especially as regards the design of the workplaces, the choice of work equipment and the choice of working and production methods
Adapting to technical progress
Replacing the dangerous by the non-dangerous or less dangerous
Developing a coherent overall prevention policy that covers technology, organisation of work, working conditions, social relationships and factors related to the working environment
Giving collective protection priority over individual protective measures
Giving appropriate instructions to workers

9.2 Elimination of the Hazard

The most effective means to control risks is to eliminate the hazard completely. This might involve switching to an alternative process that does not result in the generation of strong EMF. An example, might be switching from electrical resistance welding to laser welding. However, it is recognised that will not always be practicable. Often there will be no suitable alternative process, or the available alternatives may introduce other types of hazard (in the example above, the presence of a high power laser beam) that result in equal or greater risks to workers.

Elimination of hazards will often involve redesigning an entire process and substantial investment in new equipment. Hence often it will be viable only during the initial setup or major re-tooling. However, at these times consideration should be given to alternative means to achieve the same end without the generation of strong EMF.

9.3 Substitution by Less Hazardous Process or Equipment

An effective approach to reducing the risks from EMF is to substitute existing processes or equipment with those producing less EMF. For example, in its simplest form dielectric welding of plastics can involve high operator exposures to radiated radiofrequency EMF and even a risk of burns from touching exposed electrodes. Normally it will be feasible to design equipment incorporating shielding to limit the magnitude of the radiated field, often in combination with automation to increase the separation of the operator from the electrodes.

Although the replacement of existing plant with more highly automated and better shielded equipment will normally improve the efficiency of the process, there is a substantial capital cost. Hence this option will usually be viable only as part of the normal equipment replacement cycle.

Key message: measures to reduce risks

Where risks cannot be reduced by elimination or substitution, it will be necessary to introduce additional measures. There are many options available to employers to achieve this end and in general technical and organisational measures will be preferable because they provide collective protection. Many of the measures that might be employed to reduce risks from EMF are similar to those used for other workplace hazards.

9.4 Technical Measures

Where it is practicable to implement technical measures, these will have the advantage that they provide collective protection and will normally involve combatting risks at source. In addition, they will normally be more reliable than organisational measures since they do not rely on people to take action. A number of technical measures may be effective in preventing or limiting access to EMF; these are discussed further below.

9.4.1 Shielding

Shielding can be an effective means to reduce electromagnetic fields produced by a source and will often be incorporated into the design of equipment in order to limit emissions. A good example of this is a microwave oven. A mesh in the window is connected to the metal housing of the oven to form a continuous shield that limits the emission of microwave radiation. Shields can also be applied to rooms to produce a weak electromagnetic environment, although this is usually done to protect sensitive electrical equipment rather than people.

In practice shields for radiofrequency and low frequency electric fields rely on enclosing the source within a conducting surface (a Faraday shield). This is normally made from sheet metal, or metal mesh, although other materials such as ceramics, plastics and glass with one or more metallic coatings, or incorporating a metallic mesh, can also be used. The latter are useful for windows in situations where it is necessary to view the process. Where airflow is needed, for cooling for example, this can normally be achieved by using metallic meshes or honeycomb materials.

To be efficient it is necessary to ensure that the shield is effectively continuous. Any gaps or joints must be much smaller than the wavelength (see Appendix A) of the electromagnetic field. For this reason any panels forming part of a shield will normally be secured by closely spaced screws or bolts. If it is necessary to remove a panel it should be reassembled with all the fixings in place in order to minimise leakage. Doors and access panels will normally incorporate a contact strip all the way round. In addition to any gaps and joints, the effectiveness of shielding depends on the material from which it is made, its thickness, the shape of the shield and the frequency of the field.

Cables and other waveguides used for transmission of radiofrequency fields are shielded as standard. This is primarily to prevent radiation of the radiofrequency energy, which would result in large losses, but also serves to limit the magnitude of environmental fields. Any loss of integrity of the shield may result in leakage and so the possible degradation of joints or bends should be kept in mind.

Shielding of static and low frequency (less than about 100 kHz) magnetic fields is more difficult. It is possible to shield such fields with special metal alloys like mu-metal, but there are many limitations and this is generally restricted to specialist applications.

As passive shielding of magnetic fields is difficult, active shielding is often used instead, particularly for static fields (see the case study on NMR units in Volume 2 of this guide). In active shielding an additional coil, normally in the form of a solenoid, is used to generate an opposing magnetic field. Cancellation of the two fields results in a rapid reduction in magnetic flux density away from the source.

9.4.2 Guarding

Guarding can be a cheap and effective means to restrict access to strong field regions. As noted in Chapter 3, field strengths usually fall rapidly with distance from the source of the field so that the use of guarding to restrict access to the immediate vicinity will often be a practical option. With knowledge of the field distribution, anyone competent in the design and installation of machinery guarding should be able to provide an effective solution.

When installing guarding in strong fields consideration should be given to the coupling of the field with the guarding material. It may therefore be appropriate to use non-metallic materials, for example plastic barriers in NMR facilities with strong static magnetic fields. Furthermore, the installation of metallic guarding may necessitate a consideration of spark discharges and contact currents, along with appropriate earth bonding (Section 9.4.7 and 9.4.8).

Where there is no need to gain access to the restricted area in normal operation then fixed guards will often be the simplest and cheapest solution. These guards are attached in such a way that removal requires the use of tools.

Due to the requirement for tools to remove them, fixed guards will not be suitable for areas where frequent access is required. In this case a moveable guard may be an acceptable solution. These would normally be interlocked to the source of the field, although a non-interlocked guard (Figure 9.1) may be acceptable where the risk is relatively low.

Figure 9.1 — Example of a simple moveable guard used to restrict access to a strong magnetic field. In this case the guard is not interlocked, but is supplemented by warning signs and organisational measures

Where strong fields are only accessible via fixed vertical ladders, such as when high power antennas are installed on a rooftop (see case study in Volume 2 of this guide), then a ladder guard may be a cheap and effective means of restricting access (Figure 9.2).

Figure 9.2 — Use of ladder guard to restrict access to strong fields on a rooftop

9.4.3 Interlocks

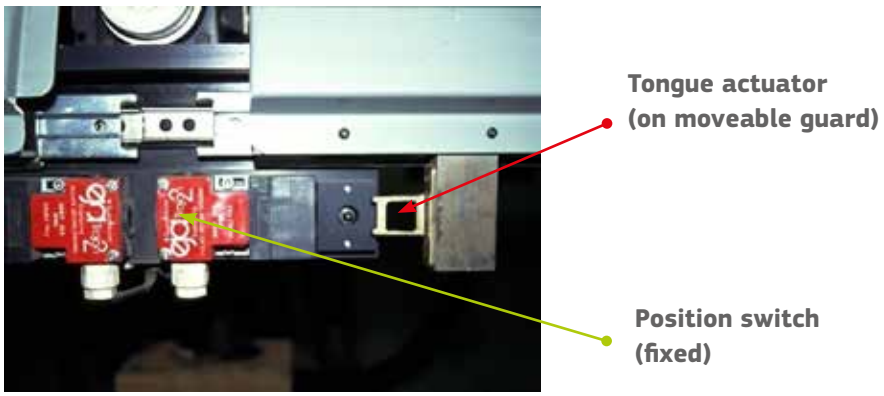
Where moveable guards are used to restrict access to strong fields, the guard should be interlocked to the source of the EMF. The interlocking device will monitor the position of the guard and prevent generation of EMF whenever the guard is not in the fully closed position.

There are a number of different types of interlocking devices, each with their own advantages and disadvantages (see Table 9.2). Selection of an appropriate device will depend on the specific circumstances and should be informed by the outcome of the risk assessment.

Table 9.2 — Examples of different types of interlocks

Type	Description	Examples
1	Mechanically actuated switch without coding	Rotary cam switch on hinged guard Linear cam switch actuated by rail on sliding guard Switch mounted internally within hinge
2	Mechanically actuated switch with coding	Tongue actuated position switch Trapped key system
3	Non-contact position switch without coding	Proximity switch based on inductive, magnetic, capacitive, ultrasonic or optical detection
4	Non-contact position switch with coding	Proximity switch with coded magnetic detection Proximity switch with RFID detection

Figure 9.3 — Tongue actuated position switch, an example of a Type 2 interlock device



Given the presence of strong electromagnetic fields, consideration will need to be given to the risk of interference with the function of the interlocking device and any associated circuits. Mechanically actuated devices may be less susceptible to electromagnetic interference.

Interlocks should meet appropriate European standards and should be installed with fastenings that require a tool for removal.

As opening the guard would normally be expected to terminate the strong field condition immediately, guard locking (where the guard remains locked until the risk has gone) will not usually be required.

9.4.4 Sensitive protective equipment

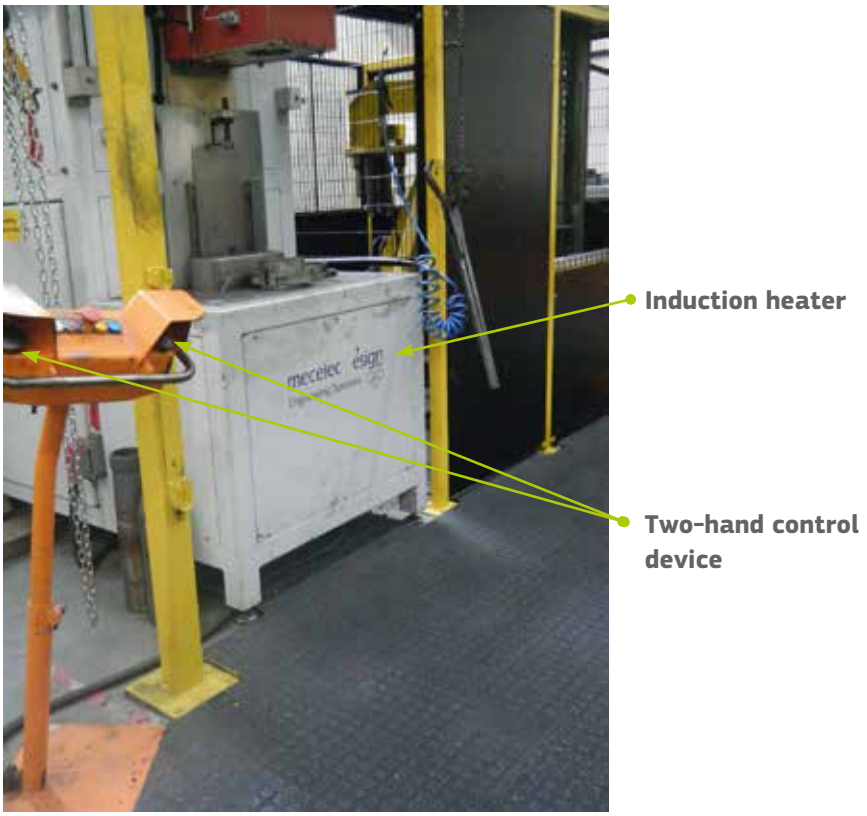
Where it is not practicable to install fixed or moveable guarding, another option may be the use of sensitive protective equipment. This includes equipment such as light curtains, scanning devices and pressure sensitive mats. The equipment can detect entry into or the presence of someone in an area of strong fields and can prevent the operation of equipment generating electromagnetic fields.

Sensitive protective equipment makes use of a range of detection technologies, which will vary in their suitability for any particular situation. Employers should seek competent advice in the selection of appropriate systems. In particular, consideration must be given to the risk of interference from strong electromagnetic fields.

9.4.5 Two-hand control device

A two-hand control device (Figure 9.4) can be used to require simultaneous activation by both of an operator's hands. This may be useful to ensure that an operator is in a particular position or that their hands are kept out of a strong field area. However, the device provides no protection for other workers.

Figure 9.4 — Two-hand control device used to ensure worker separation from induction heater



9.4.6 Emergency stops

When workers can access potentially hazardous environments, it is essential to provide emergency stops. Most people will be familiar with red mushroom-headed emergency stop buttons. The emergency stop must respond quickly, stop all services in the area and prevent any restart before being reset.

Emergency stop buttons should be located around the area in sufficient quantity that there will always be one within easy reach, and certainly without having to pass through a more hazardous area to get to one. When providing coverage for large areas it is often convenient to use grab wires instead of buttons.

9.4.7 Technical measures to prevent spark discharges

Spark discharges may occur in strong electric fields when a person touches a conductive object that is at a different electric potential because one of them is grounded and the other is not. Spark discharges can be prevented by ensuring that such potential differences do not exist. This may be achieved by technical measures such as grounding conductive objects and bonding of workers to conductive work objects (equipotential bonding).

In practice it may be difficult to comprehensively implement these technical measures due to the difficulty of achieving effective grounding or bonding of moveable objects. Hence, it will normally be necessary to combine technical measures with appropriate organisational measures, especially staff training, and possibly the use of personal protective equipment.

9.4.8 Technical measures to prevent contact currents

When a person makes contact with a conducting object in a radiofrequency field and one of them is ungrounded, a radiofrequency current can flow through the person to ground. This can result in shock or burn. A number of measures can be implemented to limit contact currents. Reducing the strength of stray fields will reduce the magnitude of the radiofrequency current that can flow, whilst further improvements can be made by insulation and grounding. Finally, it should be noted that organisational measures, such as the removal of unnecessary conductive objects, particularly large ones, will reduce the opportunity to make contact.

9.5 Organisational Measures

In some situations it may not be practicable to minimise risks from EMF by means of technical measures. In these situations the next stage will be to examine the possibility of using organisational measures. These should still provide for collective protection, but because they generally rely on people to act on information they will only be as effective as the actions of those people. Nevertheless, organisational measures have an important role and may be the principal control measure under some circumstances, such as during commissioning and servicing.

The selection of organisational measures depends on the nature of the risk and the way the work is carried out. Measures may include delimitation of areas and restriction of access, signs, signals and labels, the appointment of individuals to supervise areas or work activities, and written procedures.

9.5.1 Delimitation and restriction of access

In some situations it may not be practicable to restrict access to areas of strong fields by technical measures, such as guarding. In these situations a range of organisational measures may be used to delimit the areas and place restrictions on access or activities. In general this is likely to involve warning signs and notices to alert workers to the risk, often in combination with floor markings to identify areas of strong fields.

Table 9.3 — Examples of access or other restrictions that may be required for areas where there are strong EMFs

Criteria	Restrictions
Non-thermal effects Health effects ELV exceeded High AL exceeded Limb AL exceeded	No access while fields present
Thermal effects Health effects ELV exceeded Exposure AL exceeded Induced limb current AL exceeded	Access restrictions to limit time averaged exposure
Sensory ELV exceeded temporarily Low AL exceeded temporarily	Access restricted to trained workers Other restrictions may apply
Projectile risks from strong static magnetic fields	Restrictions on ferromagnetic materials being taken into the area
Risks to workers at particular risk	Restrictions on access into areas with strong fields Information for access to site
Risk of spark discharges from strong electric fields	Access restricted to trained workers
Risk of contact currents	Access restricted to trained workers Prohibition on unnecessary conductive objects

In some situations, where floor markings may already be present to warn of other hazards or restrictions, it may be acceptable to use alternative means of delimiting areas, such as wall markings or posting of area plans with marked areas.

Where EMFs are only present at certain stages of an equipment cycle, it may be helpful to indicate when the fields are present by means of visual (an illuminated beacon, for example) or audible (a siren, for example) warning signals.

Where access is restricted to certain workers, there will need to be a process to formally authorise those permitted access.

In some cases it may be necessary to establish temporary access restrictions. This would be appropriate for a temporary installation, or during commissioning works on a permanent installation, but before fixed guards are installed. In these situations, it is normally acceptable to deploy temporary barriers. These will normally have warning signs posted on them. For high risk, short duration situations, it may also be appropriate to assign workers to supervise the boundary of the area to ensure that nobody crosses the barriers.

Figure 9.5 — Temporary barriers and warning signs to restrict access into strong fields generated by a temporary installation

Where there are risks of ignition of flammable atmospheres or initiation of electro-explosive devices, it is normal practice to delimit the area where the primary hazard (flammable atmosphere or electro-explosive device) exists and then place restrictions on all sources of ignition or initiation, including EMF, in that area.

9.5.2 Safety signs and notices

These form an important part of any system of organisational measures. Safety signs and notices are only effective if they are clear and unambiguous. They should be placed at eye level to maximise their visibility. The nature of the hazard should be clearly indicated. Example pictograms relevant to EMF are shown in Figures 9.6 — 9.8 along with their recognised meanings. In general it will be appropriate to add a supplementary text notice to aid comprehension. This is particularly relevant in relation to mandatory signs requiring the wearing of insulating or conducting footwear or gloves.

Figure 9.6 — Standard warning signs often displayed in relation to EMF

Warning: magnetic field

Warning: non-ionising radiation

Figure 9.7 — Standard prohibition signs often displayed in relation to EMF

No access for people with active implanted cardiac devices

No access for people with metallic implants

Figure 9.8 — Standard mandatory signs that might be displayed in relation to EMF

Wear safety footwear

Wear protective gloves

Wear eye protection

General mandatory action sign

If electromagnetic fields are only intermittently present, then the warning signs should only be displayed when the field is on, otherwise they may be ignored. This may be achieved in practice by reversing the sign (on a hook or slotted mount) to a blank display when the hazardous situation has ended.

It is normal practice to put warning labels bearing the same pictogram on any equipment generating EMF.

9.5.3 Written procedures

Where it is necessary to rely on organisational measures to manage risks from EMF, these should be documented in the risk assessment so that everyone is clear what is required. This should include:

- Descriptions of any areas with specific restrictions on access or activities
- Details of any conditions for entering an area or carrying out a particular activity
- Specific training requirements for workers (such as training required to temporarily exceed the low AL)
- Names of those authorised to enter areas
- Names of staff responsible for supervising work or enforcing access restrictions
- Identification of any groups specifically excluded from areas, such as workers at particular risk
- Details of emergency arrangements if appropriate

Copies of written procedures should be available to consult in the areas to which they apply and should be issued to anyone who may be affected by them.

9.5.4 Site safety information

It is common practice to provide safety information or a safety briefing to those entering a site for the first time. If the site includes identified areas where access or specific activities are restricted, it would be good practice to explain this in the site safety information.

Figure 9.9 — Site safety information given to visitors should explain any restrictions on entry to areas and particularly risks to workers at particular risk

It is especially important if there are areas where there could be risks to workers at particular risk to highlight this. The recognised 'at risk' groups should be identified and anybody falling into one these groups should be advised to bring this to the attention of their host. The information should include a warning for people in these groups to remain alert for additional warning signs.

9.5.5 Supervision and management

EMF safety should be managed through the same health and safety management structure as other potentially hazardous activities. The detail of the organisational arrangements may vary according to the size and structure of the organisation.

Where fields are sufficiently strong to require specific management, it will normally be appropriate to appoint knowledgeable member of staff to supervise the day-to-day aspects of EMF safety in the workplace.

9.5.6 Instruction and training

Article 6 of the EMF Directive specifically addresses the provision of information and training to workers who are likely to be exposed to risks from EMF at work. The required content of this training is given in Table 9.4.

The level of information or training provided should be proportionate to the risks from EMF in the workplace. Where the initial assessment (see Chapter 3) has shown that accessible fields are so low that no specific action is required, it should be sufficient to provide reassurance that this is the case. However, even in this situation it will be important to alert workers or their representatives to the possibility that some workers could be at particular risk. Any worker falling into one of the recognised 'at risk' groups should be encouraged to identify themselves to management.

Table 9.4 — Content of information and training as specified in the EMF Directive

Measures taken in application of the EMF Directive
Values and concepts of the ELVs and ALs, the associated possible risks and the preventive measures taken
Possible indirect effects of exposure
Results of the assessment, measurement or calculations of the levels of exposure to electromagnetic fields carried out in accordance of Article 4 of the EMF Directive
How to detect adverse health effects of exposure and how to report them
The possibility of transient symptoms and sensations related to effects in the central or peripheral nervous system
The circumstances in which workers are entitled to health surveillance
Safe working practices to minimise risks resulting from exposure
Workers at particular risk

If it has been necessary to implement specific technical or organisational measures in relation to EMF then it will normally be appropriate to provide some element of more formal training. Where risks have been eliminated or minimised entirely through technical measures then it should suffice to provide this through a safety briefing or 'toolbox talk'. This will serve to alert workers to the risks and explain the technical

measures that have been put in place for their protection. The training should stress the importance of reporting any apparent failures or deficiencies in the protective measures so that these can be addressed.

Where the management of risks from EMF is reliant on a substantial component of organisational measures or use of personal protective equipment then the training will normally need to be more formal and more detailed.

When determining the depth, breadth and duration of training required, the employer should consider the matters in Table 9.5.It is important that any training should put EMF risks into perspective with other risks in the workplace.

Table 9.5 — Matters to be considered in deciding on the level of training required

Outcome of the risk assessments
Current expertise of staff and their awareness of the risks from EMF
Degree of involvement of workers with the management of risks from EMF
The nature of the work environment and whether it is stable or changes frequently
Whether training is for new workers or refresher training for existing staff

Where there are risks of spark discharges or contact currents, the training will need to specifically identify these risks. It will also need to explain the measures implemented to reduce the risks, particularly where these require action by workers.

The provision of training should be documented.

9.5.7 Design and layout of workplaces and workstations

Risks from EMF can often be minimised at little or no cost by giving a little thought to designing the layout of the workplace in general and individual workstations in particular.

For example, equipment generating strong fields can often be positioned away from common walkways and other areas of high occupancy. In any event care should be taken to ensure that equipment is arranged so that access can be appropriately restricted where compliance with the ELVs cannot be assured.

Equipment generating strong fields should be positioned such that workers at particular risk do not have to pass through fields that may put them at risk. Hence such fields should never extend into common walkways, and should not extend into other areas unless it will be acceptable to exclude such workers from these areas.

In considering the layout of their workplaces, employers should remember that magnetic fields will not normally be attenuated by dividing walls and they will therefore need to consider access to adjoining areas. This is illustrated for magnetic particle inspection equipment used in the engineering workshop case study in Volume 2 of this guide.

The layout of workstations is often also important. In the example in Figure 9.10, the field at the operator position in front of the spot welder is weaker than the field to the side of the welder. It is therefore important in this type of situation to organise the workstation so that the operator sits or stands where expected (Figure 9.10) and also to consider the whereabouts of workers carrying out other tasks.

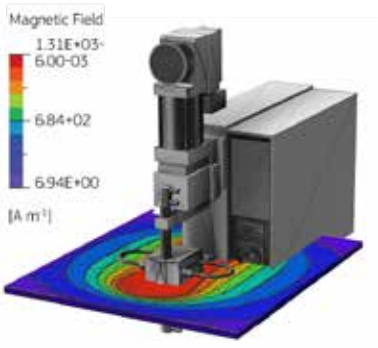
Figure 9.10 — Illustrations of good practice and bad practice when arranging the workstation for a spot welder and considering operator positioning

Good Practice:

The field is stronger to the sides of the spot welder than in front. In this layout the worker stands at the front of the equipment to carry out the weld. Worker exposure is consequently kept low.

Bad Practice:

In this layout the worker has to stand at the side of the equipment to carry out the weld. The result is that worker exposure will be higher



The graphic illustrates how the magnetic field contours are more widely spaced to the sides of the welder

9.5.8 Adoption of good working practices

It is often possible for workers to minimise the generation of strong fields or reduce their exposures through adopting simple changes to their work practices. For example, where the supply and return currents flow through separate conductors, these should be arranged in close proximity where possible. This will normally achieve a substantial reduction in the field generated as opposite current flows will result in field cancellation.

Workers should take care to route cables away from their bodies wherever practicable, particularly where there are separate supply and return cables. The illustrations in Figure 9.11 show examples of good and poor practice in welding. Welding cables are heavy

and tend to restrict the movements of the welding gun. As a result it is common practice for welders to support the cable across their shoulder, or even drape it around their neck. This inevitably brings the source of the strong field close to the brain and spinal cord. Supporting the cable by other means would not only reduce exposure, but would also be ergonomically preferable.

Figure 9.11 — Examples of good and bad practice in routing of arc welding cable

Good Practice:
The cable is routed away from the worker's body so that exposure to the field is kept low.

Supply and return cables are kept together so far as possible so that field cancellation will reduce the magnitude of fields in the work environment.

Bad Practice:
In this example the worker is supporting the weight of the welding cable across the shoulder. However this brings the cable close to the head and body and so increases exposure.

Bad Practice:
In this example the worker is supporting the weight of the welding cable across the shoulders to form a loop. However this brings the cable close to the head and body and so increases exposure.

Similarly, in magnetic particle inspection, it is common practice to complete the task by running a demagnetisation cycle, which typically generates a stronger initial field than the inspection cycle. However, unlike the inspection cycle, it is not necessary for the inspector to be close to the workpiece during demagnetisation and it would therefore be good practice for them to stand away at this stage of the process.

In some situations demagnetisation will be achieved using a degaussing coil (see the engineering workshop case study in Volume 2 of this guide). Such coils are normally provided with a rail and small trolley to mount the workpiece on. The use of push sticks to push the workpiece and trolley through the coil will minimise exposure of the operator.

9.5.9 Preventative maintenance programmes

Equipment producing EMF should be subject to a regular programme of preventative maintenance and, where appropriate, inspection to ensure that it continues to function efficiently. Adequate maintenance is a requirement of the Work Equipment Directive (see Appendix G) and will serve to minimise any increase in emissions due to degradation of the equipment.

Technical measures to limit emissions or restrict access to strong fields should similarly be subject to ongoing maintenance, inspection and testing to ensure that they remain fully effective.

The frequency of such maintenance and inspection activities will depend on the nature of the equipment, how it is used and the environment in which it is located. In general manufacturers of equipment will recommend appropriate maintenance intervals and this will provide a satisfactory guide in most cases. However, unusually harsh environments or heavy use of equipment may accelerate the rate of deterioration and in these cases more frequent maintenance and inspection will normally be warranted.

9.5.10 Restriction of movement in static magnetic fields

Movement in strong static magnetic fields can result in the induction of low frequency electric fields within the body that can elicit a range of effects. These effects can be minimised by limiting the extent and speed of movement through the fields. This is particularly important for movement of parts of the body, such as rotation of the head. With training and/or practice, workers can learn to limit their movements and so minimise any effects.

9.5.11 Co-ordination and cooperation between employers

Where it is necessary for workers from more than one employer to work on the same site, there should be an exchange of information between the employers so that all workers are adequately protected. This situation arises commonly during installation, commissioning and servicing of equipment, but can also arise in other situations. For example, it is common for employers to contract out many support functions including cleaning, facilities management, warehousing and logistics, occupational health, and IT services.

In relation to EMF this exchange of information should include details of any restrictions that may be needed in respect of access or activities in a particular area and any risks to workers at particular risk. Such restrictions will need to be agreed between the employers and each employer should ensure that they are respected by their workers.

9.6 Personal Protective Equipment

The principles of prevention from the Framework Directive (see Table 9.1) make it clear that giving collective protection should always take priority over individual protective measures. However, sometimes it may be impracticable to implement technical or organisational measures affording adequate collective protection. In these situations it may be necessary to rely on personal protective equipment.

As noted above in the section on technical measures, it is relatively straightforward to screen electric fields, but it is difficult to achieve effective protection against magnetic fields. Hence it is not generally practicable to use personal protection to provide protection from magnetic fields. The efficiency of personal protection is dependent on the frequency of the field, so that protective equipment that equipment suitable for one frequency range is unlikely to be suitable for others.

The selection of appropriate equipment will depend on the particular situation and the nature of the risks being prevented. Hence in different situations, insulating or conducting shoes, boots or gloves may all be effective in reducing risks. Where insulating footwear is required, it will usually be adequate to source sturdy work boots or thick rubber soled shoes. If an assessment shows that these will not be adequate it may be necessary to find a more specialist source of safety equipment.

Protective eyewear may be used to afford protection of the eyes from high frequency fields. In some situations the use of full protective suits may be necessary, but it should be noted that these may introduce new risks by impeding movement or heat loss from the wearer.

Personal protective equipment should be properly maintained and regularly inspected to ensure that it remains fit for purpose.

Consideration should be given to whether personal protective equipment worn for other risks is compatible with the presence of strong EMFs. For example, the use of safety boots with steel toecaps may be inappropriate in an environment with strong static magnetic fields, whilst low frequency magnetic fields, if strong enough, will heat the steel insert. Some protective suits incorporate electronic components and these may be subject to interference in strong fields. Similar problems may be encountered with active hearing protectors.

10. EMERGENCY PREPAREDNESS

Where employers operate equipment or carry out activities that could give rise to an adverse incident they should put in place emergency plans to deal with the consequences. In this context, adverse incidents would include situations where someone is injured or falls ill, and near misses or undesired circumstances. Adverse incidents could include situations where an exposure limit value (ELV) has been exceeded but nobody was injured (and there is no applicable derogation). An example would include an antenna rigger who unwittingly enters into the exclusion zone of a high power transmitter before it has been powered down.

Adverse incidents could also arise from indirect effects, such as interference with an implanted medical device or ignition of a flammable atmosphere. Another example would be a ferromagnetic object being attracted into the bore of an NMR unit by the strong static magnetic field (the so called 'projectile effect').

Table 10.1 — Scenarios to be addressed in contingency plans

Contingency plans should address actions and responsibilities in the event of:
Actual worker exposure in excess of an ELV (no applicable derogation)
Actual adverse incident arising from an indirect effect
Suspected worker exposure in excess of an ELV
Near miss or undesirable consequence arising from an indirect effect

10.1 Preparation of Plans

The risk assessment prepared in accordance with Article4 of the EMF Directive should enable the employer to identify reasonably foreseeable adverse incidents (see Chapter 5 of this guide). Once the employer has identified and understood the nature of these potential adverse incidents it will be possible to develop plans to deal with the consequences. In some cases, manufacturers may provide emergency procedures in their documentation and these should take precedence.

Most employers will already have general emergency plans in place and it may be possible to cover potential adverse incidents arising from EMFs through these existing arrangements. Emergency plans may include arrangements for administering first aid and subsequent medical examination (see Chapter 11 of this guide). In any event, the level of detail and the complexity of the plans will depend on the risk. In general it is good practice to rehearse emergency plans to identify deficiencies and keep them fresh in the mind.

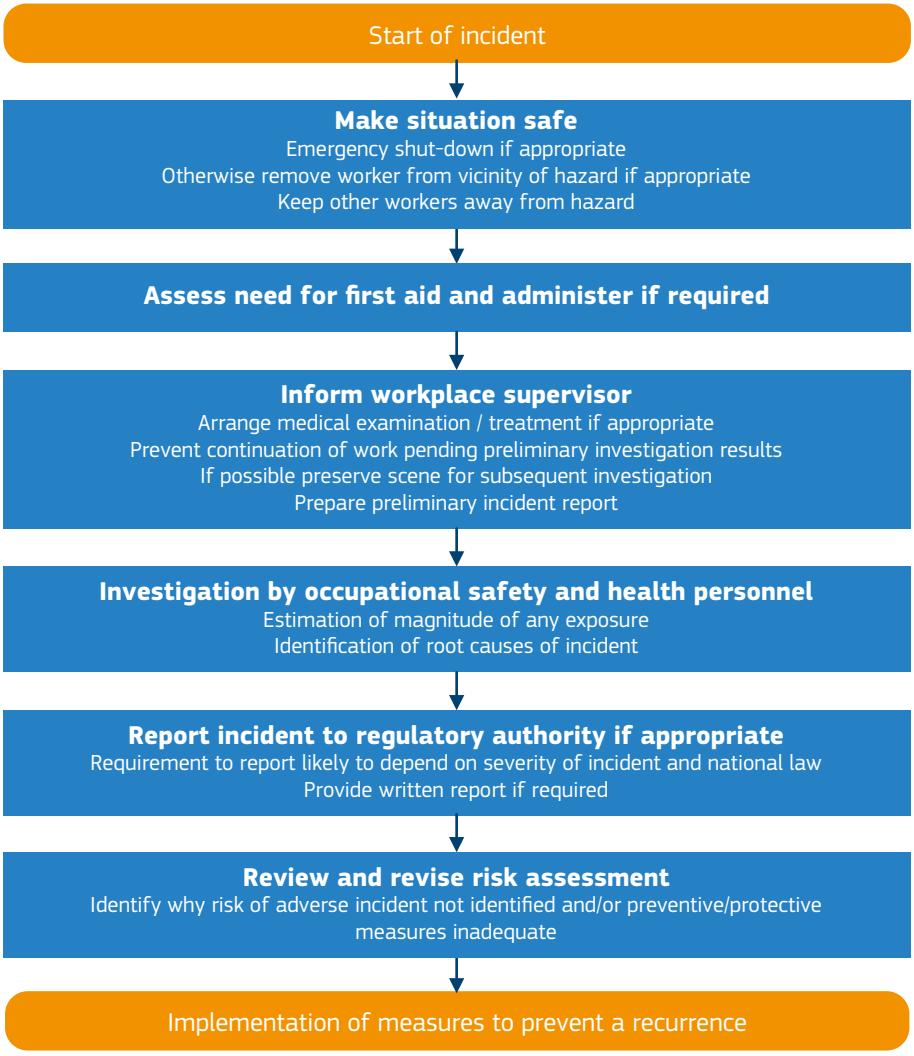
10.2 Responding to Adverse Incidents

The response to any adverse incident will inevitably be dynamic and informed by its nature and severity. Figure 10.1 illustrates a typical sequence of events in the response to an incident. Not all the actions will necessarily be appropriate for every adverse incident.

The initial adverse incident report should provide as much information as possible to assist in the subsequent investigation. The report would normally include:

- A description of the nature of the adverse incident
- How the adverse incident occurred
- Details of all personnel involved and their locations during the adverse incident
- Details of any injuries sustained
- Characteristics of EMF source involved
  - Frequency
  - Power
  - Operating currents and voltages
  - Duty cycle (if appropriate)

Figure 10.1 — Sequence of events in a typical response to an incident



Further information on managing accidental exposure to RF fields is given in the report by the Finnish Institute of Occupational Health (Alanko et al., 2014). This includes templates for an initial incident report and a technical report in the appendix.

11. RISKS, SYMPTOMS AND HEALTH SURVEILLANCE

Article 8 of the EMF Directive relates to health surveillance of workers, which should follow the requirements of Article 14 of the Framework Directive. The arrangements for health surveillance regarding electromagnetic fields are likely to be adapted from the systems already in place in Member States, The provision and availability of health records should be in accordance with national law and practice.

11.1 Risks and Symptoms

The effects of exposure to electromagnetic fields are summarised in Chapter 2 with additional details about health effects described in Appendix B. Exposures in excess of the exposure limit values (ELVs) may cause effects on nervous tissues and muscles with low frequency fields, or heating with high frequency fields. Touching metallic objects can cause shocks and burns in both frequency ranges. Generally, fields or exposures well above the action levels (ALs) or ELVs are required to produce physical injuries. The ALs and ELVs incorporate a margin of safety, so a single, brief exposure just above the limit may not produce adverse consequences.

11.1.1 Static magnetic fields (0 to 1 Hz) ([1])

Static magnetic fields at flux densities above 0.5 mT may cause interference with active implanted medical devices, such as pacemakers and defibrillators, or body-worn medical devices, such as insulin infusion pumps. Such interference could have very serious consequences.

Exposure to static magnetic fields well above the health effects ELVs may result in changes in blood flow in limbs and/or heart rate. These effects are not well understood at present and may not constitute a risk to health.

Presence or movement in strong static magnetic fields may cause vertigo, nausea and other sensory effects. There may also be less obvious changes in attention, concentration or other intellectual functions, which could have a detrimental impact on work performance and safety. It may be possible to induce nerve stimulation and involuntary muscle contraction during fast movements with whole body exposure above 8 T or situations involving a rapid change in flux density. These effects are reversible, so symptoms are unlikely to persist after cessation of exposure.

([1]) Scientifically static magnetic fields have a frequency of 0 Hz, but for the purposes of the EMF Directive they are defined as having a frequency of 0 — 1 Hz.

11.1.2 Low frequency magnetic fields (1 Hz to 10 MHz)

Exposure to low frequency fields below the low action level (AL) may cause interference with the normal functioning of active implanted medical devices or body-worn medical devices. Any malfunction could have potentially serious consequences. The presence of passive metallic implants may result in localised regions of stronger electric fields within the body, whilst the implant itself may be inductively heated, with potential for thermal injury.

The first sign of excessive exposure in other workers may occur when the worker reports seeing vague, flickering images (phosphenes), which may be distracting or annoying. However, the peak sensitivity occurs at 16 Hz and very large field strengths are required to produce phosphenes at other frequencies, well above levels normally encountered by workers. In addition, workers may experience feelings of nausea or vertigo and there may be subtle changes in reasoning, problem solving and decision-making during exposure, leading to detrimental effects on work performance and safety. As for exposure to static magnetic fields, these effects are reversible, so are unlikely to persist after cessation of exposure.

Nerve stimulation may occur, leading to tingling sensations or pain, whilst uncontrolled twitches or other muscular contractions can also occur and in very strong external fields this may even lead to effects on the heart (arrhythmia). In practice, these effects are only likely to be produced at field strengths well above those commonly encountered in workplaces.

In addition, heating effects will occur with exposures towards the upper end of this frequency range (see Section 11.1.4).

11.1.3 Low frequency electric fields (1 Hz to 10 MHz)

Low frequency electric fields will produce similar effects on nervous tissue and muscles as those produced by magnetic fields. However, the first indications of strong electric fields are likely to be when the small hairs on the body start moving or vibrating, and when workers start getting electric shocks from touching ungrounded, conducting objects in the field. Hair vibration can be distracting and annoying, and electric shocks can be irritating, unpleasant or painful depending of the intensity of the field. Touching objects in strong fields can also cause burns.

11.1.4 High frequency fields (100 kHz to 300 GHz)

Exposure to high frequency fields below the relevant action level (AL) may cause interference with the normal functioning of active implanted medical devices or body-worn medical devices. Any malfunction could have potentially serious consequences. Passive medical implants that are metallic may serve as absorbing antennas resulting in local increases in RF exposure of tissues and possible injury.

The first indication of exposure to high frequency fields may be the sensation of warmth as the worker or parts of their body are heated by the field. However this may not always be the case and feeling warm is not a reliable warning signal. It is also possible to ‘hear’ pulsed fields between 300 kHz and 6 GHz, so clicking, buzzing or hissing noises may be heard by exposed workers.

Prolonged exposure of the whole body can result in a rise in body temperature. Increased temperature of only a few degrees can lead to mental confusion, fatigue, headache and other symptoms of heat stress. High physical workloads, or working in hot and humid conditions will increase the likelihood of these effects. The severity of the symptoms also depend on the physical condition of the worker, whether they are dehydrated or not, and on the clothing they are wearing.

Partial body exposure can lead to localised heating or 'hot spots' in muscles or internal organs, and also cause superficial burns which appear instantly on exposure. Serious internal injury is possible without obvious burns on the skin. Strong local overexposure may cause damage to muscles and surrounding tissues in exposed limbs (medial compartment syndrome), which develops instantly or within a few days at most. In general terms, most tissues can tolerate increases in temperatures for short periods without harm, but a temperature of 41 °C for more than 30 minutes will produce damage.

A temporary lowering of sperm count is possible with exposures that cause substantial heating of the testis, and heating may increase the risk of miscarriage in early pregnancy.

The eye is known to be sensitive to heat, and very high exposure well above the ELV may cause inflammation of the sclera, iris or conjunctiva. Symptoms can include redness, pain in the eyes, sensitivity to light and pupillary constriction. Cataracts (opacities of the lens) are rare but a possible late effect of exposure, and can take weeks or months to develop following exposure. There are no reports of effects occurring years after exposure.

For higher frequency fields (around 6 GHz and above) energy absorption becomes increasingly superficial. These fields will be absorbed by the cornea of the eye, but exposures well above the ELV will be required to cause burns. The skin will also absorb these high frequency fields and at sufficiently high exposures this may result in pain and burns.

Workers may suffer electric shock or contact burns from touching working antennas or from contact with large metallic, ungrounded objects, such as cars, in the field. Similar effects may occur when an ungrounded worker touches a grounded metallic object. These burns may be superficial or deep within the body. Metallic implants, including dental fillings and body piercings (as well as jewellery and some tattoo pigments), can concentrate the field leading to localised heating and thermal burns. High exposure of the hand may also result in nerve damage.

Case reports of overexposed workers suggest other symptoms may also be possible. These include headaches, bowel upset, lethargy, and long-lasting feelings of 'pins and needles' in the exposed tissues.

Stress reactions may be associated with actual or suspected overexposure.

Table 11.1 — Effects and symptoms associated with exposure above the health effects ELVs

Field	Frequency	Possible effects and symptoms
Static magnetic fields	0 — 1 Hz	Interference with medical devices Nausea and vertigo. Effects on blood flow, heart rate, brain function (possible above 7 T) Nerve stimulation and muscle contraction(fast movements)
Low frequency magnetic fields	1 Hz -10 MHz	Interference with medical devices Visual sensations Nerve stimulation resulting in tingling sensations or pain Muscle contraction, heart arrhythmia
Low frequency electric fields	1 Hz — 10 MHz	Electric shock and superficial burn (touching objects)
High frequency fields	100 kHz and above	Interference with medical devices Sensation of warmth Heat stress Shock and superficial or deep burn (touching objects). Other symptoms possible
Intermediate fields (100 kHz — 10 MHz) will produce a mixture of the symptoms produced by low and high frequencies		

11.2 Health Surveillance

Routine health surveillance of workers should be carried out if required by national law or practice. However, in the absence of known risks or symptoms from exposures to electromagnetic fields below the ELVs there is no basis for regular medical examinations. Surveillance may be justified on other grounds.

Workers at particular risk from exposure to electromagnetic fields include pregnant women and those with active or passive implanted medical devices or with body worn devices. These workers should have periodic consultations with their occupational health provider to ensure that the worker fully understands any additional restrictions that may be placed upon them in their working environment. These consultations will also provide the worker an opportunity to report any undesired or unexpected health effects, and to keep the situation under review.

Medical examination may also be appropriate for workers who suffer an unexpected or undesired health effect.

11.3 Medical Examination

Accidental overexposures causing injury or harm should be treated like other accidents at work according to national law and practice.

Immediate attention from an appropriate health professional may be required if the worker has suffered shocks and/or burns, has pains, or their temperature has risen. These effects should be treated in the usual way according to existing systems in place at their place of work. Workers who have suffered shocks or burns should be followed up by a clinician with appropriate expertise. Other workers may receive follow up for their symptoms from their own general practitioner or occupational health physician.

There are no specific investigations that should be undertaken following overexposure to any electromagnetic field. For example, there is no evidence that EMF exposure causes alteration of blood parameters like blood count, urea and electrolytes, or liver function. However, an eye examination may be appropriate in the case of overexposure to high frequency fields and would normally be repeated no later than three months after the first check-up. Such an examination would normally be carried out by an ophthalmologist.

11.4 Records

Medical examinations should be made available to workers who have been, or are believed to have been exposed in excess of the ELVs. The worker should not have to pay for these examinations, and they should be made available during working hours. Record keeping should be in accordance with national law and practice.

The records should contain a summary of the actions carried out, and be in a form so that they can be consulted at a later date, taking account of confidentiality. Individual workers should have access to their own records on request.

Details of any overexposure or suspected overexposure should be recorded as soon after the event as possible, if available. This record should include the intensity and duration of exposure, and the frequency of field (to estimate the depth of penetration of the field into the body). It is also important to determine whether exposure was to the whole of the body or just specific parts of it, and whether the worker was fitted with a pacemaker or other medical device. Examples of these records are given by the Finnish Institute of Occupational Health in its report on working in electromagnetic fields with a cardiac pacemaker (Alanko et al., 2013).

Section 5

REFERENCE MATERIAL

APPENDIX A. NATURE OF ELECTROMAGNETIC FIELDS

The electromagnetic fields that we are probably most familiar with are those that occur within nature. The earth's magnetic field which we can detect on the earth's surface is thought to be produced by electric currents generated deep within the earth's molten iron core. Although we do not fully understand its origin, how this field interacts with the magnetic materials used in compasses, has been used for centuries for navigation. Similarly the electric charge generated within storm clouds result in very high voltages between the clouds and the earth's surface. These voltages result in electric fields between the clouds and earth that can result in large, rapid discharges of electric current between the cloud and the earth, which we know as lightning.

Figure A1 — Natural sources of electromagnetic fields a) a compass used to detect the direction of the earth's static magnetic field and b) high voltage discharges between the cloud and the earth known as 'lightning'

A.1 Discovery of Electromagnetism

People have been aware of the effects of static electricity and magnetism since ancient times. However, progress towards understanding electromagnetic phenomena probably began with Luigi Galvani's discovery in 1780 that frogs' legs could be made to twitch using electricity generated from two different metals. This principle was used a decade later by Alessandro Volta in the voltaic pile battery.

Discoveries continued to gather pace in Europe and by 1820 the association between electric currents and magnetic fields was demonstrated by Hans Christian Oersted when he was able to deflect a needle of a compass using a wire carrying an electric current. Andre Marie Ampere discovered that wires carrying a current produced forces on each other and Michael Faraday studied magnetic induction.

A few years later, James Clerk Maxwell formulated the theory of electromagnetism on a mathematical basis, and published his Treatise on Electricity and Magnetism in 1873. Maxwell's ideas on electromagnetic waves are still used today as the basis of electromagnetic theory.

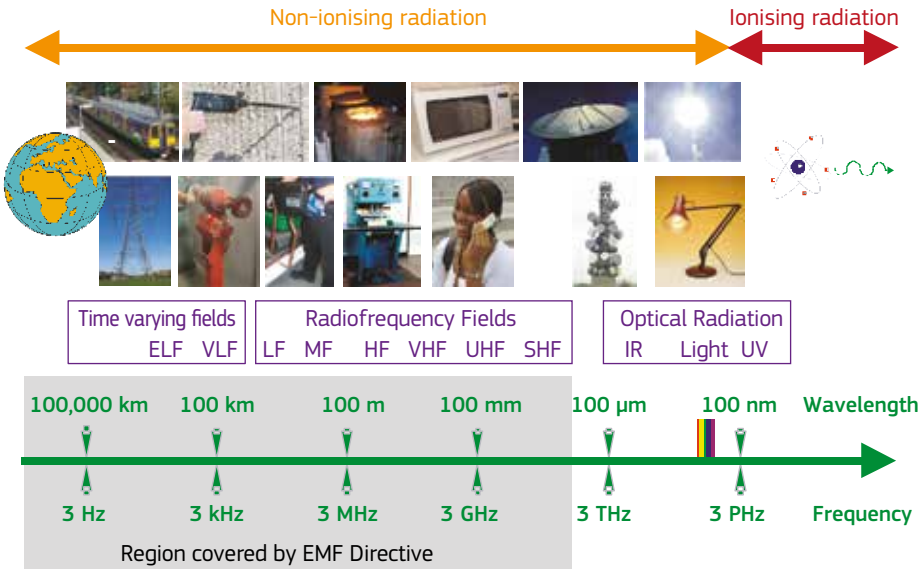
Heinrich Hertz confirmed Maxwell's ideas by generating and detecting electromagnetic waves in 1885, and a decade later, Guglielmo Marconi used this discovery to send messages over long distances by means of radio signals. Of great importance regarding the generation of electrical power, Nikolai Tesla built the first alternating current generator in 1892.

Electromagnetic fields are now commonplace in the modern world. It is difficult to imagine a modern society without electrical appliances. The twentieth century saw a massive growth in the use of electrical energy for industrial and domestic purposes. There were similar increases in broadcast radio and television, whilst the end of the century and the beginning of the twenty-first century saw a revolution in telecommunications with the use of mobile phones and other wireless devices now widespread. Electromagnetic fields are also widely used in specialist applications like radio-navigation and medical applications.

A.2 The Electromagnetic Spectrum

The electromagnetic spectrum, as illustrated in Figure A2, covers a wide range of radiations with different frequencies and wavelengths. The relationship between frequency and wavelength is explained in Appendix C. The part of this spectrum covered by the EMF Directive ranges from static fields (0 Hz) to time varying electromagnetic fields with frequencies up to 300 GHz (0.3 THz). Within this region can be found radiation commonly called static fields, time varying fields and radiowaves (including microwaves). Other sections of the electromagnetic spectrum not covered by the EMF Directive include the optical region (infrared, visible and ultra-violet) and the ionising region. These sections are covered by the Artificial Optical Radiation Directive (2006/25/EU) and the Basic Safety Standards (BSS) Directive (2013/59/Euratom) respectively.

Figure A2 — The electromagnetic spectrum

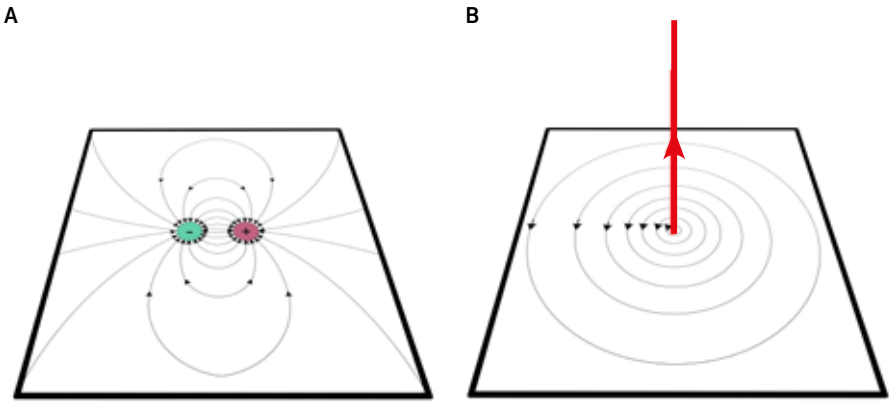


Electromagnetic radiation in the frequency range covered by the EMF Directive does not have enough energy to remove electrons from the atoms of a material and is therefore classified as non-ionising. X-rays and gamma rays are high energy electromagnetic radiations capable of removing these orbital electrons and are therefore classified as ionising radiation.

A.3 Production of Electromagnetic Fields

Electric charges produce an electric field. When they move, creating an electric current, a magnetic field is also produced. It is the health and safety risks from these electric and magnetic fields within the workplace that the EMF Directive seeks to address.

Figure A3 — Representations of field lines around: (a) electric charges and (b) a flowing electric current, shown as a red line



The production of a magnetic field around a permanent magnet is due to the summation of all the magnetic fields produced by the alignment of the movement of electrons in the material. In a non-magnetic material there is no such alignment and so the minute magnetic fields generated around each atom cancel out.

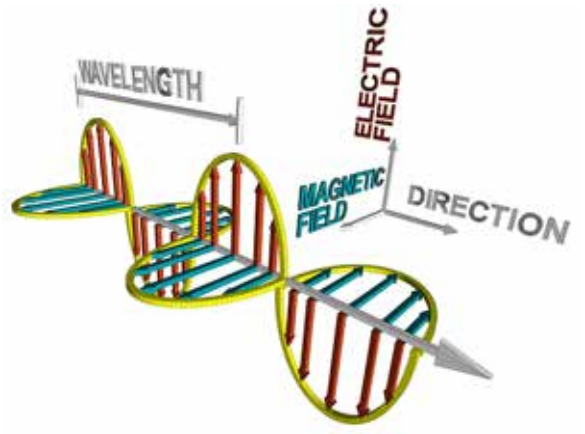
A.3.1 Time-varying fields

If the electric charge on an object changes with time or the flow of charge (current) varies then time-varying fields will be produced. The nature of time-varying fields is governed by the frequency of the oscillations. At low frequencies the electric and magnetic fields can be regarded as independent. As the frequency increases into the radiofrequency region the fields become more closely coupled: a time-varying electric field induces a magnetic field, and vice-versa. It is this interplay between electric and magnetic fields that allow electromagnetic radiation to travel long distances.

A.3.2 Radiating electromagnetic fields

The interaction between electric and magnetic fields at radiofrequencies allows energy to radiate away from the point of production. In the far field, the two components, an electric field and a magnetic field, oscillate at right angles to each other and right angles to the direction in which the wave is travelling. It does this at the same speed as light travels. The design of the transmitter will enable the radiation to be emitted in all directions or be focused in a particular direction.

Figure A4 — Electromagnetic radiation consists of a magnetic and electric field component, oscillating at right angles to each other travelling at the speed of light



APPENDIX B. HEALTH EFFECTS OF ELECTROMAGNETIC FIELDS

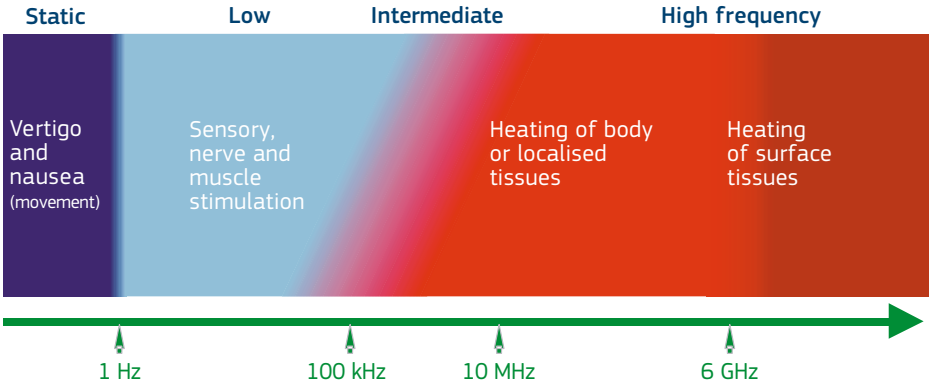
B.1 Introduction

The nature of any response caused by exposure to an electromagnetic field depends primarily on the frequency of the applied field. This is because different frequencies interact with the body in different ways, with the consequence that the effects of low frequency fields are not the same as those produced by higher frequencies: low frequency fields cause stimulation of nerves and muscles, while high frequency fields cause heating.

On the basis of their interaction with people, electromagnetic fields can be divided into four broad regions (Figure B1): those with frequency of 0 to 1 Hz (static fields); those with frequencies of 1 Hz to 100 kHz (low frequency fields); those with frequencies of 100 kHz to 10 MHz (intermediate frequency fields); and those with frequencies of more than 10 MHz (high frequency fields). Above a few GHz, heating is increasingly restricted to the surface of the body.

The EMF Directive considers that effects that arise as a consequence of actions on the nervous system are non-thermal effects whereas the heating effects that arise as a consequence of exposure to fields above 100 kHz are thermal effects.

Figure B1 — Schematic representation of principle direct effects of EMF showing the main frequency breakpoints used for the definition of exposure limit values and action levels in the EMF Directive



The size of the response at any given frequency depends on the intensity of the field, with weaker fields producing mainly perceptual or sensory effects, and stronger fields producing more serious responses. For any responses to occur, at any frequency, it is necessary to exceed a threshold value of exposure.

The EMF Directive offers protection to exposed workers by giving a series of exposure limit values (ELVs). For each frequency range, there is a lower value for limiting sensory effects and a higher value for limiting health effects (see Table B1). These values are

based on recommendations of the International Commission on Non-Ionizing Radiation (ICNIRP) and consider only the short-term effects of exposure that are based on sound biophysical interaction mechanisms.

Table B1 — Summary of relevant health and sensory effects used to limit exposures in different frequency regions

Field and frequency	Sensory effects	Health effects
Static magnetic field 0 — 1 Hz	Vertigo, nausea, metallic taste	Altered blood flow in limbs, altered brain function; Altered heart function
Low frequency fields 1 Hz -10 MHz	Phosphenes (perceived as light flashes); (Minor change in brain function 1 — 400 Hz)	Tingling sensation or pain (nerve stimulation) Muscle twitches Disturbed heart rhythm
High frequency fields 100 kHz — 6 GHz	Microwave hearing effect (200MHz — 6.5 GHz)	Excessive whole-body or localised heating or burns
High frequency fields 6 — 300 GHz		Localised heat damage to eyes or skin
NB: The effects of intermediate frequency fields (100 kHz - 10 MHz) are a combination of the effects of low frequency fields and high frequency fields.		

While it is always possible that repeated, long-term exposure might carry some as yet unidentified risks to health, the EMF Directive states that it does not cover any suggested long-term effects.

B.2 Static Magnetic Fields (0 — 1 Hz)

People at rest are generally unaffected by static magnetic fields, perhaps except at very high intensities when there may be effects on the heart or brain (see Table B1). However, effects are caused when people move around in these fields. Movement causes the production of electric fields in tissues and these can affect nervous tissues. Some recent results suggest that these effects may also occur whilst stationary. The magnitude of the induced electric fields depends on the temporal and spatial gradients.

The organs of balance in the ear are particularly sensitive, leading to feelings of dizziness (vertigo) while walking through, or quickly moving the head in the field. The tongue may also be affected, with sensations of taste being produced, and nausea and other symptoms have also been reported while working around operating MRI machines. All these effects are transient, and will cease when movement stops or slows down.

There is no evidence that exposure causes any permanent impairment or severe adverse effect. Moving slowly in the field will help to prevent these effects, and limiting the external magnetic flux density to 2 T will protect the worker.

B.3 Low Frequency Fields (1 Hz — 100 kHz)

B.3.1 Low frequency electric fields

Low frequency electric fields external to the body can induce electric fields within the tissues of the body. However, the surface of the body provides a high degree of shielding such that the induced field within the body is much smaller in magnitude than the external field.

In principle, the induced electric fields could engender similar effects to the fields induced by exposure to low frequency magnetic fields (see Section B3.2). However, the consequence of the shielding effect is that the induced electric field is normally too weak to elicit adverse effects for typical external electric fields encountered in the workplace.

In addition, low frequency electric fields produce another effect not seen with magnetic fields. A worker may experience a prickling or tingling sensation on the skin when standing in an electric field of sufficient intensity; this can be sometimes felt underneath a high voltage power line on a dry day. This occurs because the low frequency electric field causes the surface of the body to be charged-up, and this electrical charge causes the hairs in the skin to move and vibrate (at twice the frequency of the low frequency field). Similar sensations may also be felt as hairs vibrate against clothing.

B.3.2 Low frequency magnetic fields

Low frequency magnetic fields will induce electric fields in the human body, which can cause stimulation of sense organs at lower field values, or stimulation of nerves and muscles (particularly in the arms and legs) in stronger fields. The effects on sense organs are not harmful but could be annoying or distracting to workers, whereas the effects in stronger fields could be unpleasant or even painful.

Different tissues exhibit peak sensitivity to different frequencies and so the effects experienced also change with frequency.

Table B2 — Sites of interaction and peak sensitivities for different effects

Effect	Site of interaction	Peak sensitivity (Hz)
Metallic taste	Receptors in tongue	< 1Hz
Vertigo, nausea Nerve and muscle stimulation	Inner ear (vestibular system) Blood flow-induced electric fields in tissues	< 0.1 — 2 Hz
Phosphenes	Retinal cells in eye	~ 20 Hz
Tactile and pain sensation Induced muscle contraction Effects on heart	Peripheral nerves Peripheral nerves and muscles Heart	~ 50 Hz

The eyes appear very sensitive to the effects of induced electric fields, and the most reported effect of exposure are phosphenes which are elusive, flickering visual sensations in the periphery of vision (a somewhat similar effect can be produced by gently massaging the closed eyes). Limiting the induced electric field in the nervous system will prevent these effects and provide protection to the worker.

These surface charge effects are not limited to people, however, and any metallic or conducting objects, such as vehicles or fences which are not electrically grounded, can also be charged by the electric field. Anyone touching these objects would receive a small electric shock. While one shock might be surprising, repeatedly receiving shocks from touching the object could become annoying or worse. It is also possible to receive a shock when someone who is not earthed themselves touches a grounded object. In order to provide the necessary protection, specific training of those working in these conditions may be necessary, as well as appropriate grounding controls of objects and workers, and the use of insulating shoes, gloves and protective clothing.

B.4 Intermediate Frequency Fields

Intermediate fields represent a transition zone between low frequency fields and high frequency fields. There is a gradual change in this region from effects on the nervous system to effects of heating, with the former dominating at 100 kHz and the latter dominating at 10 MHz.

Key message: intermediate frequency fields

Intermediate frequency fields are defined in this guide as fields with frequencies between 100 kHz and 10 MHz, which can produce both non-thermal and thermal effects.

Other definitions of intermediate frequency fields may be used elsewhere. For example, the World Health Organisation defines intermediate frequency fields as those with frequencies between 300 Hz and 10 MHz.

B.5 High Frequency Fields

Exposure of people to fields with frequencies above 100 kHz causes heating through the absorption of energy. Depending on the situation, this can result in either heating of the whole body, or localised heating of parts of the body, such as the limbs or head.

Healthy adults are usually able to regulate the overall temperature of their bodies very efficiently, and maintain a balance between heat generating and heat loss mechanisms. However, the normal heat loss mechanisms may not be able to cope if the rate at which energy is absorbed is too great, leading to a gradual and steady rise in body temperature of around 1 °C or more resulting in heat stress. This will not only have a detrimental effect on the ability of a person to work safely, but prolonged rises in deep body temperature of a few degrees or more can be very dangerous.

Limiting the rate of absorbed energy (the specific energy absorption rate or SAR) will prevent any heat-related disorders and provide protection to the worker. Because heating is not instantaneous, and the body can manage increased heat loads for short periods, the exposure limit values are averaged over a time period of six minutes. This also allows workers to be exposed to higher SAR values for short periods provided the average is not exceeded.

In addition, the exposure limit values are sufficiently cautious that it is not necessary to allow for other factors that can affect temperature regulation, such as high rates of manual work, or working in hot and humid environments.

In many industrial situations, however, the exposure will not be uniform, and the energy will be absorbed only in certain areas of the body, such as the hands and wrists. If the whole body limit was applied in these situations, then it is possible that thermal damage could occur in the exposed areas (as the absorbed energy would be concentrated in a far smaller mass of tissue). Therefore values limiting exposures of parts of the body are also provided by the EMF Directive.

These values are set to prevent excessive heating in the heat sensitive regions of the body, which are the (lens of the) eye and the testes (in males). The developing fetus is also known to be particularly sensitive to the effects of hyperthermia in the mother and the pregnant worker should be treated as being at particular risk.

At the highest frequencies, 6 GHz and above, the fields do not penetrate into the body to any significant degree, and heating is largely confined to the skin. Protection is provided by limiting the power absorbed over a small area of skin.

Pulsed radiofrequency fields can give rise to sensory perception in the form of 'microwave hearing'. People with normal hearing can perceive pulse-modulated fields with frequencies between about 200 MHz and 6.5 GHz. This is usually described as a buzzing, clicking or popping sound, depending on the modulation characteristics of the field. Pulse durations to perceive the field are typically of the order of a few tens of microseconds.

As with low frequency electric fields, there is a risk of receiving a shock or burn when someone in a high frequency field touches a conducting object. This risk is also managed by the EMF Directive.

APPENDIX C. ELECTROMAGNETIC FIELD QUANTITIES AND UNITS

The risks from electromagnetic fields depend primarily on the frequency and intensity of the field. In order to assess the hazard presented by a particular electromagnetic field it is necessary to be able to characterise the field in terms of established physical quantities. The quantities used in the EMF Directive are described in the sections below.

EMF quantities may be expressed in different ways. This is especially so on measurement instrument displays where space is sometimes limited. Becoming familiar with the various forms that units can take will enable better use to be made of any information supplied. Here are some examples.

- prefixes can be used to scale the magnitude of the unit so 1 volt, 1 V, 1 000 mV and 1 000 000 µV all represent the same value. The commonly used prefixes can be found in Table C1
- the use of a numerical superscript or power term after a number or unit denotes the power to which it is raised. So for example m^2 is equivalent to square metres and its use infers that an area is being measured
- units can be expressed in different ways. Hence, 100 volt per metre, 100 V/m, 100 $V.m^{-1}$ 100 Vm^{-1} and 100 Vm^{-1}all represent the same value.

Table C1 — Prefixes used with SI units

Name	Symbol	Scaling factor
Tera	T	10^{12}, or 1 000 000 000 000
Giga	G	10^{9}, or 1 000 000 000
Mega	M	10^{6}, or 1 000 000
Kilo	k	10^{3}, or 1 000
Milli	m	10^{-3}, or 0.001
Micro	µ	10^{-6}, or 0.000 001
Nano	n	10^{-9}, or 0.000 000 001

Key message: notation used in the EMF Directive

Units can be expressed in different formats. In the EMF Directive units are expressed in the format Vm^{-1}. This notation is also followed in this guide.

The EMF Directive breaks with scientific convention by using a comma to denote a decimal point.

C.1 Frequency (f)

The action levels (ALs) and exposure limit values (ELVs) given in the EMF Directive are specified according to the frequency of the electromagnetic field. Frequency is normally represented by the letter *f*.

The frequency of an electromagnetic field represents how many times the peak of the electromagnetic wave passes through a particular point each second. It represents the number of oscillations per second and is a fundamental property of a wave.

The unit of frequency is the hertz, which is abbreviated to Hz.

Frequency is closely related to the wavelength of an electromagnetic field, represented by the symbol λ. Wavelength is measured in metres, which is abbreviated to m.

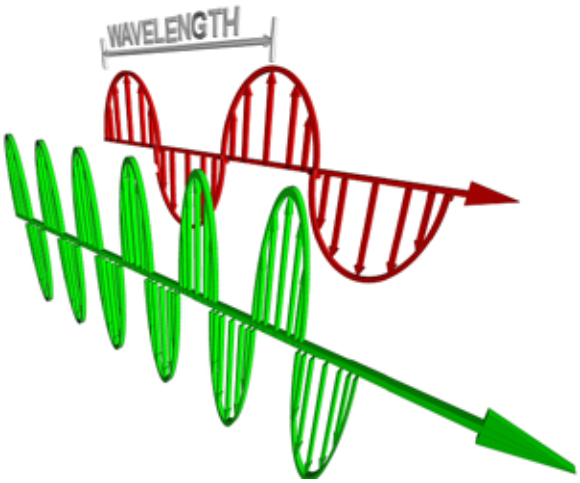
The number of wave peaks passing through a given point in one second is dependent on the wavelength as all electromagnetic waves travel at the same velocity in a vacuum. Hence fields with longer wavelengths will have lower frequencies (Figure C1).

The frequency is related to the wavelength by the expression

$$f = \frac{c}{\lambda}$$

where c is the speed of light in a vacuum (3.0×10^8 ms^{-1}).

Figure C1 — Electromagnetic waves with the wavelength indicated. A wave with a longer wavelength has a lower frequency (red), waves with a shorter wavelength have a higher frequency (green)



C.2 Electric Field Strength (E)

The electric field strength at a point in an electric field is the force acting on a unit positive charge placed at that point. It is a vector quantity and has both magnitude and direction. The electric field strength or intensity of the electric field can be thought of as analogous to the slope of a hill. The greater the slope, the stronger the force causing objects to roll downhill. For an electric field, the greater the electric field strength, the greater the force will be on a charged particle.

Electric field strength is normally represented by the letter *E* and is quantified in volt per metre, abbreviated to Vm^{-1}.

Electric fields can exist both outside and inside the body. The ALs for electric fields below 10 MHz and electromagnetic fields above 100 kHz are specified in terms of external electric field strength. The ELVs for non-thermal effects presented in Annex II of the EMF Directive are specified in terms of internal electric field strength inside the body.

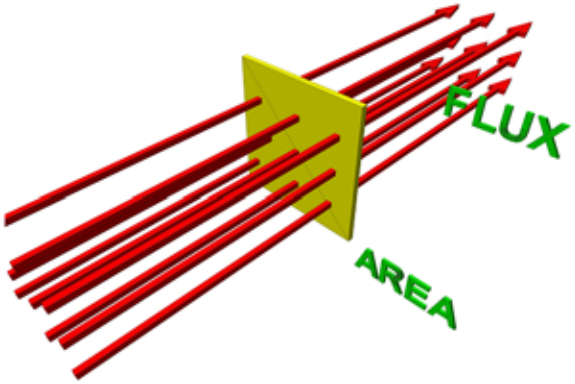
C.3 Magnetic Flux Density (B)

The magnetic flux density is a measure of the magnetic flux travelling through a particular area (Figure C2). The magnetic flux density is greater if there are more field lines in a given area, so that the density of the flux lines is high. The magnetic flux density results in a force that acts on moving charges.

The magnetic flux is a measure of the 'quantity of magnetism'. It is a scalar quantity that takes into account the strength and extent of a magnetic field.

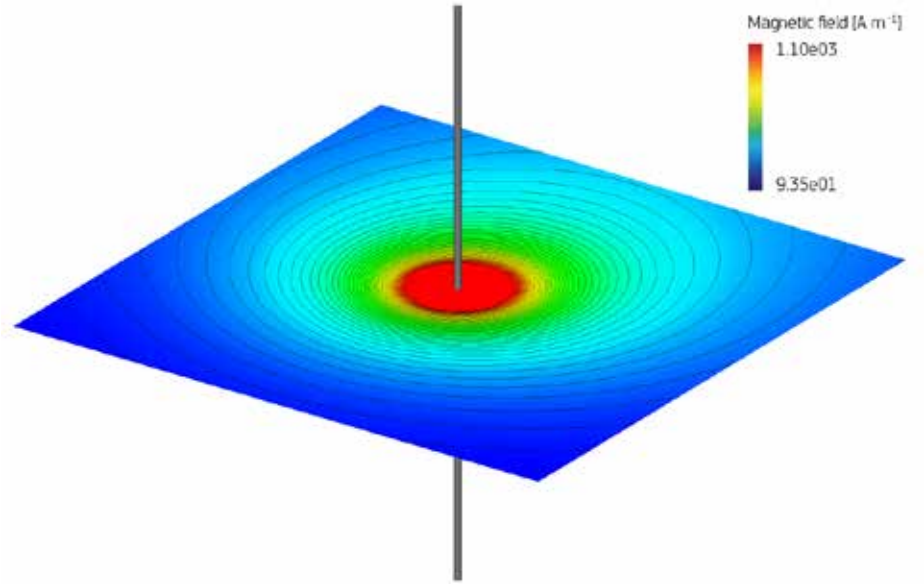
Magnetic flux density is normally represented by the letter *B* and is quantified in units of tesla, abbreviated to *T*.

Figure C2 — The magnetic flux (red) passing through a defined area (yellow). The magnetic flux density represents the amount of magnetic flux per unit area and has the units of tesla



The ELVs for exposure to fields between 0 and 1 Hz are specified in terms of magnetic flux density, as are the ALs for magnetic fields between 1 Hz and 10 MHz and electromagnetic fields above 100 kHz.

Figure C3 — The spatial distribution of magnetic field strength around a 50 Hz cable carrying a current of 70 A



C.4 Magnetic Field Strength (H)

Like magnetic flux density, magnetic field strength is a measure of the magnitude of a magnetic field. Magnetic field strength is represented by the letter *H* and is quantified in units of amp per metre (Am^{-1}). Although magnetic field strength is not used within the EMF Directive, it is used in the ICNIRP guidelines and many magnetic field meters provide results in this quantity.

In free space a magnetic field strength value can be converted to an equivalent magnetic flux density using the equation:

$$B\ [\mu T] \approx H \times 1.25\ [Am^{-1}]$$

So if H has a value of 800 Am^{-1}

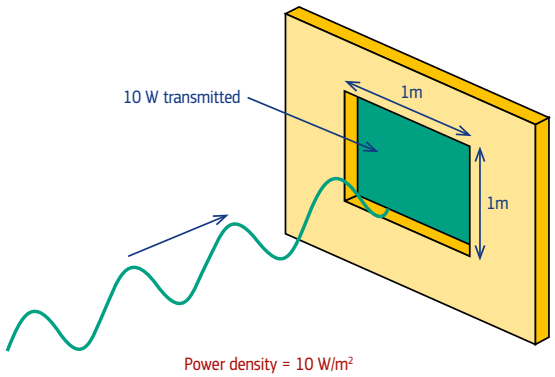
Then B is approximately equal to 800 x 1.25 µT = 1 000 µT = 1 mT

C.5 Radiofrequency Power Density (S)

At very high frequencies (above 6 GHz) where the depth of penetration within the body is low both ELVs and ALs are presented in terms of power density and have the same numerical value. Power density is defined as the radiated power, measured in watts, incident on a surface, measured in square metres. It is represented by the symbol *S* and is expressed in units of watt per square metre (Wm^{-2}).

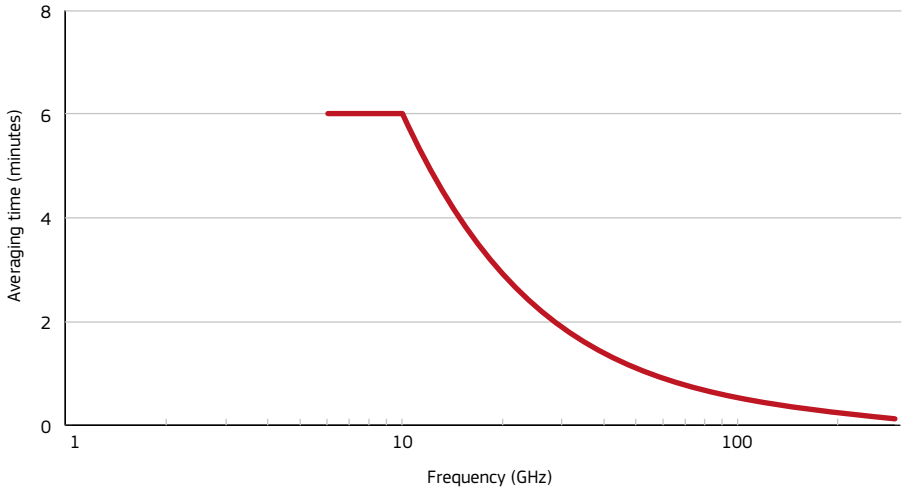
When comparing a power density with the appropriate ELV and AL it can be averaged over any 20 cm^2 exposed area, with the proviso that the power density averaged over any 1 cm^2 exposed area should not exceed 20 times the ELV or AL (i.e. 1 000 Wm^{-2}).

Figure C4 — Power density is the radiated power per unit area



Power density can also be averaged over a time period that is dependent on the frequency of the radiation. The formula for this time period is given in the Notes A3-1 and B1-4 in Annex III of the EMF Directive and is presented graphically in Figure C5.

Figure C5 — Graph showing how averaging time for power density depends on frequency



C.6 Specific Energy Absorption Rate (SAR)

The specific energy absorption rate (SAR) is a means of quantifying the rate at which a unit mass of tissue within the body absorbs energy from electromagnetic radiation. The rate of energy absorption is related to the thermal effects of EMF.

Specific energy absorption rate is quantified in units of watt per kilogram, abbreviated to Wkg^{-1}.

Specific energy absorption rate is useful for estimating elevations in the core body temperature that result from whole body exposures. In this situation the SAR is averaged over the mass of the worker's body. The possibility of tissue heating and therefore adverse health effects increases as the SAR rises. The whole-body averaged SAR for a worker tends to be at its highest at the resonant frequency of the worker's body. The resonant frequency is dependent on the size and shape of the human body as well as its orientation relative to the incident electromagnetic field. For a worker of

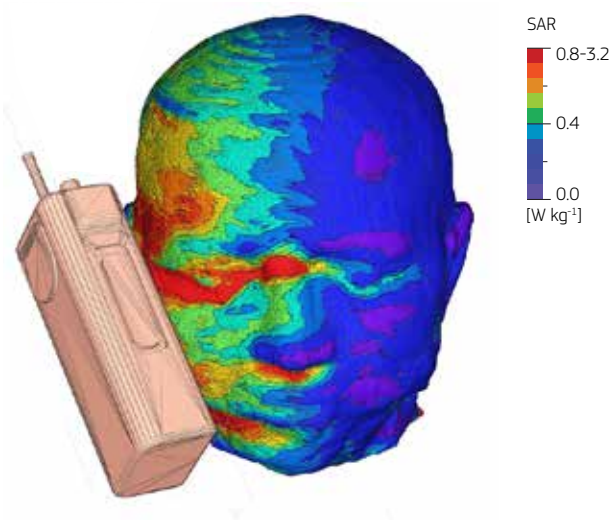
average height and mass, the resonance occurs at approximately 65 MHz when the worker is isolated from electrical ground and the incident field is vertically polarised.

Localised SAR is applicable when the absorption of the incident electromagnetic field takes place in a small region of the body, for example, the head when exposed to a TETRA handset (Figure C6). Localised SAR is averaged over a 10 g contiguous or connected mass of tissue in the body. The 10 g contiguous SAR is a more accurate representation of localised energy absorption and a better measure of SAR distribution in the body.

When the tissues of the body absorb energy from a radiated field, it takes time for the tissues to reach thermal equilibrium. For this reason, both whole-body and localised SAR are averaged over a specific period of time (six minutes).

The health effects ELVs for exposure to electromagnetic fields from 100 kHz to 6 GHz are specified in terms of whole-body and localised SAR.

Figure C6 — The specific energy absorption rate (SAR) distribution in the head from exposure to a 380 MHz TETRA (Terrestrial Trunked Radio) handset



C.7 Specific Energy Absorption (SA)

Specific energy absorption is defined as an energy absorbed per unit mass of biological tissue, expressed in joule per kilogram (Jkg^{-1}). In the EMF Directive, it is used for establishing limits for effects from pulsed microwave radiation.

Sensory effects ELVs for exposure to electromagnetic fields from 300 MHz to 6 GHz are presented in the Directive in terms of the localised SA averaged over 10 g of tissue.

C.8 Contact Current (I_C)

Contact with passive conductive objects in electromagnetic fields can give rise to currents within the body that can either result in shock and burns or localised heating. Action levels have been set to limit this effect. Contact currents are represented by I_C and are quantified in units of milliamperes (mA).

C.9 Limb Current (I_L)

The induced limb current is the electric current discharged to earth from a person subjected to an electric field, but not touching a conducting object. It can be measured either with a clamp type coil meter around the limb (Figure C7) or by measuring the current flowing to ground. It is represented by I_L and quantified in units of milliamperes (mA).

Figure C7 — A current clamp being used to measure the limb current when using a 27 MHz dielectric welder

APPENDIX D. EXPOSURE ASSESSMENT

This appendix provides employers with an overview of the process of assessing occupational exposure in relation to the EMF Directive, including special considerations involving multiple frequency and non-uniform exposures. The intention is not to define detailed measurement protocols for investigating particular pieces of equipment or workplace processes. In time CENELEC and other standards bodies will produce technical standards for these purposes.

EMFs are complex physical agents that vary in time and space. Depending on the particular workplace situation the exposure may be dominated by either the electric or magnetic field part of the wave. The wave may oscillate at one frequency or consist of many frequencies with irregular oscillations or pulses. The frequency and amplitude may also change with time during the operational cycle.

In certain industrial situations it will be necessary to make measurements for comparison with the EMF Directive action levels (ALs) and it will be necessary to go on in a few situations to use computational based techniques to assess the exposure in relation to EMF Directive exposure limit values (ELVs). In general the more sophisticated assessment methodologies require more time and cost more, but will provide better estimates of exposure that may reduce compliance distances.

Whatever the situation, the assessment will need to take into account the worst-case exposure situation in order to determine whether or not the workplace complies with the EMF Directive.

D.1 Exposure Assessment — General Principles

Figures D1 (non-thermal effects) and D2 (thermal effects), along with the Sections D1.1 to D1.3 illustrate a possible approach to compliance assessment involving three main stages. Different approaches are required for low frequency and high frequency EMF in order to account for the different ways that the fields affect people.

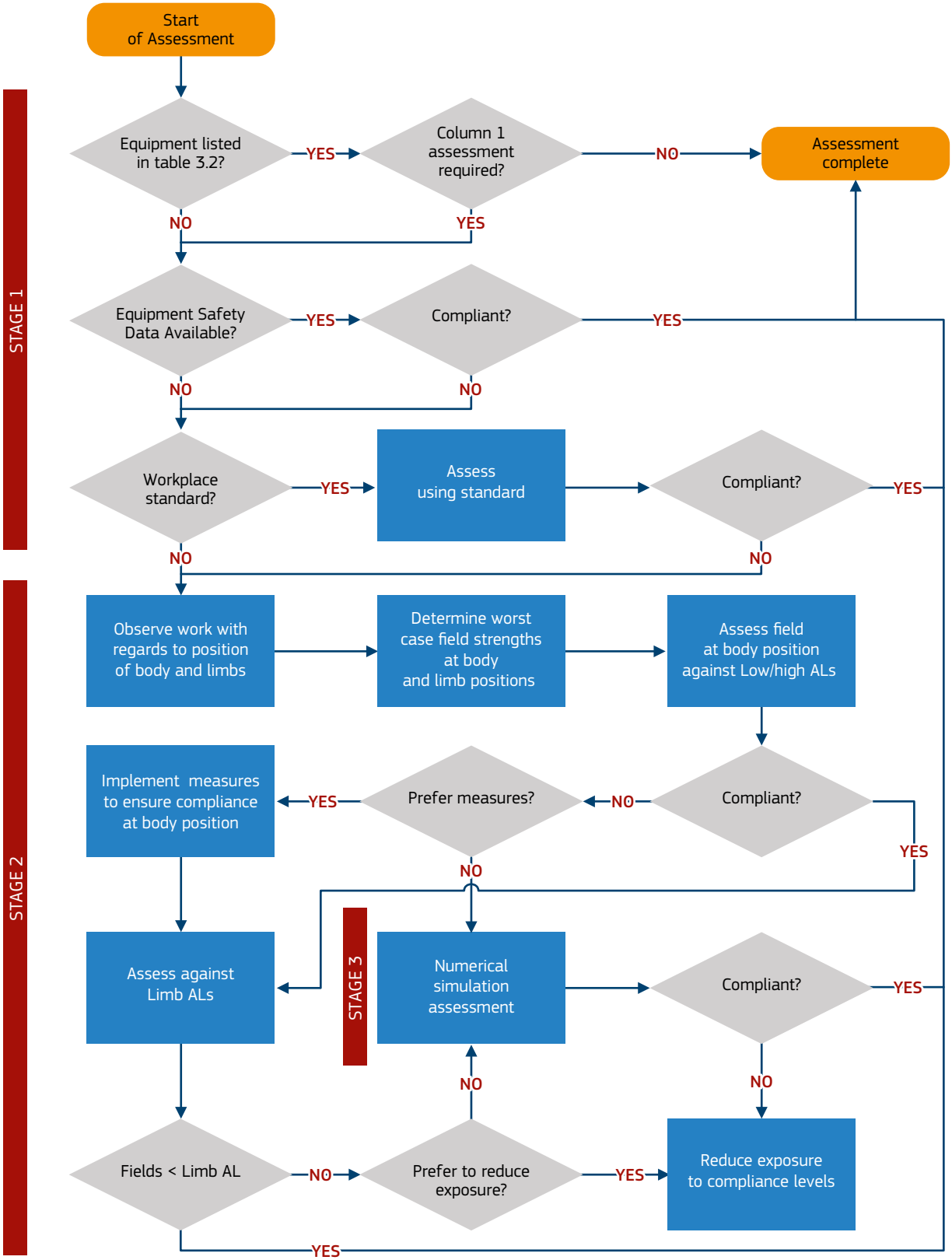
D.1.1 Stage 1 — Initial Assessment

To demonstrate compliance with the EMF Directive, employers are entitled to utilise manufacturer's data or databases of generic assessments if this information is available. In general this should enable employers to carry out assessments in-house, minimising the requirement for the use of specialised sources of assistance such as safety organisations, consultancies and research establishments.

The first step is to identify and list all equipment, situations and activities in the workplace that could generate EMFs. Then consider which of these are compliant with the EMF Directive and which will require a more detailed (stage 2 and /or stage 3) assessment. This can be done by comparison with the table in Chapter 3.

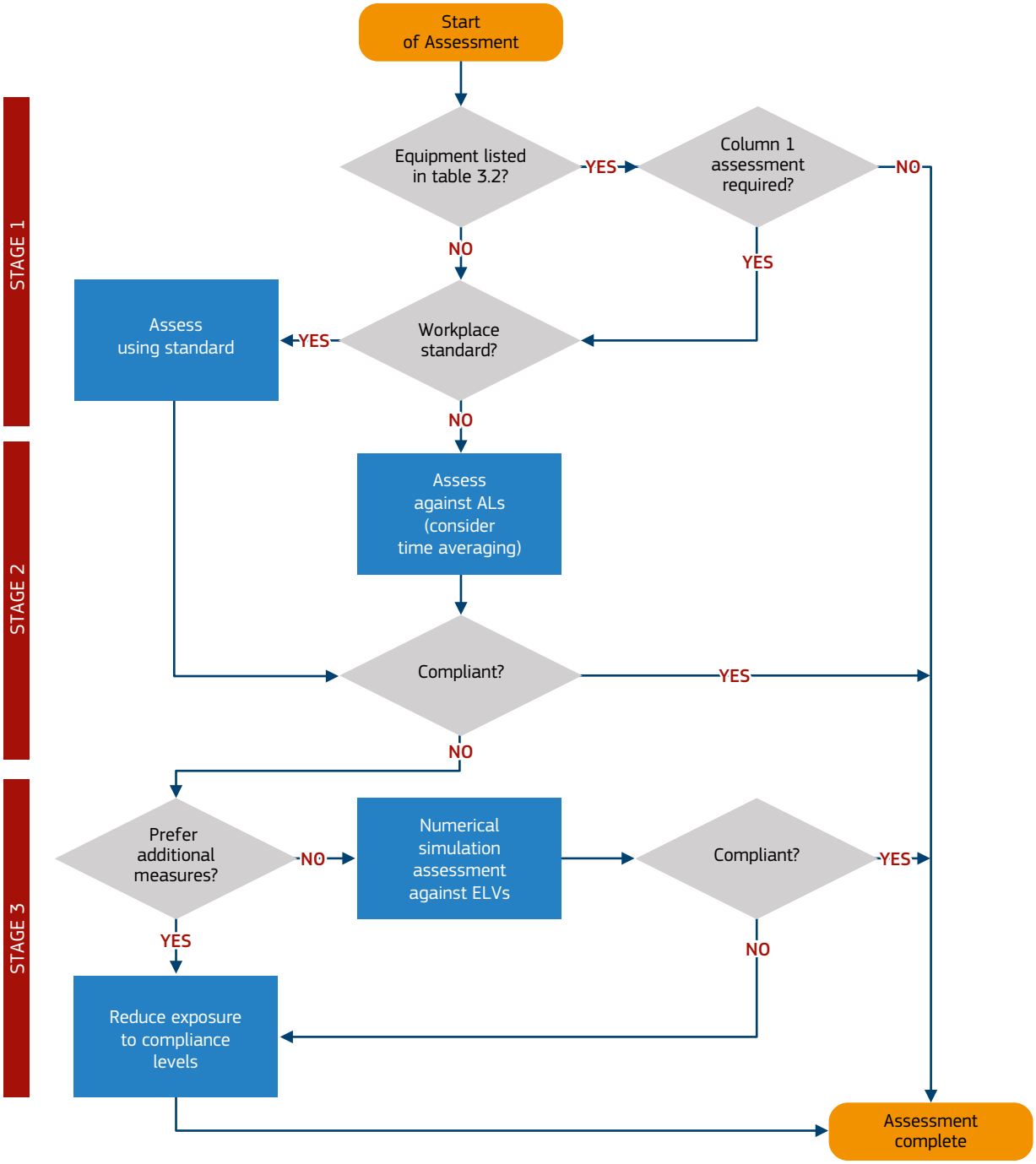
Most equipment, activities and situations will not require a stage 2 or stage 3 assessment as there will either be no field or the fields will be at very low levels.

Figure D1 — Flow chart showing the various stages of a workplace EMF assessment for non-thermal effects



NB: Flowchart refers to ALs and ELVs for non-thermal effects as defined by Annex II of the EMF Directive. Assessment needs to be performed separately for electric and magnetic fields.

Figure D2 — Flow chart showing the various stages of a workplace EMF assessment for thermal effects



NB: Flowchart refers to thermal effects as defined by Annex III of the EMF Directive. Assessment needs to be performed separately for electric and magnetic fields.

Manufacturers of machinery have specific duties under the Machinery Directive (see Appendix G) to provide information about potentially hazardous fields produced by their equipment. However, there is no requirement for manufacturers of equipment to demonstrate compliance in relation to the EMF Directive. Nevertheless, many manufacturers are likely to recognise the commercial advantage in providing the information their customers need to enable them to demonstrate compliance with the EMF Directive.

In future it is likely that there will be standards developed for the purpose of demonstrating compliance with the EMF Directive. Although these standards will be informative rather than normative, they should provide a basis for the information that manufacturers will provide. The information provided by manufacturers would normally be included in the manuals provided with equipment. If not, it may be necessary to contact the manufacturer or supplier of the equipment to request any available information.

For equipment to be considered stage 1 compliant it must be installed, used and maintained according to the manufacturer's instructions. Consideration should also be given as to whether the exposure situation is likely to be different during maintenance/servicing/repair, in which case a further more detailed stage 2 assessment may be necessary.

Workplaces that are stage1 compliant do not require any further assessment other than to document the findings as part of the overall risk assessment. Where the workplace cannot be shown to be stage1 compliant, a stage 2 and possibly stage 3 assessment will be necessary.

D.1.2 Stage 2 — Assessment against action levels

Certain types of equipment, activities and situations, such as those indicated by a 'Yes' in Column 1 of Table 3.2 will require a further more detailed assessment. This may be possible using information available from manufacturers or other sources. However, where such information is not readily available then it will normally be necessary to investigate compliance using measurement or computational techniques. In general, measurement-based approaches are used to assess compliance with ALs, whereas more complex numerical modelling techniques are required to assess compliance with ELVs.

D.1.2.1 Preparatory phase

In preparing for a stage 2 assessment, first consider what is known about the equipment, activity or situation. Record details about how the work is carried out and information provided by the manufacturer or supplier, where this is available.

The key to determining the correct assessment approach is a clear understanding of how the work is carried out and an understanding of the characteristics of equipment generating fields. This will normally include information on frequency, voltage, power and duty cycle.

- Check the manufacturer's user guide and technical specifications supplied with the equipment to become familiar with equipment and how it should be used.
- Consider how the work is carried out and the position of the operator and other workers in the workplace. Consider also the positions of workers during maintenance and repair work, which may require a different assessment.
- Consider who will be present in the work area; have any employees reported being pregnant, having a medical implant, or a body-worn medical device?

D.1.2.2 Scoping measurement phase

In most situations it will be necessary to perform scoping or pilot measurements in the workplace to investigate the nature of the field to be assessed. These measurements are performed at the start of the survey and help to determine the types of measurements and instrumentation needed to properly assess the fields. Table D1 gives some examples of the factors to consider during the scoping phase.

Table D1 — Considerations for stage 2 scoping measurement phase

EMF Attribute	Example considerations	Implications for the assessment
Physical quantity of interest	Is the field magnetic, electric or both?	Determines the type of instrument required to perform measurements.
Frequency and amplitude	Does the field vary as a continuous wave at one frequency or is it a complex waveform consisting of multiple frequencies?	Determines the type of instrument required to perform measurements. Simple sinusoidal waveforms at one particular frequency may be assessed using simple broadband instruments and the results compared directly with ALs. Complex waveforms may require the application of sophisticated spectral techniques to identify the various frequency components and complex analyses such as RMS, Peak or Weighted Average approaches for comparison with the ALs.(see Section D3).
Spatial characteristics	Does the field vary in strength across the location of interest in which case the exposure is likely to be non-uniform?	Consider the size of probe, and the location and number of measurements. Measurements need to be made to capture worst-case exposure situations (see Section D2).
Temporal characteristics	Does the field vary in frequency and or strength during the operation cycle?	Determines the instrumentation required and the timing and duration of measurements. Logging meters may be available in which case the sampling rate and integration period for a measurement needs to be considered. Measurements need to be made to capture worse-case exposure situations. The challenge is to record the field for long enough and at a sufficient sampling rate to capture the maximum field value.

D.1.2.3 Physical quantity of interest

At low frequencies, it is necessary to assess both the electric and magnetic fields separately. Many types of industrial process use high current equipment that produce magnetic fields. Strong electric fields tend to be less common in the workplace because relatively few applications use high voltages or open (unshielded) conductors. Magnetic fields are much more difficult to screen.

It is also important to establish whether the exposure is in the far field, at a location distant from the source or in the near field region. The far field — near field boundary is governed mainly by the wavelength of the field and the size of the source. In the far field there is a simple relationship between electric and magnetic fields determined by the wave impedance, thus either the electric field or the magnetic field can be assessed to determine overall exposure.

The relationship between magnetic and electric fields in the near field region close to the source is much less easy to predict as the fields can vary considerably over very short distances, so much so that they need to be assessed separately. Measurements in the near field are generally difficult to make as the field levels can vary over very short distances and the sensor itself can couple with the field and affect the measurement. In industrial situations involving power transmission and heating processes, the size of the source and frequency of the signal dictate that electric and magnetic fields are assessed separately.

It may not be possible to make meaningful measurements in the near field, in which case the alternative course of action is a stage 3 assessment, which relies on numerical modelling.

D.1.2.4 Spatial variation

It is important at an early stage of the investigation to determine how the field is distributed in relation to the position of the worker and how the field varies across the workstation. The assessment needs to take into account where the maximum field strength occurs in relation to the position of the worker and in many situations the field will fall off rapidly with increasing distance from its source.

If the field varies considerably over very short distances, careful consideration should be given to the size of the probe as large probes may give incorrect readings in these situations. Also the action levels relevant to limb exposure may be more appropriate in such circumstances, depending on the part of the body exposed, and these are less restrictive than the other action levels.

Approaches to spatial averaging and demonstrating compliance in non-uniform exposure situations are considered in Section D2 of this appendix.

D.1.2.5 Characterisation of the waveform

Many EMFs encountered in the workplace vary as a continuous wave of the same frequency in which case a relatively simple assessment can be employed, involving fairly simple broad band instrumentation. Some types of industrial equipment produce complex waveforms that are made up of a range of frequencies and in these situations it is necessary to use sophisticated instrumentation such as a spectrum analyser or wave capturing instrumentation, to sample the signal.

Assessments involving multiple frequencies and complex waveforms are considered in detail in Section D3 of this appendix.

D.1.2.6 Time variation

It is important to determine how the frequency and /or strength (amplitude) of the field varies with time. In some situations the field may change during the operational cycle, in which case the assessment will need to allow for the field strength and frequency changes and identify the time when the maximum or peak field occurs.

The temporal changes may be intentional, for instance the way signals are modulated to carry information in telecommunications systems or incidental, for example the harmonic signals produced during induction heating processes or where AC rectification or the rapid switching of current is used to control the delivery of power to certain types of industrial equipment. It is important to identify harmonic signals when these occur because the ALs and ELVs vary with frequency. The way in which exposures at multiple frequencies should be treated in the exposure assessment is discussed in Section D3.

Many modern instruments have logging capability whereby the field can be recorded at predetermined sampling intervals for periods of up to several hours. The sampling rate is selected on the basis of how quickly the field varies in time. If the sampling rate is too slow in relation to the field variation, the peak level may be missed, leading to an underestimation of exposure. The integration period of the instrument i.e. the time taken for the meter to process and record the signal, also needs to be considered carefully as an under- or overestimation of exposure can occur if the field is changing rapidly during the integration period. Most modern instruments require an integration period of at least a second, so if the field changes more rapidly than this it is advisable to capture the peak signal or entire waveform.

D.1.2.7 Static magnetic fields

The EMF Directive includes ELVs for external magnetic fields from 0 Hz to 1 Hz. Movement in static magnetic fields produces induced electric fields inside the body similar to those produced by low frequency time-varying fields. The EMF assessment necessary in this situation is considered in Section D4.

D.1.2.8 Main survey phase

Safety aspects of performing measurements

In addition to the normal safety considerations in an occupational setting, care should be taken that the person carrying out the measurements is not themselves exposed to EMFs exceeding the ALs or ELVs and not at risk from indirect effects. It is good practice to start measurements at some distance from the source of the fields. This ensures that the surveyor will not be exposed to fields above the AL or ELV and protects the instrument from damage in high fields that may be encountered close to a strong source.

Particular care should be taken in static magnetic fields to avoid the risk of projectile effects and in strong electric fields, excessive microshocks and contact currents need to be avoided.

A suitable risk assessment should be made in advance and appropriate protective or preventive measures implemented. These measures may well be predominantly organisational in nature.

Survey approach

Careful consideration should be given to determining the location, timing and duration of the measurements. This will normally start by talking to workers to find out what tasks they undertake and a period spent watching them while they work to identify appropriate body and limb positions for measurements. Assessments should take account of the range of activities normally undertaken, including normal operation, cleaning, clearing blockages, maintenance, and servicing/repair if this is undertaken in-house.

The most common approach to a survey is the use of spot measurements at defined locations in the workplace or at specific locations around EMF sources. These should reflect the areas occupied by the worker whilst performing their duties as discussed above. However, it should be noted that the ALs specified in the Directive are body absent values, so the worker should not be present during the actual measurement (see below). To take into account any possible field variation in time, logging meters can be set to record the field at various locations whilst the spot measurements are performed

It is good practice to repeat measurements in the same location at various intervals during the assessment to provide assurance that the measurements are stable and the meters are behaving correctly.

Measurements of electric fields are more difficult to perform than magnetic fields, because electric fields are easily perturbed by surrounding objects including the human body. The EMF Directive defines unperturbed ALs so care should be taken to keep workers' or surveyors' bodies well away from the measurement probe (and the probe well away from metallic objects) when making such measurements.

Instrumentation

For the assessment to be valid it is important that appropriate instrumentation is used to make the measurements and this depends on the nature of the EMF being assessed. Consideration should be given to technical specifications of the instrument to make sure

it is suitable for measuring the signal of interest. In some situations it may be necessary to measure both the electric and magnetic fields. If the source is known to operate at frequencies above a few tens of MHz and the operator is in the far field, the field strength for electric and magnetic fields may be converted from one to the other based on the value of the impedance of free space (Z_0 = 377 Ohms (Ω)). Another important requirement is that the instruments should be calibrated to traceable standards, to provide assurance that they are performing correctly. Always begin a survey with the instrument set to its highest measurement range, to minimise the risk of overloading it.

Instruments with a single axis sensor will measure only one component of the field, thus when using this type of sensor it is important that it is used in three orthogonal orientations at the measurement location so that the resultant field can be calculated. More sophisticated instruments have three orthogonal sensors which can measure the resultant field. It is also important to consider the size of the probe as the probe needs to smaller than the volume over which the field varies. Further information on appropriate probe sizes is given in IEC617861.

Many modern instruments can be set to measure peak values or root-mean-square (RMS) values for direct comparison with the limit values given in the EMF Directive. The ALs in the EMF Directive are normally given as RMS values. However RMS measurement devices may not be appropriate for measuring the fields produced by spot welding or radiofrequency identification (RFID) equipment where the signal may be pulsed and the field changes are much more rapid than the averaging time for the instrument. In situations involving complex signals weighted peak exposure assessments are preferable (see Section D3).

Some of the main factors to consider in selecting suitable instrumentation are summarised in Table D2.

Table D2 — Factors to consider in selecting suitable instrumentation

EMF characteristic to be assessed	Instrument requirements
Frequency	The instrument needs to be capable of responding to the full range of frequencies in the signal being assessed.
Amplitude	Instrument needs to have a sufficiently large dynamic range to measure the field strengths likely to be encountered.
Modulation Characteristics	The instrument needs to be capable of detecting different modulation schemes
Temporal variation / duty cycle	Consider the sampling rate and integration time of the instrument, and the duration of the logging period.
Spatial variation	Probe needs to be smaller than the volume over which the field varies.
Location: Interior/Exterior/both Weight/durability of instrument	Surveys outside away from mains supply may require sufficient battery duration. Is the instrument suitable for exterior survey

Report Parameters

Examples of key parameters to log as part of the workplace assessment are presented in Table D3.

If the stage 2 assessment indicates that the environmental fields are below the ALs, the workplace is compliant with the EMF Directive and the assessment can be concluded (Figure D1).

If static field ELVs or ALs may be exceeded then the employer will need to implement appropriate preventive or protective measures.

At low frequencies if the low ALs are exceeded, then the employer will need to carry out a further assessment against the high ALs. If the measurements are below the high ALs, the employer may choose either to either implement protective or preventive measures, including worker training, or carry out a stage 3 assessment to demonstrate compliance with the sensory ELVs.

Table D3 — Example of parameters to record on a survey sheet

Parameter	Comment
Date and time of survey	Reference
Contact name/Location details/structures	Reference
Workplace assessed	Details of equipment present, including summary of operating specification
Worker task or activity assessed	Routine operation, maintenance or cleaning
Physical quantity of interest	Electric field, magnetic field or power density
Details of measurement instrumentation	Broadband or narrow band meter, frequency response, dynamic range, sampling rate, calibration date and uncertainty.
Measurement strategy	Peak/ Root-Mean-Square (RMS) Resultant, x, y, z Spot or extended measurements Sampling locations (include diagram or map if appropriate) Sampling rate

If the measured fields exceed the high ALs, then the spatial extent of the field needs to be considered in relation to the part of the worker's body exposed and if appropriate the fields compared with the limb ALs. If the exposure is not localised, or the localised exposure exceeds the limb ALs, the employer has two choices. They can either implement protective and/or preventive measures or proceed to a stage 3 assessment to evaluate compliance with ELVs (see Section D1.3).

At high frequencies, if the environmental fields exceed the ALs, the employer again has the choice of implementing protective and/or preventive measures, or proceeding to a stage 3 assessment.

If the ALs for contact current are exceeded then the employer will need to implement appropriate protective or preventive measures.

D.1.3 Stage 3 — Assessment against Exposure Limit Values (ELVs)

D.1.3.1 Introduction

The EMF Directive defines ELVs that are intended primarily to restrict the induced electric fields and specific energy absorption rate (SAR) within the body. Such quantities are not easily measurable and consequently a stage 3 assessment usually relies on sophisticated numerical modelling techniques to determine compliance with the ELVs, although some measurement approaches are available.

The ALs provide conservative estimates of the maximum environmental fields to which a worker's whole body may be exposed without exceeding the relevant ELVs. If

measurements indicate that an AL may be exceeded for a particular exposure situation, it may be necessary to carry out a dosimetric assessment to determine compliance with the ELVs.

Numerical simulations can be used to assess whether the electromagnetic fields produced by a device will result in the ELVs being exceeded. Simulations and the application of computational dosimetry provide the link between the ALs (externally measured unperturbed electromagnetic fields) and ELVs (modelled dose quantities representing the interaction of the electromagnetic field and the human body). These simulations are used to translate electromagnetic field values, measured in the absence of the body, to dose quantities within the body.

The dose quantities included in the ELVs include induced electric field strengths, the specific energy absorption rate (SAR) and power density. Health effects and hence dose quantities, depend on the frequency of the incident field. At low frequencies, the Directive specifies ELVs in terms of induced electric field strengths, whereas at higher frequencies, SAR and power densities are used (Table D4).

Table D4 — Potential adverse biological effects, ELV and AL quantities

Frequency	Potential Adverse Biological Effect	ELV Dose Quantity (Numerically Simulated)	AL Exposure Quantity (Typically measured)
1 Hz to 10 MHz	Effects on central nervous system (CNS) and peripheral nervous system (PNS)	Induced electric fields in stimulated tissues in V/m	Electric field strength, magnetic flux density, induced and contact currents
100 kHz to 6 GHz	Tissue heating	SAR in W/kg SA in J/kg	(Electric field strength)^2, (magnetic flux density)^2, induced and contact currents
6 GHz to 300 GHz	Surface heating	Power density in W/m^2	(Electric field strength)^2, (magnetic flux density)^2 and power density

D.1.3.2 Electromagnetic Field Interactions with Human Tissue

Low Frequency Fields

At low frequencies, electric and magnetic fields can be considered as decoupled (the quasi-static approximation) and therefore can be treated separately.

External Electric Field

The human body will significantly perturb an incident low frequency electric field. In the majority of exposure situations, the external electric field is orientated vertically with respect to ground. The human body is a good conductor at low frequencies and the internal electric fields induced within the body are many orders of magnitude smaller than the external applied field.

The distribution of charges induced on the surface of the body from exposure to an external electric field is non-uniform. The result is a mostly vertical orientation of the internal currents induced within the body. Another factor that strongly influences the magnitude and spatial distribution of the induced electric fields within the body is the contact between the human and electric ground. The highest internal electric fields are induced when the body is in perfect contact with ground through both feet. The more isolated the body is from electric ground, the lower the induced electric fields in tissues. This is why wearing insulating work shoes can, in some circumstances, provide a degree of protection from the effects of low frequency fields.

External Magnetic Field

In contrast to applied electric fields, the human body does not perturb an applied magnetic field. The magnetic field in human tissue is the same as the external magnetic field. This is because the magnetic permeability of tissues is the same as that of air. Magnetic materials (magnetite, for example) can be present within tissue; however in such small amounts that for practical purposes they can be ignored.

The main interaction of an external magnetic field with the body is the Faraday-induction associated current flow in conductive human tissue. In heterogeneous tissues consisting of different conductivity regions, currents also flow at the interfaces between these regions.

High Frequency Fields

At high frequencies, the human body can be considered as an imperfect conducting antenna. Electric fields and currents will be induced in the tissues of the body. If the body is standing on a ground plane, the induced currents will flow through the body in a vertical direction through the feet into ground. Induced electric fields and currents will give rise to thermal effects within human tissues, both locally and throughout the body. The magnitude and spatial distribution of these induced electric fields are very dependent on the exposure configuration and frequency.

The body has a natural resonant frequency related to its height. Radiofrequency electromagnetic fields are absorbed more efficiently at frequencies near this resonant frequency. At frequencies less than approximately 1 MHz, the human body absorbs very little RF energy. Significant absorption occurs at the resonant frequency of 60-80 MHz when isolated and 30-40 MHz when the human body is grounded. Additionally, parts of the body can also be resonant. The adult head is resonant at around 400 MHz. If the body adopts a sitting posture, the upper and lower halves of the body can have their own resonant frequencies. Therefore, the frequency at which the maximum amount of RF energy is absorbed is dependent on body size and posture. Generally, less RF heating occurs as the frequency increases above the resonance region. However, the heating at higher frequencies tends to be more concentrated on the surface of the body as the penetration depth of the incident field decreases.

D.1.3.3 Exposure Limit Values

ELVs represent dose quantities within the body intended to protect against adverse health effects from human exposure to electromagnetic fields. The ELVs applied are dependent on the frequency of the field under investigation.

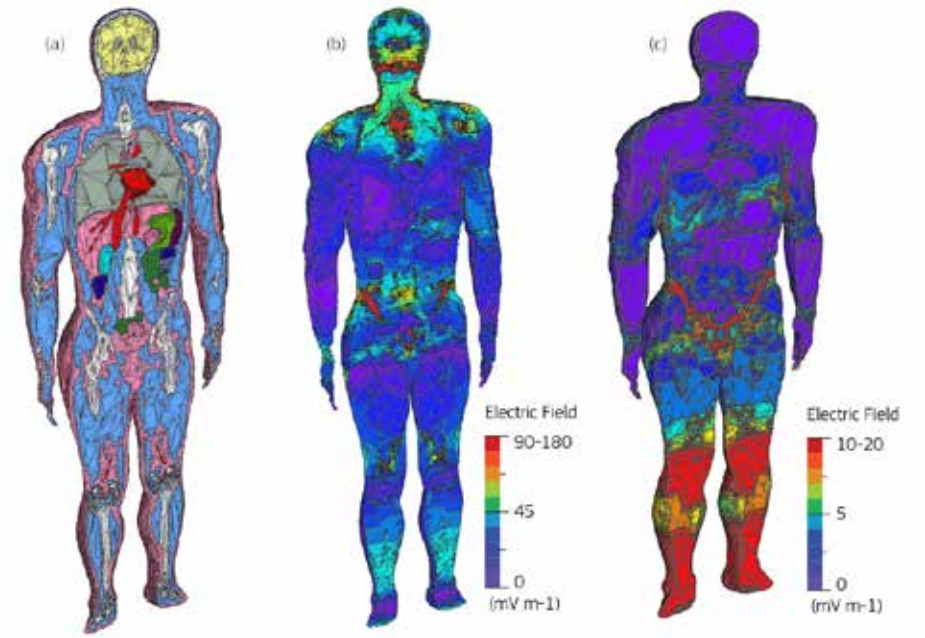
Low Frequency

At low frequencies (1 Hz to 10 MHz), the primary dosimetric quantity is the internal electric field induced within the human body. This is because thresholds for human nerve tissue stimulation are defined by the magnitude and spatial variation of these internal electric fields. The induced electric field has units of Volts per metre (Vm^{-1}).

For exposure to low frequency electric fields, internal electric fields are produced in the body significantly perturbing the incident field. Non-uniform charges are induced on the surface of the body from the external electric field, and internal electric fields are set up within the body, which may generate currents within the body.

For exposure to low frequency magnetic fields, internal electric fields are produced by the magnetic field inducing an electric field and associated currents in human tissue. Fields are also produced by currents flowing between regions of different tissue conductivity in the body. Figure D3 shows how these induced electric fields are absorbed in the body from exposure to external low frequency electric and magnetic fields.

Figure D3 — Low frequency Exposure: Cutaway images of the human body showing (a) internal organs within the body (b) internal electric fields produced from exposure to an external low frequency magnetic field and (c) internal electric fields from exposure to an external low frequency electric field

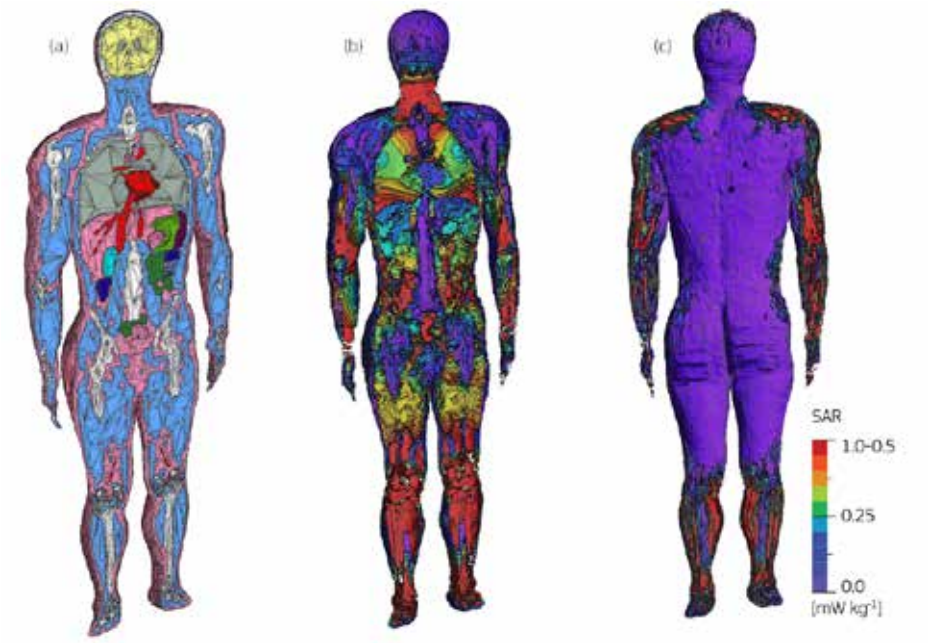


High Frequency

At high frequencies (100 kHz to 300 GHz), the primary dosimetric measure of electromagnetic field absorption is the specific energy absorption rate (SAR). This is due to the dominant adverse biological effects from exposure to electromagnetic fields at these frequencies being caused by temperature rises in tissues.

SAR can be defined as the power absorbed per unit mass. It has units of watts per kilogram (Wkg^{-1}). It is used as the dose quantity in the EMsF Directive as it is closely correlated with temperature rise in human tissue. Figure D4 shows how the SAR is distributed in the human body when exposed to a high frequency electromagnetic field.

Figure D4 — High Frequency Exposure: Cutaway images of the human body showing internal organs within the body (b) SAR produced in tissues from exposure to a 40 MHz electromagnetic field and (c) SAR produced in tissues from exposure to a 2 GHz electromagnetic field



The internal dose quantities (electric fields and SAR) that are used to define the ELVs cannot be accurately assessed by measurement, as field strengths within the human body cannot be measured non-invasively. ELV dose quantities have been measured in animals, however data are limited and the accuracy of these measurements is relatively poor. Additionally, extrapolation of animal studies to humans cannot be directly applied due to physiological differences between the species in many areas. Numerical simulations of human electromagnetic absorption, hence compliance with the EMF Directive ELVs, allows internal dose quantities to be directly investigated.

D.1.3.4 Assessment of Compliance with the ELVs

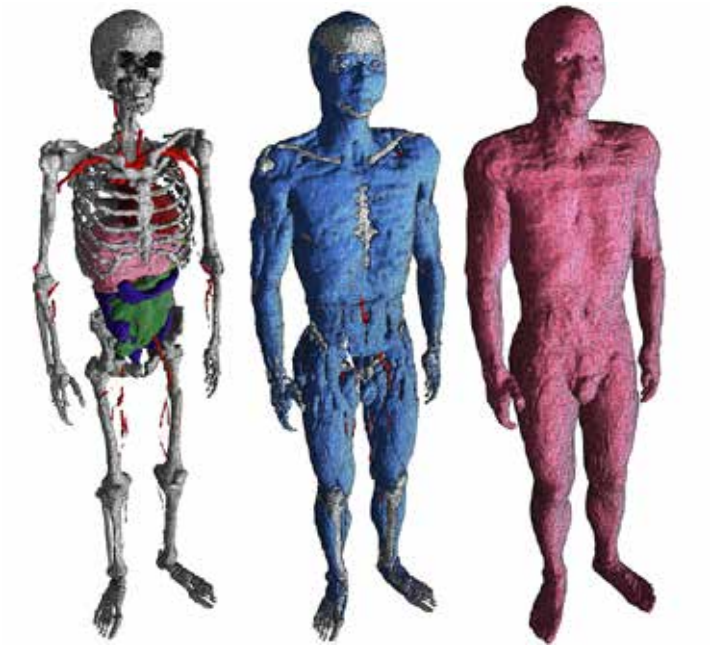
To calculate the dose quantities in the body required for comparison with the ELVs, a representation of the human body, a numerical method able to model the interaction of the electromagnetic field with biological tissues and a representation of the electromagnetic field source are required.

Human Model

The human body can be considered as a receiving antenna when exposed to electromagnetic fields. Therefore, the body's anatomical, geometrical and electrical properties are extremely important when assessing compliance with the ELVs.

Historically, simple homogeneous structures such as spheres, spheroids, cylinders, disks and cubes have been used to replace the body for the evaluation of internal dose quantities. For these homogeneous shapes, a single value of conductivity and permittivity is used, representing an average value over the whole body, which is not usually frequency dependent. The use of such simple structures make the numerical simulation of exposure to electromagnetic fields easier. However, the results of such procedures produce inaccurate results which significantly overestimate the actual exposure.

Figure D5 — Human Model: An example of a heterogeneous, anatomically realistic male model. Indicated are the skeleton and internal organs (left), muscle layer (centre) and skin layer (right)



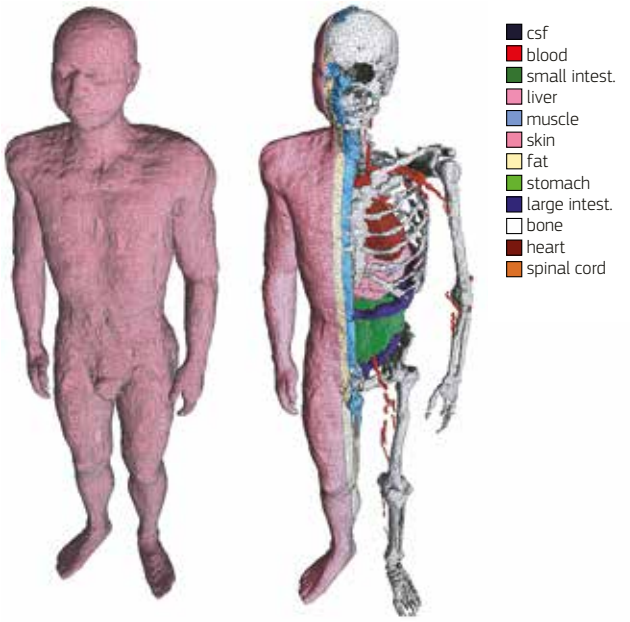
It is recommended that heterogeneous, anatomically realistic models of the human body are used for the assessment of exposure to electromagnetic fields. Currently, a number of organisations have developed a variety of heterogeneous models of the human body (male, female, pregnant, postured etc.) with realistic anatomy and numerous tissues identified. Due to the investment required to produce such a model, there will normally be a cost associated with their use. Moreover, there will inevitably be difference between the different models available, so they are likely to produce slightly different results.

Anatomically realistic models tend to be developed by computer segmentation of data from magnetic resonance images of the body into different tissue types. Special care is taken to make these models anatomically realistic. Examples of a heterogonous male adult model are shown in Figures D5 and D6. It is common for these models to consist of over 30 distinct tissues and organs. The model can be voxel (volume-pixel) or surface based.

When utilised in simulations employing a numerical method such as the finite-difference time-domain, the human body model is typically represented by cubic cells (voxels) of 1 to 2 mm in dimension. Voxels are assigned a conductivity and permittivity value based on measured values for various organs and tissues.

In order to calculate dose quantities in the human models shown, the dielectric properties of the tissues making up these models have to be specified. If it is assumed that different tissues are largely homogeneous, the electrical properties can be described by two parameters, namely the conductivity (σ) and permittivity (ε). These properties vary with frequency for biological tissues. Generally, the conductivity of a tissue will increase and the permittivity will decrease as the frequency increases.

Figure D6 — Human Model: cutaway image of a heterogeneous human model showing selected tissue types



Dielectric properties differ largely depending on the particular tissue (see http:/niremf.ifac.cnr.it/tissprop/). Tissues with a high proportion of water, e.g. body fluids, show almost no frequency dependence for frequencies below 100 kHz. The proportion of water or fluid present in a human tissue is significant in the dielectric properties exhibited and the way in which this changes with frequency. As a result, tissues that display similar behaviour when exposed to electromagnetic fields can be grouped according to their water content. For example, blood and cerebro-spinal fluid have a high water content and can conduct currents relatively well. The lungs, skin and fat are relatively poor conductors whereas the liver, spleen and muscles are intermediate in their conductivities.

Numerical Methods

Various numerical methods have been used to assess electromagnetic field absorption in heterogeneous, anatomically realistic human models. Suitable numerical methods are limited by the highly heterogeneous electrical properties of the human body and equally complex external and internal organ shapes.

The methods that have been successfully used for high resolution electromagnetic field dosimetry include the finite difference (FD) method in the frequency domain and the time domain (FDTD), the finite element method (FEM) and the finite integration technique (FIT).

These methods provide a direct solution of the Maxwell curl equations. They tend to divide the computational domain into a 3D lattice of cells or surfaces which are assigned discrete electrical properties. In the case of the finite difference methods, the computational code iterates through time and space, evaluating field values in each cell until convergence of the solution is obtained.

Each method offers some advantages and limitations. All methods and some computer codes have undergone extensive verification by comparison with analytic solutions and experimental results to ensure that the results produced by these methods are representative for a wide variety of electromagnetic exposure situations.

D.1.3.5 Averaging: 99th Percentile Induced Electric Field, WBSAR and Localised SAR

99th percentile induced electric field

When restricting adverse effects of in-situ electric fields induced in the worker, it is important to define the region over which the in-situ electric field is averaged. As a practical compromise, satisfying requirements for a sound biological basis and computational constraints, it is recommended that the in-situ electric field is determined as a vector average of the electric field in a small contiguous tissue volume of 2 x 2 x 2 mm^3.

Often, numerical methods used to calculate induced electric fields in the body utilise a model of a human discretised into cells or voxels. However, if a method is used that does not employ cells; an appropriate averaging algorithm that calculates the electric field over a 2 x 2 x 2 mm^3 volume within the numerical code should be prepared. For a specific tissue, the 99th percentile value of the electric field is the relevant value to be compared with the exposure limit value (ICNIRP 2010).

Whole-body averaged SAR (WBSAR)

The WBSAR ELV is intended to protect against whole-body heating effects. To calculate the whole-body SAR, the absorption rates in all voxels of the human model are summed and then divided by the mass of the body.

Localised SAR

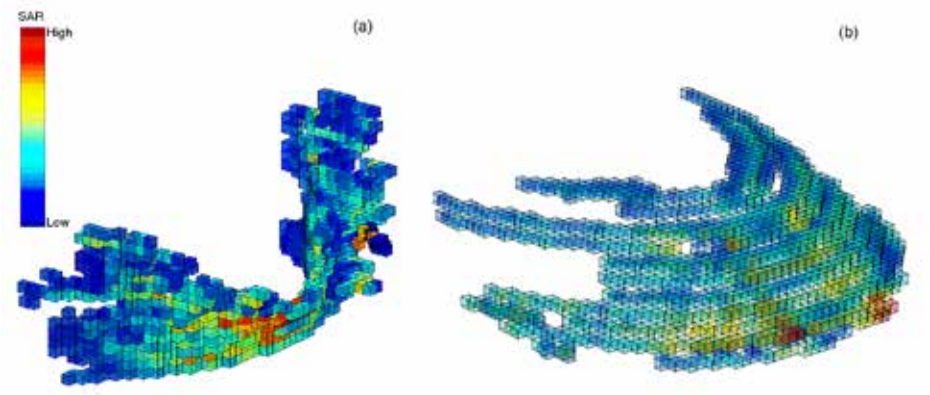
Localised SAR ELVs are specified in the EMF Directive to protect against localised heating in the human body, primarily from exposure to near field sources of electromagnetic radiation.

For the calculation of the localised SAR for exposure to electromagnetic fields between 100 kHz to 6 GHz, the EMF Directive states that the averaging mass used should be any 10 g of contiguous (i.e. connected) tissue. The maximum localised SAR value in the body should be used for exposure estimation.

A procedure for calculating the localised SAR over a 10 g contiguous region is as follows. A cell is selected with the maximum SAR in a horizontal section of the human model. A search is then performed amongst its six neighbouring cells touching the faces of the original to find the one with the highest absorption rate. Once this is complete, the powers and masses are summed. A search is performed amongst the corresponding neighbours on its surface to obtain a connected region of cells for which the mass is equal to 10 g and the SAR is calculated for this connected region. Approximately 1 000 cells (depending on the density of the tissue type) are used in this procedure for a voxel resolution of 2 mm since the volume of each cell is 0.008 cm^3. This procedure is repeated for each horizontal section, and the maximum SAR value of any connected region over the entire human model is eventually chosen.

Examples of localised SAR averaged over a 10 g contiguous region are shown in Figure D7. This figure shows peak 10 g SAR contiguous regions calculated in a human model from exposure to a 100 MHz and 3.4 GHz plane wave electromagnetic field.

Figure D7 — Contiguous regions: SAR averaged over 10 g contiguous (connected) regions in a human model from exposure to (a) 100 MHz and (b) 3.4 GHz electromagnetic field. The colour map ranges from dark blue (low SAR) to dark red (high SAR)



D.2 Demonstration of compliance for non-uniform exposure

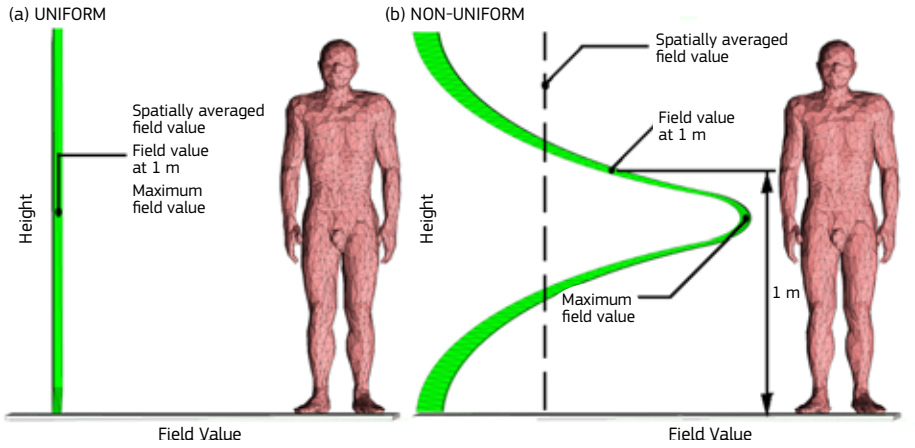
D.2.1 Introduction

Exposure to electromagnetic fields can either be described as uniform or non-uniform. A uniform electromagnetic field is defined at high frequencies as a wave that has spread out to an extent that it will appear to have the same amplitude everywhere in the plane perpendicular to its direction of travel. The uniform field is an idealisation that allows the wave to be explained in terms of an entire wave travelling in a single direction. At low frequencies, a uniform field is a field that is the same throughout a defined volume, for example, an electric field between two infinite parallel plates.

Determination of the field value for assessment of compliance with ALs is trivial for a uniform electromagnetic field, as the value will be the same along a line perpendicular to the wave's direction of travel (Figure D8).Where a field is uniform in this way, or relatively uniform (within 20 %), a measurement of the field in one location of a space occupied by a worker should be sufficient.

Devices producing electromagnetic radiation can create non-uniform exposure conditions over the height of the body if positioned close to a person or in an environment where there is variation in the produced field due to ground reflections/ scattering from nearby objects.

Figure D8 — Examples of uniform and non-uniform exposure: The variation of the field with distance from the ground for (a) a uniform field (b) a typical dipole. The spatially averaged field value, maximum field value and field value at 1 m are indicated.



Determination of a single field value for comparison with the ALs is not trivial if the field varies significantly in the region occupied by the worker. In this exposure situation, the maximum field value at the workers' body position can be used, but this will result in a conservative assessment. Some organisations have suggested using a single field value at a height of 1 m; however this value is also often unrepresentative.

In these non-uniform situations, an appropriate method of obtaining a single value of the field needs to be defined. The Directive states that spatial averaging of the field can be used in these cases. Spatially averaged measurements or calculations are recommended as they give a more representative indication of exposure in situations where the field varies along the height of the human body.

D.2.2 Issues relating to non-uniform exposure

The Directive specifies ALs in terms of a single value for a particular frequency. The magnitude of these ALs are established to ensure compliance with the relevant ELV or which prevention or protection measures specified in Article 5 must be taken.

However, if the field is non-uniform within the area occupied by the worker (as in Figure D8 (b)), the electric field strength or magnetic flux density varies depending on the position at which the field is assessed. A valid question would be what single value of the field should be compared with the ALs?

The Directive recommends, in these exposure situations, that the maximum field over the relevant volume or spatial averaging is carried out. In cases where there is a very localised source close to the body, compliance with the ELVs should be determined dosimetrically.

The Directive states in Note B1-3 and B2-3 of Annex II for non-thermal effects:

'ALs represent maximum calculated or measured values at the workers' body position. This results in a conservative exposure assessment and automatic compliance with ELVs in all non-uniform exposure conditions. In order to simplify the assessment of compliance with ELVs, carried out in accordance with Article 4, in specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14. In the case of a very localised source within a distance of a few centimetres from the body, the induced electric field shall be determined dosimetrically, case by case.'

The Directive states in Note B1-3 of Annex III for thermal effects:

'ALs (E) and ALs (B) represent maximum calculated or measured values at the workers' body position. This results in a conservative exposure assessment and automatic compliance with ELVs in all non-uniform exposure conditions. In order to simplify the assessment of compliance with ELVs, carried out in accordance with Article 4, in specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14. In the case of a very localised source within a distance of a few centimetres from the body, compliance with ELVs shall be determined dosimetrically, case by case.'

D.2.2.1 Maximum field value

This is the simplest way of assessing compliance with the limits presented within the Directive; however it is also the method that presents the most conservative estimate of field exposure to a worker. No spatial averaging is performed. The measurement or calculation of the unperturbed field, i.e. without the worker present, is carried out in a spot within a region occupied by the worker where the field is at its maximum. The field is assessed without the worker present as the presence of a worker can, in certain exposure situations, distort the field value. Note that at low frequencies it is only electric field that is affected by the presence of a worker. Humans are non-magnetic and the induced currents are not sufficient to affect the field.

ICNIRP (2010) states in the section 'Spatial averaging of external electric and magnetic fields':

'Reference levels have been determined for the exposure conditions where the variation of the electric or magnetic field over the space occupied by the body is relatively small. In most cases, however, the distance to the source of the field is so close that the distribution of the field is non-uniform or localised to a small part of the body. In these cases the measurement of the maximum field strength in the position of space occupied by the body always results in a safe, albeit very conservative exposure assessment.'

D.2.2.2 Spatial averaging

Spatial assessment of the field for non-uniform exposure can be carried out in a variety of different ways. Three commonly used approaches, in order of decreasing complexity, are to spatially average the field over

- a volume occupied by the worker or part of the worker
- a cross-sectional area occupied by the worker or part of the worker
- a line in the region occupied by the worker or part of the worker

Details of these approaches can be found in various international standards and guidelines, e.g. IEEE C95.3 (2002), CENELEC EN 50357 (2001), IEC 62226 (2001), IEC 62233 (2005), IEC 62110 (2009). The more complex the averaging procedure, the better the approximation of the non-uniform field. However, it is accepted that for compliance assessment purposes, determination of the field values over a projected volume or area may prove difficult as these approaches require many sampling points. Line averaging methods can provide a fair representation of a non-uniform electromagnetic field and are therefore recommended in the following sections.

(a) Exposure to electric and magnetic fields between 1 Hz and 10 MHz

The spatially averaged values of the electric field strength (E_{avg}) or magnetic flux density (B_{avg}) should be calculated using the following formulae:

$$E_{avg} = \frac{1}{n}\sum_{i=1}^{n} E_i \qquad \textbf{(Equation 1)}$$

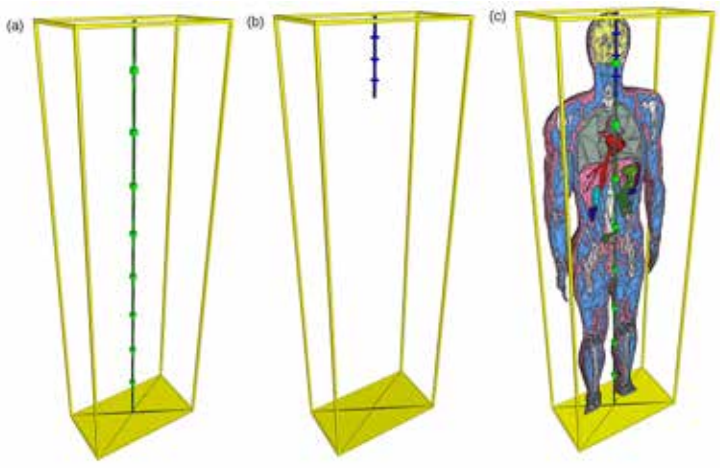
$$B_{avg} = \frac{1}{n}\sum_{i=1}^{n} B_i \qquad \textbf{(Equation 2)}$$

where *n* is the number of locations, *Ei* and *Bi* are the electric field strength and magnetic flux density respectively, measured in the i^{th} location.

The position of the line over which the field should be averaged is dependent on whether the resultant spatially averaged value is to be compared with a low, high or limb AL. The high ALs are provided to protect against peripheral nerve stimulation in the head and trunk. Therefore, if the E_{avg} or B_{avg} value is intended to be compared with the high AL, a simple linear scan of the fields over the height of the head and trunk, through the centre of the projected area, will usually be sufficient. The low ALs are presented to protect against sensory effects in the central nervous system in the head. Therefore, if the E_{avg} or B_{avg} value is intended to be compared with the low AL, a simple linear scan of the fields over the height of the head, through the centre of the projected area, will normally be adequate. Lastly, the limb ALs are provided to protect against nerve stimulation in the limbs. Thus, if the B_{avg} value is intended to be compared with the low AL, a simple linear scan of the fields over the height of the limb, through the centre of the projected area, will usually be sufficient.

It is recommended that the average of a series of no less than three measurements, performed with uniform spacing, for spatial averaging over the head, head and trunk or limb regions will normally be adequate. Additional field measurements, for example, as obtained through the use of data-logging or spatial averaging equipment, are acceptable and would provide more detail on the spatial distribution of the field.

Figure D9 — (a) spatial averaging the field over a vertical line in the region occupied by the worker (b) spatial averaging the field over a vertical line in the region of the worker's head (c) averaging points with a cutaway view of the worker in place



(b) Exposure to electric and magnetic fields between 100 kHz and 300 GHz

The spatially averaged values of the electric field strength (E_{avg}), magnetic flux density (B_{avg}) and power density (W_{avg}) should be calculated using the following formulae:

$$E_{avg} = \frac{1}{\sqrt{n}} \left[\sum_{i=1}^{n} E_i^2 \right]^{\frac{1}{2}} \quad \textbf{(Equation 3)}$$

$$B_{avg} = \frac{1}{\sqrt{n}} \left[\sum_{i=1}^{n} B_i^2 \right]^{\frac{1}{2}} \quad \textbf{(Equation 4)}$$

$$W_{avg} = \frac{1}{n} \sum_{i=1}^{n} W_i \quad \textbf{(Equation 5)}$$

where, n is the number of locations, E_i, B_i and W_i are the electric field strength, magnetic flux density and power density respectively, measured in the i^{th} location.

The ALs for exposure to electric and magnetic fields from 100 kHz to 300 GHz are provided to protect against adverse health effects due to heating in the body. Therefore, if the E_{avg} or B_{avg} value is to be compared with the thermal effects AL, a simple linear scan of the fields performed in a vertical line with uniform spacing starting at ground level up to a height of 2 m, through the centre of the projected area, will be sufficient.

It is recommended that the average of a series of no less than ten measurements, performed with uniform spacing, for spatial averaging over the height of the worker should be adequate for the majority of exposure situations. The locations of the field strength measurements are shown as green cubes in Figure D9 (a). Additional field strength measurements, for example, as obtained through the use of data-logging or spatial averaging equipment are acceptable and would provide more detail on the spatial distribution of the field.

Measurements in these situations should be performed with field sensors placed at least 0.2 m away from an object or person to avoid field coupling effects. Note that spatial averaged values will also be dependent on the spatial characteristics of the radiofrequency fields in relation to the posture of the exposed worker.

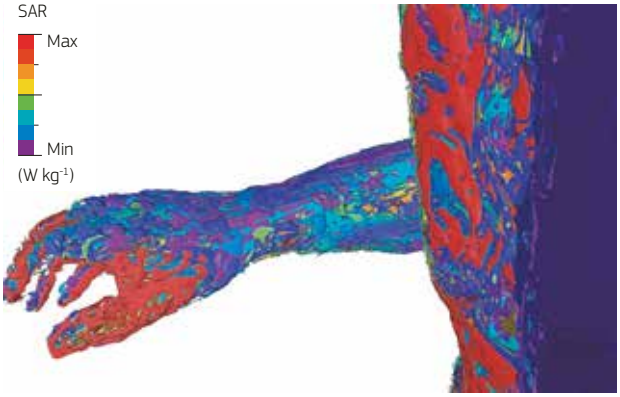
D.2.2.3 Dosimetric assessment for direct comparison with the ELVs

Where the source of the electromagnetic field is within few centimetres of the body, the

Directive recommends that compliance should be determined dosimetrically for direct comparison with the ELVs.

The determination of the induced electric fields within the body at low frequencies, or the SAR and power density at high frequencies can only be performed accurately by numerical calculations. The procedure used to calculate internal dose quantities have been outlined in earlier sections of this appendix. An example of a dosimetric assessment using numerical calculations is shown in Figure D10.

Figure D10 — The determination of dose quantities, in this case the SAR in the hand and torso from exposure to an unshielded cable, for direct comparison with the ELVs. The Directive recommends this approach to demonstrate compliance for very localised electromagnetic field sources within a few centimetres of the body



D.2.2.3.1 Underlying dosimetric concepts

The concept and accuracy of non-uniform exposure assessment techniques can be examined using examples.

(a) Example 1: Spatial averaging of the field from exposure to a reflected plane wave

When a reflected electromagnetic wave interferes with the incoming wave, a standing wave can be produced. In some locations the intensity of the field is cancelled out, whereas at the maxima of the standing wave the electric field is doubled. This situation is shown in Figure D11.

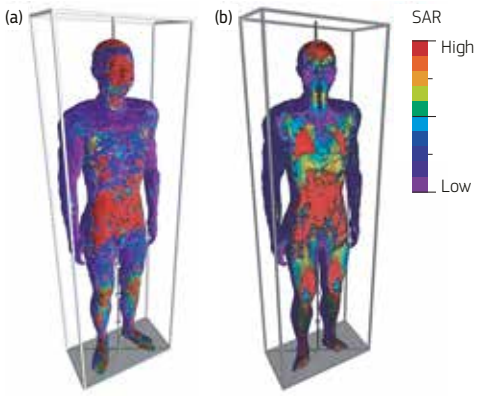
Here, a worker is exposed to a horizontally polarised field from above with the field orientated front to back. The wave is reflected back from the conducting ground plane back into the region occupied by the worker. If a single measurement was taken in this region, a value between zero and the maximum field value would be obtained. Therefore it is very likely that this single measured field value would be unrepresentative of the exposure situation. Figure D12 shows the result of this standing wave exposure at 200 MHz on the worker. It can be seen that the location of the absorption is mainly determined by the positions of the peaks and troughs of the standing wave.

Figure D11 — Example 1: Human model exposed to an electromagnetic field reflected back into region occupied by the human. This region is shown as a yellow box. The standing wave is shown in green.

$$E_{spa} = \left[\frac{\int E^2(z)dz}{\int dz} \right]^{\frac{1}{2}} \quad \textbf{(Equation 6)}$$

The integral shown in Equation 6 gives us a precise answer to the linearly averaged field value in the region occupied by the worker.

Figure D12 — Example 1 SAR plots: The SAR distributions in (a) whole body and (b) section views of a human model from exposure to a horizontally polarised, electric field aligned front to back, plane wave irradiation at 200 MHz from above under grounded conditions



As a finite number of measurements are used to calculate the spatially averaged field, it would be expected that the more measurements taken, the closer this value would be to the exact solution as calculated by the integral. This is generally true; however, for compliance assessment, approximately ten measurements are sufficient. The differences between the exact value of the spatially averaged electric field and the value calculated using *x* measurements are typically low, even when using only a few measurements. The exception to this is when a node in the standing wave is located near a measured value.

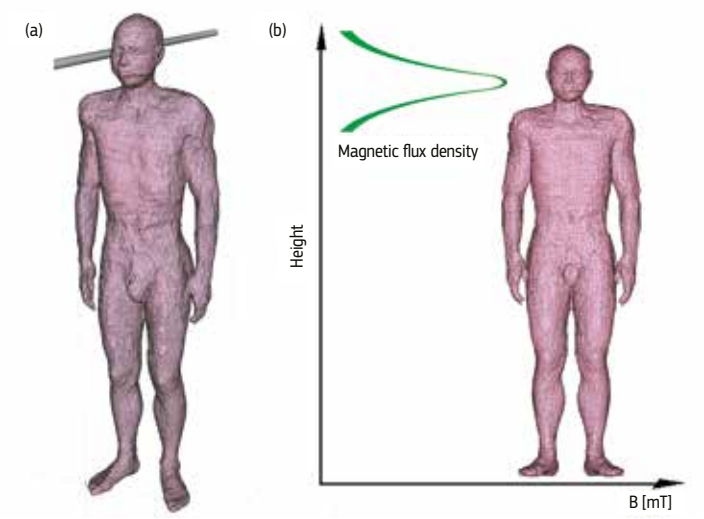
Although the spatially averaged field can be represented using ten measurements, more measurements will provide a more accurate value of the spatially averaged field. Hence the advice that, if available, the use of modern survey equipment which has the ability to make in the order of 200 to 300 measurements over the length of the body (e.g. probe moved in 10 seconds using a logging rate of 32 data points per second produces 320 measurements) would be recommended as obviously the more measurements, the greater degree of accuracy.

When an electromagnetic field source is positioned close to the body, the incident field is the region occupied by the body can be non-uniform. An example of this is a wire positioned close to the head (Figure D13).

(b) Example 2: Spatial averaging of the field from exposure to a 50 Hz wire

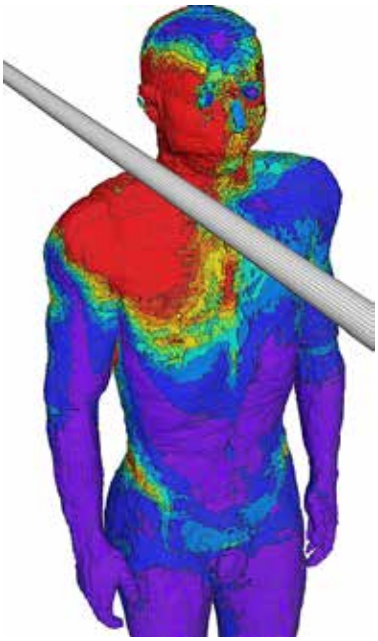
Figure D14 shows the induced electric field distribution for exposure at head level from a 50 Hz, straight wire. As can be seen, the electromagnetic field absorption is fairly localised within the head and shoulder region of the body.

Figure D13 — Example 2: (a) human model exposed to a straight wire (b) variation of the field produced with height



Research has shown that the recommendation of making 3 measurements to be sufficient in the ELF range for localised sources. The difference using 3 points over the head region and an infinite number of points for this 50 Hz example is approximately 8 %. This difference can obviously be improved if desired by taking more measurements in a vertical line with uniform spacing.

Figure D14 — Example 2: Induced electric field distribution from exposure to a 50 Hz wire positioned near the head.



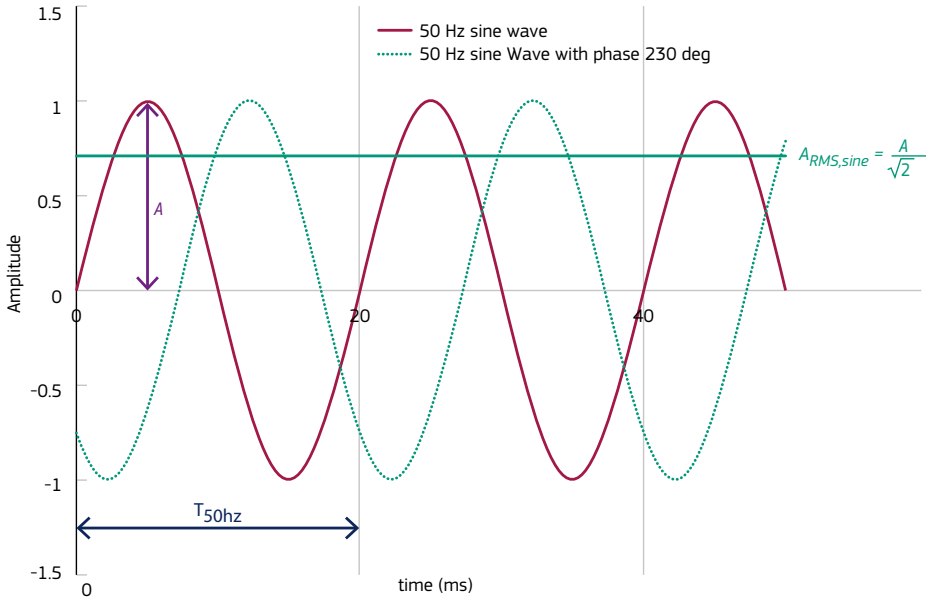
Key message: spatial averaging

Three measurement points for low frequency exposure assessments, or ten measurement points for radiofrequency surveys, will normally be adequate for the purposes of spatial averaging. The improvement in accuracy becomes progressively smaller with each additional measurement point, so that it is not generally necessary to use more than ten points. If spatial averaging over a line is difficult for an exposure situation, a single maximum measured field strength should be used.

D.3 Assessment of multiple frequency exposures

As mentioned in Chapter 3 and Appendix A, external time-varying low frequency electric and magnetic fields induce internal electric fields. The variation of the field with time is described by a waveform. For an external field described by a simple sine wave (Figure D15), the induced electric field in the body is proportional to the amplitude of the external field and its frequency.

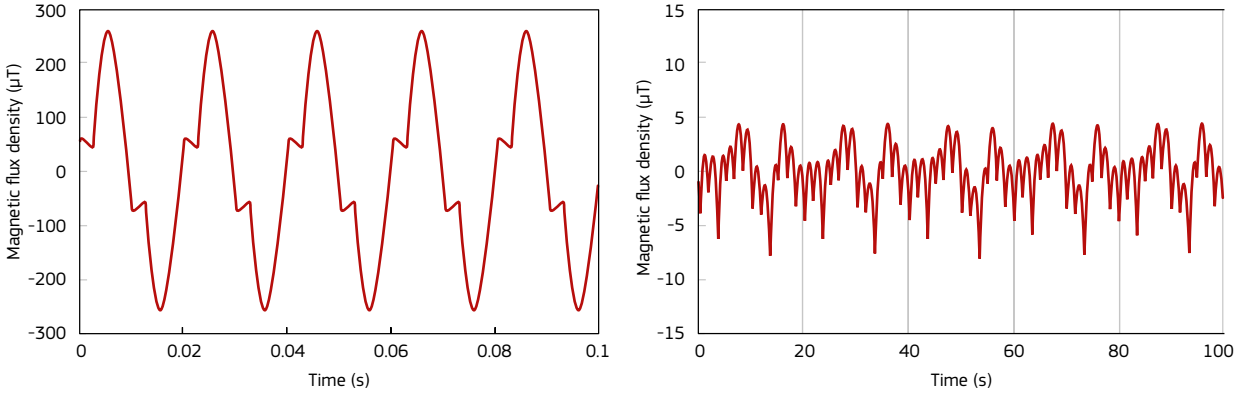
Figure D15 — A 50 Hz sine wave. Sine waves are periodic and have a frequency f given by 1/T, where T is the period of the waveform (e.g. T = 20 ms for 50 Hz sine wave). The root-mean-squared (RMS) value of a sine wave is given by the peak amplitude divided by √2. The effect of phase of the sine wave is to shift it along the time axis.



Electric and magnetic field sources below 10 MHz quite often exhibit waveforms that differ (sometimes substantially) from a perfect sine wave (Figure D15), but are nonetheless periodic (Figure D16). That is, the waveform repeats itself over time. These kinds of complex waveforms are equivalent to a sum of a series of sine waves with different frequencies, typically referred as spectral components. For a given waveform, each of these spectral components is described by an amplitude and phase. As an analogy, a given colour can be decomposed into different quantities of primary colours (red, green and blue). The colour would be the waveform, the red, green and blue are spectral components, and the intensity of each primary colour is the amplitude of each

spectral component. The spectrum of the waveform provides the spectral information (frequencies, amplitudes, phases), and is typically obtained by performing a Fourier analysis on the waveform, or directly measuring it with narrowband instrumentation (although the latter may not provide phase information).

FigureD16 — Example of complex magnetic flux density waveforms around crack detection systems. On the right, periodicity of 20 ms has been highlighted with vertical dotted gridlines



D.3.1 Non-thermal effects (> 1 Hz to 10 MHz)

Compliance assessment with ALs (and ELVs) in the low frequency region (below 10 MHz) can be performed in different ways, with some methods being more conservative than others but simpler to apply.

Key message: assessment of multiple frequencies

The weighted peak method in the time domain is the reference method recommended by the EMF Directive, although alternative methods can be used provided they give broadly equivalent (or more conservative) results, such as the multiple frequency method described in section D3.1.2.

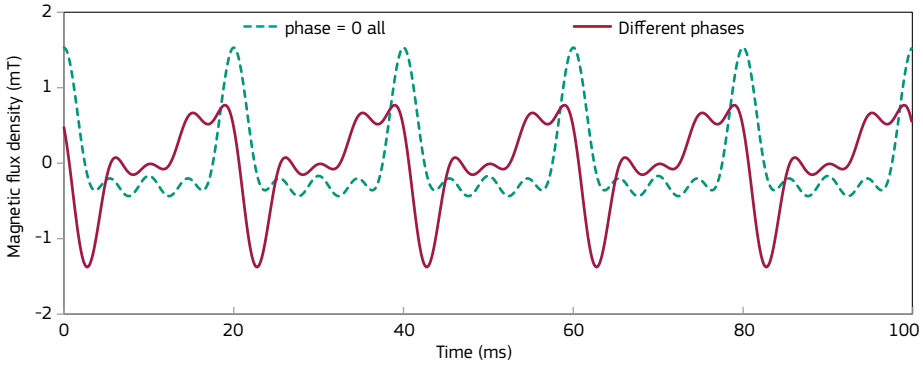
D.3.1.1 The weighted peak method

The weighted peak method (WPM) is a method that takes into account both the amplitude and the phases of the spectral components that make up the signal (see Figure D17 for effect of spectral phases on waveform and exposure index). The method is called weighted peak as the waveform is weighted by the frequency-dependent ALs and the peak amplitude of the weighted waveform gives the exposure index. The weighting (or filtering) can either be done in the frequency domain or in the time-domain. This method is also appropriate for assessing compliance with both sensory and health effects exposure limit values (ELVs).

Key message: exposure index (EI)

The exposure index represents the observed exposure divided by the limit value. If the exposure index is less than one, the exposure is compliant.

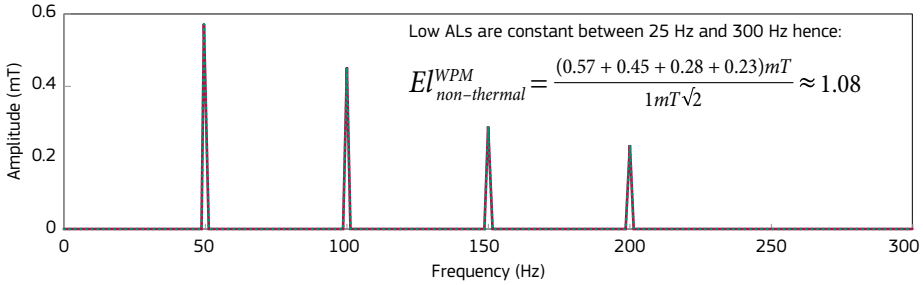
Figure D17 — Example of the effect of spectral components phases on waveform (top graph). Both waveforms consist of cosine waves at 50 Hz, 100 Hz, 150 Hz, and 200 Hz (bottom graph). The only difference between the two waveforms is that for one, all the phases of the four spectral components have been set to 0 (dotted green line), while the phases of three spectral components of the other waveform (red solid line) have been changed (middle graph).

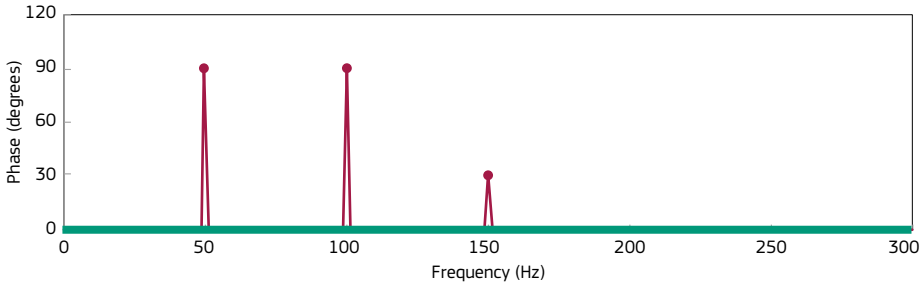


Low ALs are constant between 25 Hz and 300 Hz hence, for low ALs:

All phases 0: $El^{WPM}_{non-thermal} = \frac{1.53mT}{1mT\sqrt{2}} \approx 1.08$ => Non-compliant

Different phases: $El^{WPM}_{non-thermal} = \frac{1.38mT}{1mT\sqrt{2}} \approx 0.97$ => Compliant





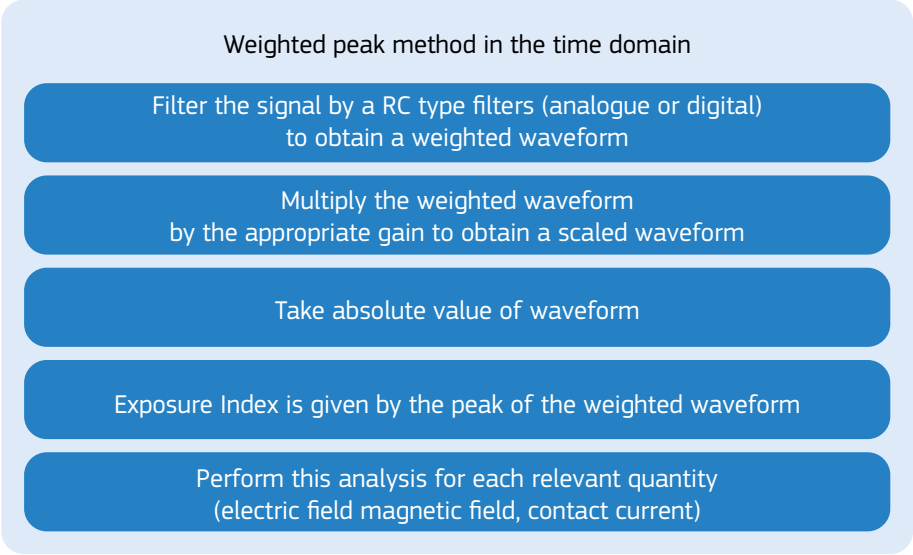
WPM in the time domain

When applying the weighted peak approach in the time-domain, the weighting is performed using RC filters with frequency-dependent gains that reflect the ALs amplitude and frequency dependence (Figure D18). Some slight differences in the amplitude and phase of the filter are present when using RC filters as opposed to the piecewise values given in the Directive [1](Figures D19 and D20), however RC filters

[1] Piecewise amplitude of the filter is given by the inverse of the AL while piecewise phase of the filter is given by Equation 7.

represent a more realistic biological behaviour and these differences are deemed acceptable by ICNIRP [ICNIRP 2010, Jokela 2000].

Figure D18 — Calculation steps for the weighted peak method in the time domain



The filtering in the time-domain can be performed through post-processing the measured waveform, or digitally, for example using some commercially available equipment with this filtering capability (the function is sometimes referred as Shaped Time Domain (STD)). If commercially equipment is used, the user should ensure that the relevant set of ALs is being used by the equipment (as opposed to other exposure standards or methods).

Figure D19 — Amplitude of the weighting function for the WPM: Piecewise linear values used in the frequency domain (as defined in the subsection below) and approximated values (RC filter) used in the time domain

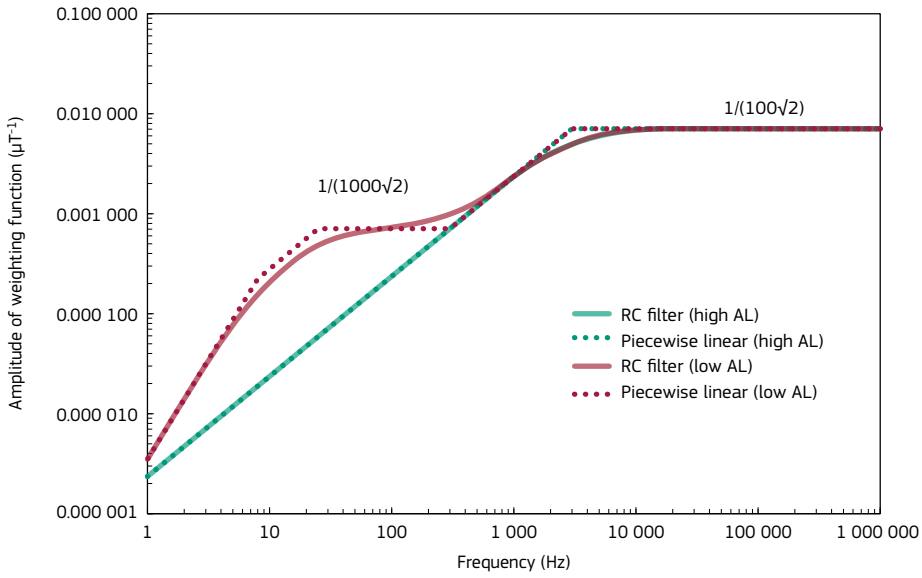
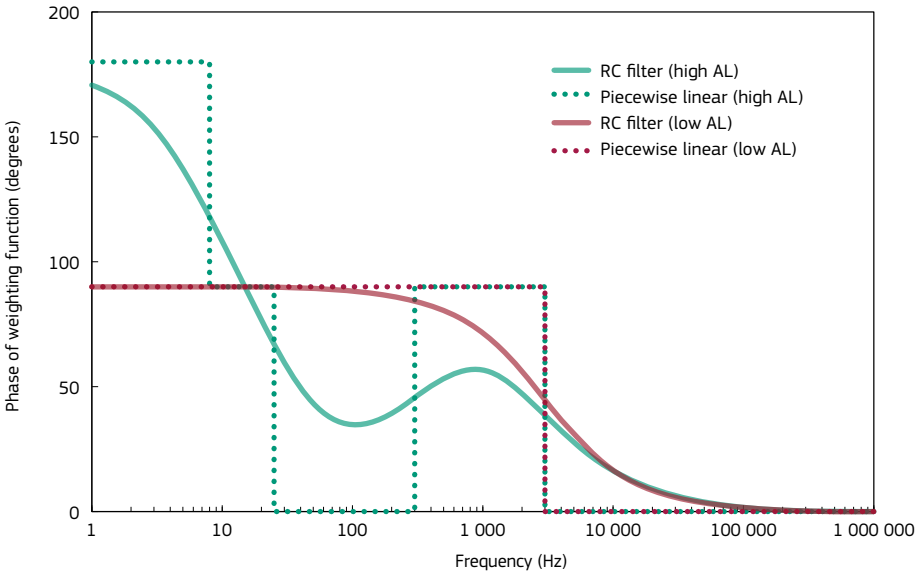


Figure D20 — Phase of the weighting function for the WPM: Piecewise linear values used in the frequency domain (as defined in the subsection below) and approximated values (RC filter) used in the time domain.



WPM in the frequency domain

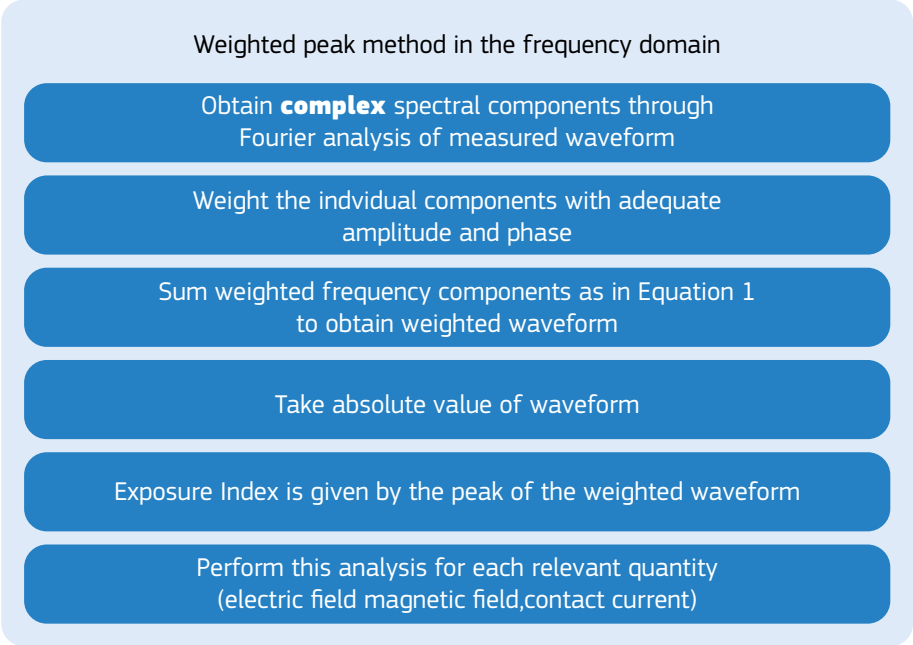
The steps for performing the weighted peak approach in the frequency-domain are shown in Figure D21, and are described in the ICNIRP 2010 guidelines (ICNIRP2010). To calculate the weighted waveform, the amplitude of each spectral component is divided by the relevant ALs (or ELVs if the amplitudes under investigation are internal electric fields), and a phase φ_f is added to the phase of each spectral component. The weighted spectral information is then converted back to the time domain using:

$$EI^{WP}_{non\text{-}thermal} = Maximum\left\{\left|\sum_f \frac{|A_f|}{AL_f\sqrt{2}} * \cos\left(2\pi f t + \theta_f + \varphi_f\right)\right|\right\} \qquad \textbf{Equation 7}$$

Where $|A_f|$ and θ_f are the peak amplitude (electric field strength or magnetic flux density) and phase of the spectral component at frequency f respectively, and AL_f is the relevant AL at that frequency. The phase φ_f is a function of frequency, and is defined in the appendix of the ICNIRP 2010 guidelines (ICNIRP 2010):

$$\varphi_f = \begin{cases} 180°, f\ or\ AL_f\ \alpha\ {}^{1}\!/_{f^2} \\ 90°, f\ or\ AL_f\ \alpha\ {}^{1}\!/_{f} \\ 0°, f\ or\ AL_f = constant\ (\alpha\ f^0) \\ -90°, f\ or\ AL_f\ \alpha\ f \end{cases} \qquad \textbf{Equation 8}$$

Figure D21 — Calculation steps for the weighted peak method in the frequency domain



These are the piecewise values referred in Figure D20. As mentioned above, this method is appropriate for assessing compliance with both sensory and health effects exposure limit values (ELVs). For assessing compliance with ELVs, the and $|A_f|$ and θ_f are the amplitude and phase of induced (internal) electric fields and the ALs are replaced with ELVs in Equation 7 and Equation 8. As in the non-thermal calculations, the $\sqrt{2}$ is removed from the equation when using ELVs, as these are defined as peak values not RMS.

D.3.1.2 Alternative method: Multiple-frequency rule

An alternative method to the weighted peak approach is the multiple frequency rule (MFR), which is simpler to apply but more conservative than the weighted peak approach. If exposure is likely to be close to ALs (or ELVs) at low frequencies, this method may not be adequate because it often leads to a very conservative assessment, as it ignores the phases of the spectral components and assumes the sine waves of the spectral components coincide at the same time such that the total field changes sharply with time [ICNIRP 2010].

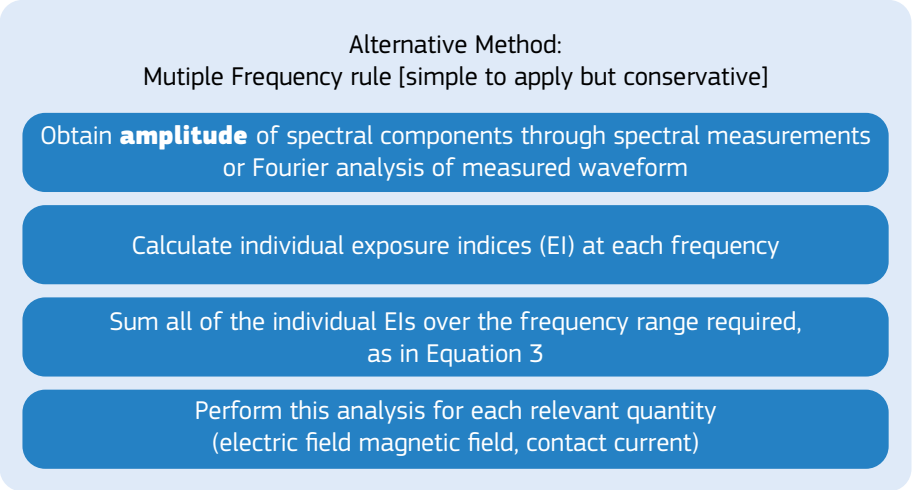
The MFR method is described in Equations 3 to 6 in the ICNIRP guidelines [ICNIRP 2010], although ALs and ELVs need to be used instead of reference levels and basic restrictions respectively:

$$EI^{MFR}_{non\text{-}thermal,X} = \sum_{f=1\,Hz}^{10MHz} \frac{X_f}{AL\,(X)_f} \qquad \textbf{Equation 9}$$

where X_f is the amplitude (RMS), at frequency f, of the external quantity measured (or calculated) and $AL(X)_f$ is the relevant action level at frequency f. Relevant AL means the AL at the frequency of the spectral component, but also the type of AL required for the

assessment (electric field strength, magnetic flux density, low, high, contact), as defined in Table B2 of Annex II of the Directive. When assessing against ELVs, X_f becomes the amplitude of the induced electric field strength (peak, not RMS), at frequency, and $AL(X)_f$ is replaced by ELV_f. Figure D22 shows the steps for calculating the exposure index using the multiple frequency summation method.

Figure D22 — Calculation steps for the multiple frequency rule



The multiple-frequency summation method is fairly straightforward and there is a range of equipment that can perform this assessment automatically for ICNIRP guidelines. This equipment is suitable for assessing compliance with ALs, so long as the relevant set of ALs has been uploaded onto the equipment. This method is also appropriate for assessing compliance with both sensory and health effects exposure limit values (ELVs).

Tables 5a to 5d show a comparison of exposure indices using the WPM in the frequency domain and the MFR method, as well as that obtained directly using the STD feature (time domain WPM) in a commercially available probe.

Table D5a — Spot 50 Hz (50 kVA) welding machine. Measurements were taken at a distance of 0.3 m at same height as welding point

Method	Low ALs	High ALs	Limb ALs
MFR[a]	3.18	1.70	0.57
WPM[a]	0.94	0.45	0.15
STD[b]	0.83	0.34	0.13

[a] Calculations were made in the frequency domain from a trace with N=4096, T = 0.84 s (i.e. maximum frequency considered was around 2 kHz).

[b] STD measurements were performed using equipment with frequency range 1 Hz to 400 kHz.

Table D5b — 2 kHz welder (Measurements were taken at a distance of 0.33 m from centre of welding clamp)

Method	Low ALs	High ALs	Limb ALs
MFR[a]	4.52	3.44	1.15
WPM[a]	1.08	0.81	0.27
STD[b]	-	1.00	-

[a] Calculations were made in the frequency domain from a trace with N=4096, T = 0.5 s (i.e. maximum frequency considered was 4 kHz).

[b] STD measurements were performed using a equipment with frequency range 1 Hz to 400 kHz.

Table D5c — Transcranial Magnetic Stimulator (TMS)

Method	Low ALs	High ALs	Limb ALs
MFR[a]	21.88	21.81	7.27
WPM[a]	13.43	13.23	4.41
STD[b]	-	12.22	4.11

[a] Calculations were made in the frequency domain from a trace with T = 5 m s (i.e. maximum frequency considered was 409 kHz).

[b] STD measurements were performed using an equipment with frequency range 1 Hz to 400 kHz.

Table D5d — Seam 100 kVA welder (measurement taken 28 cm in front and below of welding point)

Method	Low ALs	High ALs	Limb ALs
MFR[a]	4.30	2.59	0.86
WPM[a]	1.09	0.61	0.20
STD[b]	1.13	0.59	0.16

[a] Calculations were made in the frequency domain from a trace with T = 333 ms (maximum frequency considered was 6.1 kHz).

[b] STD measurements were performed using an equipment with frequency range 1 Hz to 400 kHz.

If there are non-negligible spectral components beyond 100 kHz, thermal effects need to be considered, and assessed independently from the non-thermal effects. These will be discussed in the next subsection.

D.3.1.3 Alternative method: Simple assessment on physiological basis

In the time domain pulsed fields can be segregated in parts of sinusoidal, trapezoidal, triangular or exponential single and multiple or constant field components (see Figure D23).Given this, a simplified assessment can be performed in the low frequency area using the parameters described below (Heinrich, 2007). The method is based on the physiology, especially on the mechanism of stimulation, as follows:

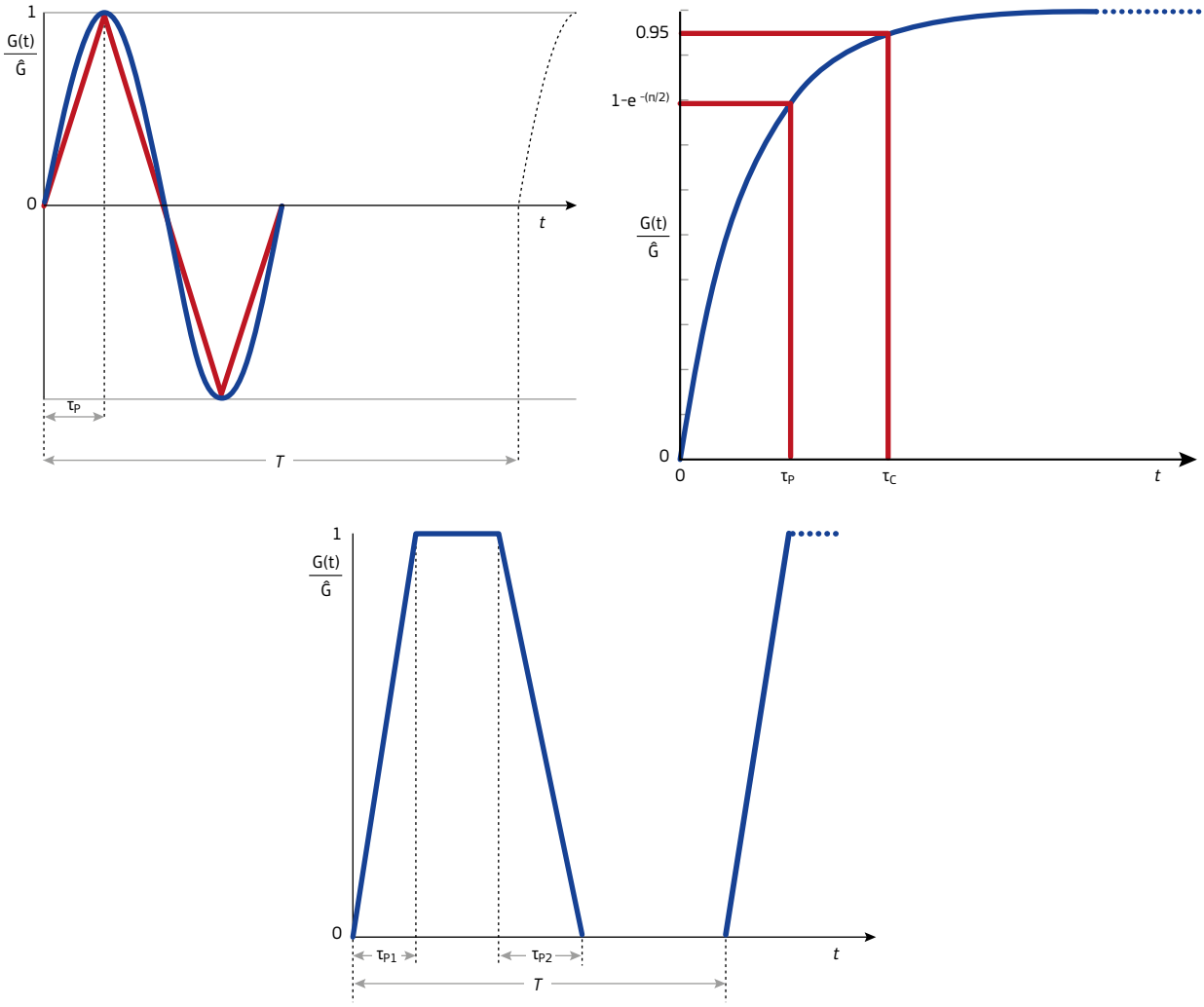
(1) Stimulation effects only take place if the well-defined threshold is exceeded.

(2) Pulses below this threshold cannot create any stimulus even if they are very long.

(3) If the pulses are very short higher intensities are necessary.

The assessment procedure is included in the Accident Prevention Regulation of the German Social Accident Insurance (BGV B11, 2001). However, it has to be noted that this regulation from 2001 does not use the action levels and the exposure limit values of the new Directive 2013/35/EU.

Figure D23 Signal curves (Pulses) of sinusoidal (top left), exponential (top right) and trapezoidal or triangular (bottom) shape



The fields linked to these types of signal curves (Figure D23) are described by the following additional parameters:

G	Instead of quantity G use the electric field strength, E, the magnetic field strength, H, or the magnetic flux density, B. *G(t)* indicates the time function, Ĝ the peak value.
T	Pulse duration or pulse width with the following break
τ_p	Time duration of a field change for sinusoidal, triangular or trapezoidal signal curves from zero to the positive or negative peak value or from the positive or negative peak value to zero respectively. The investigation of τ_p for exponential signal curves shall be performed according to the above diagram. If the individual time durations τ_{Pi} differ, then all these values τ_{Pi} shall be included for further calculations.

T_I	Integration time, where $T_I = \begin{cases} T & \text{where } T \le 1\ s \\ 1s & \text{in all other cases} \end{cases}$
τ_{Pmin}	The smallest value for all time durations τ_{Pi}: $\tau_{Pmin} = \min_i(\tau_{Pi})$
τ_C	Auxiliary quantity for defining exponential signal curves. If the individual time durations τ_{Ci} differ, then all these values τ_{Ci} shall be included for further calculations.
τ_D	Sum of time of all field changes i during a time interval T_I for:. — sinusoidal, triangular, trapezoidal signal curves: $\tau_D = \sum_i \tau_{Pi}$ — exponential signal curves: $\tau_D = \sum_i \tau_{Ci}$
f_P	Frequency of a field change, where: $f_p = \frac{1}{4 \cdot tp_{min}}$
V, V_{max}	Weighting factor, maximum weighting factor $V = \begin{cases} \sqrt{\frac{T_I}{\tau_D}} & \text{where } \sqrt{\frac{T_I}{\tau_D}} \le V_{max} \\ V_{max} = 2.6 & \text{in all other cases} \end{cases}$
$\left\lvert \frac{dB(t)}{dt} \right\rvert_{p,max}$	Maximum time derivative of the magnetic flux density $\left\lvert \frac{dB(t)}{dt} \right\rvert_{p,max} = \omega \hat{B} \cdot V = 2\pi \cdot f_p \sqrt{2} \cdot B \cdot V$
$\left\lvert \frac{dB(t)}{dt} \right\rvert_{p,mean}$	Mean time derivative of the magnetic flux density $\left\lvert \frac{dB(t)}{dt} \right\rvert_{p,mean} = \frac{\omega \hat{B} \cdot V}{\pi/2} = 4 \cdot f_p \sqrt{2} \cdot B \cdot V$

Table D6: — Action levels of the maximum time derivate of the magnetic flux density in Directive 2013/35/EU $\left\lvert \frac{dB(t)}{dt} \right\rvert_{p,mean}$ (T/s) according to Table B2 of

Frequency range	Low action level	High action level	Action level for the exposure of limbs to a localised magnetic field
1 Hz < f_P< 8 Hz	1.8 · V/f_P	2.7 · V	8 · V
8 Hz < f_P< 25 Hz	0.2 · V	2.7 · V	8 · V
25 Hz < f_P< 300 Hz	0.01 · f_P· V	2.7 · V	8 · V
300 Hz < f_P< 3 kHz	2.7 · V	2.7 · V	8 · V
3 kHz < f_P< 10 MHz	0.001 · f_P· V	0.001 · f_P· V	0.003 · f_P· V

Table D7: — Action levels of the mean time derivate of the magnetic flux density $\left|\frac{dB(t)}{dt}\right|_{p,mean}$ in (T/s) according to Table B2 of Directive 2013/35/EU, averaged over the time interval τ_p

Frequency range	Low action level	High action level	Action level for the exposure of limbs to a localised magnetic field
1 Hz < f_P< 8 Hz	1.15 · V/f_P	1.7 · V	5.1 · V
8 Hz < f_P< 25 Hz	0.13 · V	1.7 · V	5.1 · V
25 Hz < f_P< 300 Hz	6 · 10^{-3} · f_P· V	1.7 · V	5.1 · V
300 Hz < f_P< 3 kHz	1.7 · V	1.7 · V	5.1 · V
3 kHz < f_P< 10 MHz	6 · 10^{-4} · f_P· V	6 · 10^{-4} · f_P· V	2 · 10^{-3} · f_P· V

The exposure limit values of the Directive 2013/35/EU will be complied with, when the action levels are applied for this procedure.

The weighting factors V, V_{max} and the tables for the action levels for this assessment procedure are adapted to the requirements of the Directive 2013/35/EU.

D.3.2 Thermal effects (100 kHz to 300 GHz)

D.3.2.1 Assessment against ALs

For electromagnetic fields with non-negligible spectral components above 100 kHz, thermal effects are relevant, and the total EI for thermal effect is given by [ICNIRP 1998]:

$$EL_{thermal,X} = \sum_{f=100\,kHz}^{300\,GHz} \frac{X_f^2}{AL(X)^2_{thermal,X}} \qquad \textbf{Equation 10}$$

where X_f is the amplitude (RMS) at frequency f, and X stands for electric field strength, magnetic flux density or contact current. $AL(X)_{therminal,f}$ is the action level for thermal effects at frequency, as defined in Table B1,B2 and B3 of Annex III of the Directive. If the comparison is against field strength, X_f^2 needs to be an average over a six minute period for frequencies below 6 GHz, or a period of duration given by $\tau = 68/f^{1.05}$ *minutes* (where f is in units of GHz) for frequencies above 6 GHz. For contact currents, the summation is only performed between 100 kHz and 110 MHz and no time-averaging is required.

The slope of the EMF waveform does not influence the heating of tissues and therefore the weighted peak approach is not used for assessing compliance with action levels set to avoid thermal effects.

For RF pulses with carrier frequencies above 6 GHz, the peak power density averaged over the pulse width is required to be below 50 kWm^{-2}, which is 1 000 times the AL for power density (Table B1, Annex III of the Directive).

As in the non-thermal calculations, where external fields vary considerably over the body of the worker, it may be necessary to include spatial averaging of exposure levels, appropriate to that part of the body mentioned in the limit being employed. This is discussed in the previous section (Section D2).

Assessment against AL on limb currents (10 MHz — 110 MHz)

The assessment of limb currents uses the same equation as for the electric and magnetic fields, but only frequencies between 10 MHz and 110 MHz are considered. Note that , the square of the limb current at frequency , needs to be averaged over a six minute period.

D.3.2.2 Assessment against ELVs

Assessment against health effect ELVs (100 kHz — 300 GHz)

As described in [ICNIRP 1998], the exposure index for thermal health effects is given by:

$$EL_{thermal,ELV} = \frac{1}{ELV(SAR)} \sum_{f=100\,kHz}^{6\,GHz} W_i \langle SAR_f \rangle + \frac{1}{ELV(S)} \sum_{f>6\,GHz}^{300\,GHz} \langle S_f \rangle \qquad \textbf{Equation 11}$$

where,

$\langle SAR_f \rangle$ is the specific absorption rate (SAR) at frequency , in W/kg, averaged over a six minute period.

ELV(SAR) is the ELV for the specific absorption rate (SAR), in W kg^{-1}, as specified in Table A1 of Annex III of the Directive.

$\langle S_f \rangle$ is the power density at frequency *f*, in Wm^{-2}, averaged over any 20 cm^2 of exposed area and over a period given by $\tau = 68/f^{1.05}$ *minutes* (where is in units of GHz).

ELV(S) is the ELV for the power density, equal to 50 Wm^{-2}, as specified in Table A1 of Annex III of the Directive.

For assessing localised SAR, as opposed to the average over the whole body, the localised SAR needs to be averaged over any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used in Equation 10. Section D2 provides more information on averaging.

Assessment against sensory effect ELVs (300 MHz — 6 GHz)

Sensory auditory effects can result from exposure to the head from a pulsed microwave radiation with a frequency between 300 MHz and 6 GHz. To avoid such effects, compliance with the Specific Absorption ELVs must be met, where the exposure index is given by:

$$EL_{auditory\ ELV} = \frac{1}{ELV(SAR)} \sum_{f=300\,MHz}^{6\,GHz} SA_f \qquad \textbf{Equation 12}$$

Where,

SA_f is the specific absorption (SA) at frequency *f* in the head, in J kg^{-1}, taken to be equal to the maximum from averaged values over 10 g of tissue, and *ELV(SA)* is equal to 10 mJ kg^{-1}.

D.3.3 Assessment of EMFs with frequencies between 100 kHz and 10 MHz

Where there are RF signals with frequencies between 100 kHz and 10 MHz, including harmonics of fundamental signals with frequencies below 100 kHz, compliance with limits on both non-thermal effects and thermal effects must be demonstrated. This could be through comparison of internal field levels with relevant ELVs though more normally would be a comparison of external field levels with appropriate AL.

Figures 6.2 and 6.7 show what assessment is required depending on the frequency range of the source (for compliance with ALs and ELVs respectively). In many cases only one type of effect (thermal or non-thermal) is relevant due to the frequency characteristics of the source, but in cases where the source lies in the frequency range of 100 kHz to 10 MHz (shown in red in Figures 6.2 and 6.7), both effects are relevant and therefore compliance with both is required, as highlighted in Table D8 (for ALs).

For example, consider an environment where exposure to a worker was shown to comprise a 75 kHz fundamental signal together with significant harmonic content at 225 kHz, 375 kHz and 525 kHz. As all of these frequencies are below 10 MHz they must be included in the evaluation of the non-thermal exposure index for electric fields, for magnetic fields and where relevant for contact currents at all identified frequencies across the frequency range 1 Hz to 10 MHz. This may well involve contributions from power frequency (50/60 Hz) signals and corresponding harmonics. In addition, the 225 kHz, 375 kHz and 525 kHz signals must be included in the evaluation of the thermal exposure index for this environment as these frequencies lie in the 100 kHz to 300 GHz frequency range. All other frequencies identified in this range must also be entered in the calculation of the thermal exposure index. Thermal compliance with ALs can be assessed using values for either external electric or magnetic field strength but an evaluation of contact current exposure index should be made where relevant. All of the exposure indices (non-thermal, thermal and contract current) must be below unity. If this is not so, constraints must be placed on the worker or source so as to ensure compliance. It is possible that if compliance with ALs cannot be demonstrated then compliance with ELVs could still be shown though the cost of this approach may be considerable.

Table D8 — Non-exhaustive list of examples and associated AL compliance requirements based on frequency range of source. Abbreviations and equations are explained in subsequent subsections.

Frequency range of source	Measurement required	Equations to use	AL compliance requirements	Example of source
1 Hz to 100 kHz	B, E, I_C	Eqn 6 or Eqn 8	$EI^M_{non\text{-}thermal,X} \leq 1$ $X = \{B, E, I_C\}$ and M = {(1) *or* (2)}	Power industry transmission lines, Magnetic particle induction
100 kHz to 10 MHz	B, E, I_C	Eqn 6 or Eqn 8 and Eqn 9	Same as above, plus: $EI_{thermal,X} \leq 1$ For $X = \{B, E, I_C\}$	Electronic Article Surveillance System, AM radio broadcast base stations, Power Line Communication systems
10 MHz to 110 MHz	B, E, I_C, I_L	Eqn 9	$EI_{thermal,X} \leq 1$ For $X = \{B, E, I_C, I_L\}$	FM radio broadcast base stations, Plastic welding machine
110 MHz to 300 GHz	B, E (if in the far-field, then B *ot* E)	Eqn 9	$EI_{thermal,X} \leq 1$ For $X = \{B, E\}$ (if in the far-field, then $X = \{B$ *or* $E\}$	Mobile communications base stations, Military radars

It should be highlighted that non-thermal effects are instantaneous while thermoregulatory processes in the body mean thermal effects depend on the duration or duty factor of exposure. Thus, for the assessment of non-thermal health effects the maximum instantaneous exposure is used for the assessment, while for the assessment of thermal health effects the EMF Directive allows the exposure to be time-averaged over a six minute period and over a period of $\tau = 68/f^{1.05}$ *minutes* (where f is in units of GHz) for frequencies below and above 10 GHz respectively. If the comparison is against field strength, flux density or limb current ALs, the time-averaging should be done on squared values.

D.4 Assessment of exposure to static magnetic fields

D.4.1 Introduction

The main effects induced by movement of a body or parts of the body in a static magnetic field are peripheral nerve stimulation (PNS) and transient sensory effects such as vertigo, nausea, metallic taste and visual sensations such as retinal phosphenes.

The EMF Directive sets limits for static magnetic fields for the two types of working conditions:

- normal (uncontrolled) and
- controlled, where preventive measures, such as controlling movements and providing information to workers have been adopted

The compliance assessment for movement in static magnetic fields is dependent on the working environment, whether normal or controlled and different effects may need to be considered. The process is illustrated in the flowchart in Figure D24. Compliance under normal working conditions ensures compliance under controlled working conditions. However, in controlled working environments, only compliance with ELVs and ALs accounting for peripheral nerve stimulation needs to be demonstrated.

The ELVs provided in Table A1 in Annex II of the EMF Directive for external magnetic flux density apply to static magnetic fields. Movement through a static magnetic field gradient induces low frequency electric fields within the body. In this case the ELVs provided in Tables A2 and A3 and the ALs from Table B2 in Annex II of the EMF Directive should be used as the basis for assessing exposures. Further guidance on limiting exposure to electric fields induced by movement through static magnetic fields has been published (ICNIRP, 2014). This guidance is based on the best available evidence, but at the time of preparation of this guide it had not been incorporated in the EMF Directive. The values are summarised in Table D9.

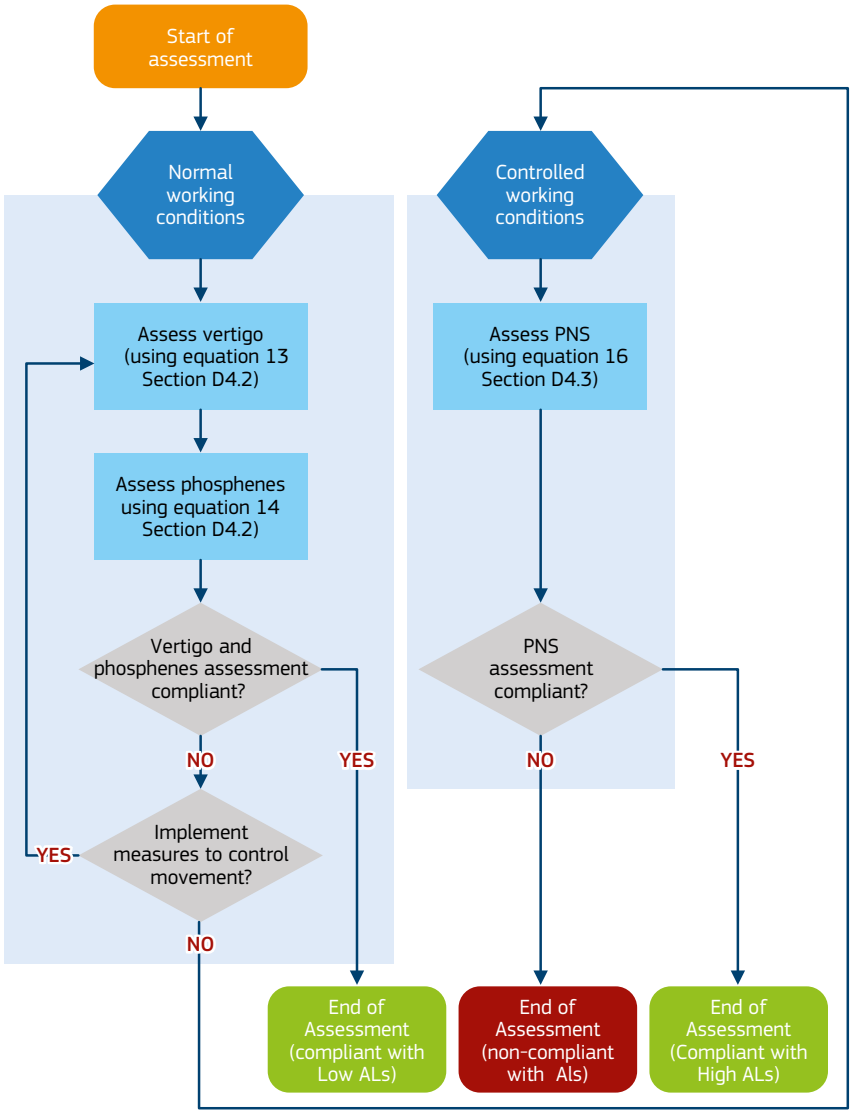
The guidance from ICNIRP is non-binding and uses different terminology from the EMF Directive. The basic restrictions are quantities that should not be exceeded and are conceptually equivalent to the ELVs in the EMF Directive. Reference levels are conservatively derived from the basic restrictions, but are set in quantities that are more readily assessed. Reference levels are conceptually equivalent to the action levels used in the EMF Directive.

Table D9 — Basic restrictions and reference levels for limiting occupational exposure from movement in static magnetic fields (from ICNIRP, 2014)

Frequency [Hz]	Basic restrictions Internal electric field strength ($Vm^{-1}_{(peak)}$)		Reference levels Time derivate of magnetic flux density ($Ts^{-1}_{(peak)}$)	
	Sensory effects[1]	Health effects[2]	Sensory effects[1]	Health effects[2]
0 — 0.66	1.1	1.1	2.7	2.7
0.66 — 1	0.7/f	1.1	1.8/f	2.7

NB: 1 — Restrictions provided to minimise the sensation of phosphenes in normal working conditions.
2 — Restrictions provided to minimise the occurrence of PNS effect in controlled working conditions.
3 — To prevent vertigo due to movement in static magnetic field, the maximum change of magnetic flux density ΔB over any three second period should not exceed 2 T. In controlled working conditions, this value may be exceeded (ICNIRP 2014).

Figure D24 — Process for compliance assessment in the case of movement in static magnetic fields



D.4.2 Normal working conditions

In normal working conditions, the restrictions on exposure from movement in static magnetic fields are based on sensory effects such as vertigo, nausea and phosphenes. The spectrum of movement induced fields extends up to 25 Hz and should be considered when selecting sensory effects ELVs (Annex II, Table A3 in the EMF Directive) and ICNIRP basic restrictions (Table D9). In general it will be appropriate to compare exposures with the low ALs (Annex II, Table B2 in the EMF Directive) and ICNIRP reference levels (Table D9).*Minimising vertigo effect*

The occurrence of sensory effects such as vertigo and nausea due to movement in a static magnetic field can be minimised by moving as slowly as possible in the field. Therefore, to minimise the probability of vertigo and nausea, the change of magnetic flux density ΔB during any three second period should not exceed 2 T:

$$|\Delta B|_{3s} \leq 2\ \mathrm{T} \qquad \textbf{Equation 13}$$

Minimising phosphenes

To minimise the sensation of phosphenes, the sensory effects ELVs (Annex II, Table A3) and basic restrictions (Table D9) for the internal electric field strength E_i should be used. As internal electric field strength cannot be readily determined, it is generally more convenient to assess compliance using the reference levels (Table D9) and the time derivate of the low ALs (Annex II, Table B2).

The electric field induced by movement through a static magnetic field is non-sinusoidal with a spectrum extending up to 25 Hz. Hence it is necessary to take account of the frequency components present using the weighted peak method (see Appendix D3)

The exposure index for *dB/dt* is given by the following equation based on a frequency-dependent and phase related weighting function:

$$EI_{movement}^{phosphene} = Maximum \left\{ \left| \sum_{f=0}^{25\ Hz} \frac{|A_f|}{RL_f} * \cos\left(2\pi f t + \theta_f + \varphi_f\right) \right| \right\} \qquad \textbf{Equation 14}$$

where $|A_f|$ and θ_f are the amplitude and the phase of the spectral component at frequency f of the time derivate of magnetic flux density *dB/dt* and RL_f is the sensory effects reference level at that frequency. The phase φ_f (the so called phase angle of the filter) is a function of the frequency dependence of RL_f and has the values of 90°, 180° and 90° on the frequency ranges 0 — 0.66Hz, 0.66 — 8 Hz and 8 — 25 Hz, respectively, where the frequency dependence of RL_f is of f^0, $1/f$ and f^0. The phase values of the filter function for *dB/dt* are defined in the appendix of the ICNIRP 2010 guidelines (ICNIRP, 2010) and explained in Appendix D3.

When applying the above equation to calculate the exposure index for *dB/dt*, attention should be paid to the fact that reference levels for *peak dB/dt* are provided only below 1 Hz. Above 1 Hz, ALs are provided (Annex II, Table B2) as root-mean-square (rms) values of magnetic flux density, but not as time derivates. It is, however, possible to use these ALs to calculate the equivalent RL_f for *peak dB/dt* above 1 Hz:

$$\left(\frac{dB}{dt}\right)_{RL,peak} = 2\sqrt{2}\pi f B_{lowAL,rms} \qquad \textbf{Equation 15}$$

where $B_{lowAL,rms}$ is the root-mean-square value of low AL for magnetic flux density at frequency f and $\left(\frac{dB}{dt}\right)_{RL,peak}$ is the converted RL_f for peak *dB/dt* at that frequency.

D.4.3 Controlled working conditions

As discussed in Section D4.2 above, the induced electric field includes components with frequencies up to 25 Hz and this has to be considered when selecting appropriate health effects ELVs (Annex II, Table A2) and basic restrictions (Table D9). Again, it will generally be more appropriate to compare exposures with the high ALs (Annex II, Table B2) and health effects reference levels (Table D9).

Preventing peripheral nerve stimulation

To prevent peripheral nerve stimulation, both the ICNIRP basic restriction and the health effects ELV limit internal electric field strength E_i to 1.1 Vm^{-1}. The corresponding ICNIRP reference levels and the time derivate of the high ALs have a value of 2.7 Ts^{-1}. Because both the reference level and the time derivate of the high AL are constant over the frequency range of interest, the exposure index is obtained by summing the spectral components at frequencies up to 25 Hz without spectral weighting of amplitude (filter phase φ_f is set to zero for all spectral components), but taking into account the phases of spectral components of *dB/dt*:

$$EI^{PNS}_{movement} = \frac{1}{2.7} * Maximum \left\{ \left| \sum_{f=0}^{25\,Hz} |A_f| * \cos(2\pi f t + \theta_f) \right| \right\} \qquad \textbf{Equation 16}$$

where $|A_f|$ and θ_f are the amplitude and the phase of the *dB/dt* spectral component at frequency f. The expression in brackets in Equation 16 is equivalent to taking the absolute value of the dB/dt waveform (so all values of dB/dt are positive). The exposure index is then given by the peak value from this waveform divided by 2.7 Ts^{-1}.

D.5 Uncertainty considerations

The purpose of a measurement or calculation is to determine the 'true value' (1) of the quantity under investigation and any deviation is attributable to uncertainty.

The Directive requires employers to consider uncertainty and record it as part of the overall exposure assessment. Article 4 states that 'assessment shall take into account uncertainties concerning the measurements or calculations, such as numerical errors, source modelling, phantom geometry and the electrical properties of tissues and materials, determined in accordance with relevant good practice.'

(1) The true value itself has associated uncertainty as it is an estimate based on present knowledge and data.

One of the main challenges for an employer in carrying out a compliance assessment is demonstrating the accuracy of the measurements and /or calculations in relation to the Directive ALs and ELVs. Identifying the sources of uncertainty, quantifying their influence and demonstrating that this influence is within acceptable bounds provides the means of gaining such assurance.

International standards such as ISO/IEC Guide 98-3:2008 represent a good source of practical advice regarding measurement uncertainty, and CENELEC and other standards bodies have published standards that describe various best practice options for dealing with uncertainty in comparing electromagnetic exposure quantities with limit values (see Appendix H).

Ideally, the overall uncertainty should be small in relation to the difference between the measured and/ or computed value and the AL or ELV. If the uncertainty is very large, there is likely to be less confidence in the assessment of compliance or non-compliance of an exposure value with a limit, and it may be desirable to repeat the assessment using more accurate methods and /or instrumentation that reduce the uncertainty.

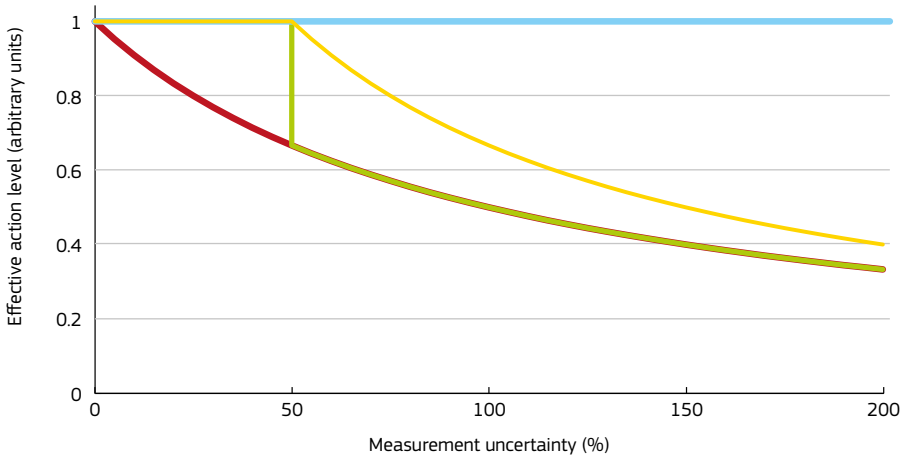
Two general approaches are recognised to address uncertainty in a compliance assessment, each with relative strengths and weaknesses. The first approach is the direct comparison or 'shared risk' approach, in which the measured or computed value is compared directly with the ALs or ELVs. The second approach is the additive approach in which the uncertainty is added to the measured or computed value before it is compared with the appropriate AL or ELV. Whilst both involve the careful assessment of uncertainty, the second by its very nature involves a more transparent approach.

Different combinations of these two approaches may be used and the selection of a particular approach is likely to depend on factors such as national custom and practice or the exposure circumstances. The effect of the different approaches is illustrated in Figure D25. Different approaches may be justifiable where the uncertainty is not excessively large on the basis that the ALs and ELVs are derived from restrictions that include reduction factors to ensure there is a sufficient 'safety' margin to prevent sensory and health effects.

D.5.1 Uncertainties with regard to measurements

The uncertainty in any measurement regime usually arises from a combination of factors, including the *systematic error* related to the performance of the measuring instrument and the *random error* that may arise from the way the measurement is made. It is important to recognise that potential sources of error can be identified and the maximum uncertainty associated with each can be quantified. In general, quantitative estimates of uncertainty are made in two ways. They may be derived from statistical evaluation of repeated readings (known as Type A evaluation), or they may be estimated using a variety of other information such as past experience, calibration certificates, manufacturer's specifications, published information, calculations and common sense (known as Type B evaluation).

Figure D25 — Comparison of different approaches to dealing with uncertainty. The blue line illustrates the effect of ignoring uncertainty. The red line illustrates the effect of applying the additive approach. The green line illustrates an example of a 'shared risk' approach — in this case the measured value is compared directly provided the uncertainty is less than 50 % — when uncertainty exceeds this value the approach switches to additive. The yellow line illustrates an alternative 'shared risk' approach — when the uncertainty exceeds 50 % an additive approach is applied from that point onwards



Once all the individual sources of error have been identified and the resulting uncertainties quantified, the cumulative effect can then be calculated by following established rules governing the 'propagation of uncertainty'. This will permit an estimate of the overall uncertainty associated with a measurement, which can be expressed as a 'confidence interval'. The percentage confidence associated with the confidence interval is obtained by applying a coverage factor, *k*, which is related to a bell-shaped probability curve. A *k* of 1 corresponds to 68 % confidence, *k* = 2 to 95 %, *k* = 3 to 99.7 %.

The evaluation of measurement uncertainty can be complicated in many workplace environments, with no one approach being applicable to all situations. There are, however, various commonly understood good practices such as the use of instruments with low measurement uncertainty and ensuring that traceable calibrations are used for instrumentation (reduces systematic error). Application of good measurement techniques such as repeating and averaging measurements during an assessment can be used to reduce random error.

Many CENELEC product standards tend to adopt a hybrid approach whereby a measurement can be compared directly with the limit values, providing a specified maximum level of uncertainty is not exceeded. If the maximum level is exceeded then the uncertainty is factored directly into the measurements or limit values to make the compliance criteria more stringent and compensate for the excess uncertainty.

In general, the maximum allowed uncertainty values for electromagnetic field measurements are of the same order of magnitude as the accuracy and precision values that are achievable with the types of measurement equipment and calibration procedures that are commonly used.

Technical standards provide useful sources of information on combining different elements of uncertainty in order to produce an overall estimate. Uncertainty budgets can be a useful tool in the assessment of uncertainty for electromagnetic field exposure

and they are discussed in various product standards relating to electromagnetic fields. A good example is available in EN 50413, a default measurement standard that can be used in situations where a technology- or industry-specific standard is unavailable.

Care should be taken when applying a permissible uncertainty range to ensure that a worker's exposure does not exceed the Directive's AL or ELVs. As stated in Article 5 of the Directive 'Workers shall not be exposed above the health effects ELVs and sensory effects ELVs, unless the conditions under either Article 10(1)(a) or (c) or Article 3(3) or (4) are fulfilled. If, despite the measures taken by the employer, the health effects ELVs and sensory effects ELVs are exceeded, the employer shall take immediate action to reduce exposure below these ELVs.'

D.5.2 Uncertainties with regard to exposure calculations

With regard to internal and external exposure calculations, sources of numerical error can be numerous if the models are not set up correctly. Therefore, it is important to investigate the uncertainty associated with dosimetry. The various sources of the uncertainty can be grouped into 3 categories, which are described in the following sections.

D.5.2.1 Uncertainties related to numerical methods

An example would be the errors associated with calculating an internal dose quantity, such as the SAR. The SAR value requires the electric field to be correctly calculated within the body in terms of both the magnitude and the distribution of the SAR. If a peak spatial value is required to be averaged over a specific mass such as a 10 g contiguous region as specified in Annex III of the Directive, errors will be introduced if the SAR is evaluated over, for example, a cube. If the boundary conditions for the numerical simulation are incorrectly set, errors will be introduced into the solution through the artefactual reflection of the electromagnetic field back into the computational domain. Additionally, discretisation of the solution, e.g. representing the exposure situation in cubes, can lead to staircasing errors that can cause significant problems for low frequency calculations.

D.5.2.2 Uncertainties related to the electromagnetic device model

To simulate an exposure situation, a representative model of the device producing the electromagnetic field has to be created. In these cases, errors can be introduced into the solution if the device dimensions, position, output power, emission characteristics etc. are poorly represented. Device positioning is particularly important if the field source is close to the body, as the field produced by most devices reduces rapidly with increasing distance.

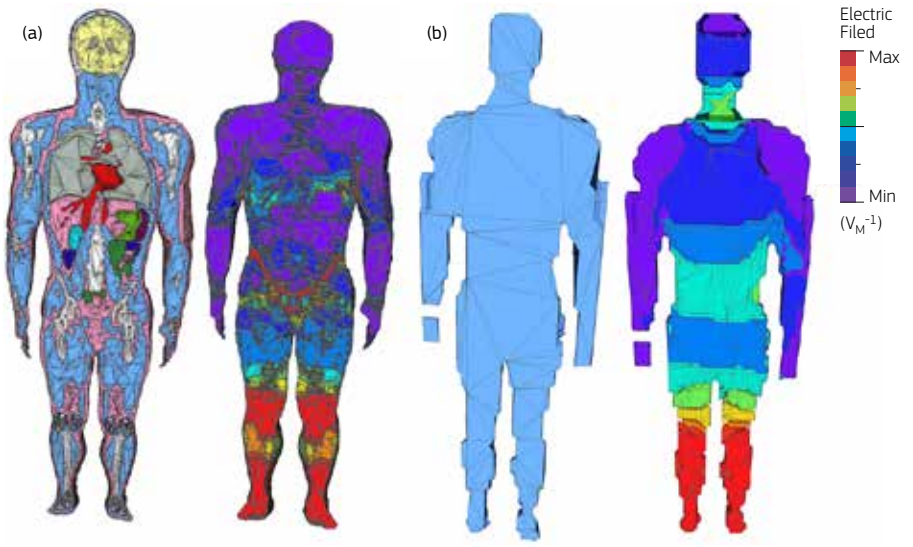
D.5.2.3 Uncertainties related to the human body model

If the body model is not representative of the exposed worker in terms of anatomy and posture etc., errors can be introduced into the results. For example, a simple, homogeneous model of the body can produce considerably different values of internal dose quantities such as induced electric fields and SARs when compared to calculations performed with anatomically realistic heterogeneous models. Additionally, these simple human models can produce artificial phenomena such as the appearance of maximum localised SAR or induced electric fields deep within the body, when used in numerical simulations (Figure D26).

Recommended practices to mitigate the production of inaccuracies in the calculation of dose quantities include:

- comparisons of results obtained using other numerical methods for the same exposure situation. If similar results are obtained, this can provide validation of the numerical simulation used for a particular exposure configuration
- comparisons of numerical results with measurements. Simulations of external field quantities such as electric and magnetic field strengths should be compared with measured values when these exist to validate the model of the electromagnetic field source
- comparisons of results from different organisations (inter-laboratory comparisons). Comparisons of numerical results with other published data for the same or similar exposure configuration can give the assessors a higher degree of confidence in the validity of results produced
- convergence tests. The numerical methods used to calculate internal dose quantities within the body are often iterative in nature (e.g. FDTD method, SPFD method, FEM etc.) and therefore usually converge to a solution. If the convergence and stability of a solution is poor, it is highly probable that the results obtained from the simulation are inaccurate

Figure D26 — Induced electric field distribution from exposure to a 50 Hz external electric field in (a) 2 mm resolution, high quality heterogeneous human model (b) 16 mm resolution, low quality homogeneous human model. Using low quality, low resolution homogeneous human models can introduce errors in the calculated values.



Key message: uncertainty

All measurements and calculations are subject to uncertainties and these should always be quantified and taken into consideration when interpreting results. The approach to dealing with uncertainty will vary depending on national legislation and practice. Often this will involve a 'shared risk' approach, but some authorities may require the use of the additive approach.

APPENDIX E. INDIRECT EFFECTS AND WORKERS AT PARTICULAR RISK

The EMF Directive requires employers to consider both indirect effects and workers at particular risk when undertaking risk assessments. However, with the three exceptions listed in Table E1, below (see Section 6.2 for further details), it provides no action levels (ALs) or other guidance on what constitutes a safe field condition. This appendix provides further explanation of the difficulties in defining safe field conditions and provides additional guidance to those employers who need to assess risks for these situations.

Table E1 — Indirect effects ALs cross-referenced to further details in this guide

Indirect effects ALs	Section
Interference with active implanted medical devices by static magnetic fields	6.2.1
Attraction and projectile risk from static magnetic fields	6.2.1
Contact currents from time varying fields < 110 MHz	6.2.2

E.1 Indirect Effects

Indirect effects arise when an object present in an electromagnetic field becomes the cause of a safety or health hazard. The EMF Directive identifies five indirect effects that should be considered in any risk assessment:

- interference with medical electronic equipment and devices
- projectile risks from ferromagnetic objects in static magnetic fields
- initiation of electro-explosive devices (detonators)
- ignition of flammable atmospheres
- contact currents

Consideration should also be given to any other indirect effect that might occur (see Section E1.6).

In general, indirect effects will only occur under specific conditions and it will often be straightforward to establish that those conditions do not exist in a particular workplace meaning that the risk is already minimal. However, sometimes this will not be the case, and in these situations a more detailed assessment will be required.

E.1.1 Interference with Medical Electronic Equipment and Devices

EMF may potentially cause interference with the correct functioning of medical electronic equipment in the same way that it can cause interference with any other electronic equipment. However, as such equipment may have a vital function in medical treatment; the consequences of interference may be severe.

Since 30 June 2001, all medical electronic equipment placed on the market or put into service in the European Union has had to comply with the *essential requirements* of the Medical Devices Directive (93/42/EEC as amended). In reality much of the equipment put into service after 1 January 1995 will also have complied with the Medical Devices Directive.

These essential requirements include a condition that devices must be designed and manufactured in such a way as to remove or minimise risks connected with reasonably foreseeable environmental conditions such as magnetic fields, external electrical influences, and electrostatic discharge.

In practice manufacturers achieve compliance with the essential requirements of the Medical Devices Directive by manufacturing their products in conformity to an appropriate harmonised standard. In relation to immunity to interference, the main standard is EN 60601-1-2, although there may also be requirements in particular standards. Whilst the essential requirements in respect of immunity to EMF are identical for both the Medical Devices Directive and the AIMD Directive (see below), the interpretation in harmonised standards has not been. Versions of EN60601-1-2 up to and including edition 3 (2007) required that essential functions of equipment should not be compromised by exposure to:

- power frequency magnetic fields of up to 3 A/m (3.8 μT)
- electric field strengths of up to 3 V/m at frequencies from 80 MHz to 2.5 GHz (fields are typically amplitude modulated at 1 kHz)
- for life support equipment the electric fields strength immunity between 80 MHz and 2.5 GHz is increased to 10 V/m.

These values provide a basis on which to assess the potential for interference with medical electronic equipment.

Edition 4 (2014) of EN60601-1-2 addresses the issue of consistency between the Medical Devices Directive and the AIMD Directive. It requires the manufacturer to state suitable environments for use and increases the immunity levels for devices intended for use in the home healthcare environment.

The standard also accepts that achieving these levels of immunity would be difficult for equipment designed to monitor physiological parameters. It therefore allows lower immunity for this equipment, in the expectation that it will be used in a low field environment.

E.1.2 Projectile Risks from Ferromagnetic Objects in Static Magnetic Fields

In strong static magnetic fields, ferromagnetic objects may experience strong attractive forces that can result in movement of the object. Under appropriate circumstances this movement may constitute a projectile risk. The risk of movement depends on a number of factors, including the magnetic field gradient, the mass and shape of the object and the material from which it is fabricated.

The EMF Directive specifies an AL of 3 mT to prevent the projectile risk for ferromagnetic objects in the fringe field of strong static magnetic sources (> 100 mT).

E.1.3 Initiation of Electro-explosive Devices (Detonators)

It is well established that under appropriate conditions EMF can cause initiation of electro-explosive devices (detonators). This effect is dependent on the presence within the workplace of both electro-explosive devices and field strengths sufficient to initiate

them. Hence this is unlikely to be an issue for the majority of workplaces, but may need to be considered by some employers, in the defence sector, for example.

As electro-explosive devices may present a risk even in the absence of strong EMF, their storage and use is normally strictly controlled, with restrictions on activities that may take place in the vicinity, including generation of EMF.

There is a European technical report (CLC/TR 50426) that provides guidance on assessments of the risk of initiation of bridge-wire devices. The report provides approaches to assess the risk that sufficient energy can be extracted from the field to cause initiation.

Another European technical report that may be useful is CLC/TR 50404, which provides guidance on assessment of risks and measures to avoid initiation of explosive materials by static electricity.

E.1.4 Fires and Explosions from Ignition of Flammable Atmospheres

It is well established that the interaction of electromagnetic fields with objects can result in the generation of spark discharges that have the capacity to ignite flammable atmospheres. As this effect requires the presence of both a flammable atmosphere and field strengths sufficient to ignite them, it is unlikely to be an issue for the majority of workplaces, but may need to be considered by employers in some sectors.

Flammable atmospheres may be at risk of ignition from a number of sources and so the normal approach is to identify areas where such atmospheres may exist and to place restrictions on activities in those areas. Those restrictions will normally include limitations on the generation of EMF in the area.

There is a European technical report (CLC/TR 50427) that provides guidance on assessments of the risk of inadvertent ignition of flammable atmospheres by radiofrequency EMF. The report provides approaches to assess the energy that can be extracted from the field and to compare this with the energy required to ignite different classes of flammable materials.

Another European technical report that may be useful is CLC/TR 50404, which provides guidance on assessment of risks and measures to avoid ignition of flammable atmospheres by static electricity.

E.1.5 Contact Currents

Contact between a person and a conducting object in an electromagnetic field, where one of them is grounded and the other is not, may result in a flow of current to ground through the point of contact. This can result in shocks and burns.

The EMF Directive specifies ALs for contact current that are intended to avoid painful shocks. It is possible that the person touching the object may still perceive the interaction at contact currents below the ALs. Although this will not be harmful it may be annoying and can be minimised by following the advice in Section 9.4.8.

E.1.6 Unspecified indirect effects

Consideration should also be given to any other indirect effect that might occur. Interactions that should be considered include:

- interaction of fields with shielding or metalwork in the work environment leading to heating and thermal hazards

- interaction of fields with electronics and control systems in the workplace resulting in interference and malfunction
- interaction of fields with metal items or components worn or carried close to the body
- interaction of fields with electronic components or equipment worn or carried close to the body.

E.2 Workers at Particular Risk

The EMF Directive identifies four groups of workers who may be at particular risk from EMF in the workplace:

- workers who wear active implanted medical devices (AIMD)
- workers who wear passive implanted medical devices
- workers with medical devices worn on the body
- pregnant workers.

Employers should also be aware of the possibility of specific risks to currently unspecified groups of workers (see Section E2.5).

These workers may not be adequately protected by the ALs and ELVs specified in the Directive. Where employers identify that there could be risks to these groups of workers, information should be provided in staff induction training and site visitor information. This should include encouragement for these workers to identify themselves to management so that a specific risk assessment can be undertaken.

E.2.1 Workers Wearing Active Implanted Medical Devices (AIMD)

E.2.1.1 Background

There are many active devices that may be implanted into people for medical purposes. These include:

- pacemakers
- defibrillators
- cochlear implants
- brainstem implants
- inner ear prostheses
- neurostimulators
- drug infusion pumps
- retinal encoders.

In general, devices that have leads to connect to the patient for the purposes of sensing or stimulation will normally be more sensitive to interference than those that do not. This is because the leads will form a loop that can couple to the electromagnetic field. Even amongst devices with leads, sensitivity may vary depending on function and arrangements. Devices designed to sense neurophysiological signals within the body are likely to be the most susceptible to interference as they are designed to be sensitive to small changes in voltage on the leads. Such voltage changes can be readily generated

by interaction with fields, but the magnitude of the induced voltage will depend on the length, type and position of the leads within the body. In general, devices with a single lead that can form a large effective loop will couple strongly into the field, whereas bipolar devices are generally less sensitive as they form much smaller effective loops.

Pacemakers normally incorporate a reed switch (a type of magnetic switch) that can be activated by strong magnetic fields to switch the device from 'demand' to 'pacing' mode. Some AIMD are designed to sense radiofrequency or inductively coupled signals for programming purposes, whilst other such as cochlear implants may use inductive coupling as part of the normal function. All of these devices are designed to be sensitive to external fields and will consequently be susceptible to interference in the presence of specific fields.

Since 1 January 1995, all AIMD placed on the market in the European Union have had to comply with the *essential requirements* of the Active Implanted Medical Devices Directive (90/385/EEC as amended). These include a requirement for the devices to be designed and manufactured in such a way as to remove or minimise risks connected with reasonably foreseeable environmental conditions such as magnetic fields, external electrical influences, and electrostatic discharge.

In practice manufacturers achieve compliance with the essential requirements of the AIMD Directive by manufacturing their products in conformity to an appropriate harmonised standard. Relevant harmonised standards include EN45502-1 and the EN45502-2-X series of particular standards. The immunity requirements in these standards are derived from the reference levels specified in Council Recommendation 1999/519/EC, but excluding any time averaging for radiofrequency fields and assume the device is implanted following good medical practice.

E.2.1.2 Assessment guidance

Basic approach

The first step is to consider what equipment and activities are present in the workplace and if any of the workers are known to wear AIMD. It should be noted that not all employees will declare that they wear AIMD and there is some evidence to suggest that up to 50 % of employees may refuse to disclose this information for fear it may affect their employment. The employer will need to take account of this reluctance when seeking information.

If only equipment and activities listed in Column 1 of Table 3.2 are present, then further action will not normally be necessary unless a worker is identified as having an unusually susceptible AIMD (see below).

If it is not possible to identify workers fitted with AIMD, then further action will not normally be necessary, but employers should remain alert to the possibility that new workers or visitors may wear AIMD, or that existing workers may be fitted with AIMD.

Where workers with AIMD are identified, then the employer should gather as much information about the device(s) as possible. The worker should cooperate with this process and, where available, assistance should be sought from an occupational health physician and/or the medical practitioner responsible for the worker's care.

If the worker is fitted with an older device or has been given specific warnings that their AIMD is fitted in such a way that it will be unusually susceptible, it will be necessary to carry out a specific assessment. This should be based on the known characteristics of the device.

In most other situations it should be possible to undertake a general assessment as discussed below. If this shows that the worker's normal work activities could result in a hazardous condition, then the simplest solution will normally be to make adjustments to the workstation or work activities. If this is difficult, then the employer may wish to consider a specific assessment.

Older AIMD

Older active implants that predate 1 January 1995 may not have the same immunity to interference by EMF as modern devices. It is not clear how many of these older devices remain in use. The batteries that power AIMD have a limited life and the entire device or elements of it may be replaced along with the batteries. For example, it is normal practice with pacemakers to replace the entire pulse generator along with the batteries, although other elements such as the leads normally remain in place. Pacemakers still account for the majority of implants and this would certainly have been true prior 1995. These older pacemakers were unlikely to be affected by static magnetic fields less than 0.5 mT, low frequency electric fields less than 2 kV/m, and low frequency magnetic fields less than 20 μT.

Specific warnings

All patients fitted with AIMD receive general warnings to avoid situations that could lead to interference. These warnings should be followed, but do not affect the assessment of risks using the general assessment approach given below. However, occasionally there are medical reasons for implanting the AIMD in a non-standard configuration or using non-standard settings and this may warrant specific warnings. This may also occur due to the clinical condition of the patient. Where specific warnings have been received, it will be necessary to undertake a specific assessment.

General assessment

The general assessment approach follows that given in EN50527-1 and is based on the immunity requirements of harmonised standards for AIMD. Hence, interference should not occur provided that fields, other than static magnetic fields, that do not exceed the instantaneous values of the reference levels in Council Recommendation 1999/519/EC. AIMD should also remain uninfluenced by static magnetic fields of less than 0.5 mT.

Specific assessment

In some situations it may be necessary to undertake a specific assessment. This is likely to be necessary when:

- workers are fitted with older AIMD (see above)
- workers have been given specific warnings
- it is difficult to make adjustments of the workstation or work activity to ensure exposure does not exceed the reference levels in Council Recommendation 1999/519/EC.

Further information on specific assessments is given in Annex A of EN505271. Further guidance is also available in the German Social Accident Insurance Association document BGI/GUV-I 5111.

E.2.2 Workers Wearing Passive Implanted Medical Devices

A range of medical implants may be metallic. This includes artificial joints, pins, plates, screws, surgical clips, aneurism clips, stents, heart valve prostheses, annuloplasty rings, contraceptive implants, cases of AIMD and dental fillings.

Where these devices are made from ferromagnetic materials, they may experience torques and forces in the presence of strong static magnetic fields. Evidence to date suggests that static magnetic flux densities of 0.5 mT or below will not exert sufficient effect to constitute a health hazard (ICNIRP, 2009). This is consistent with the AL specified in the EMF Directive to prevent interference with AIMD in static magnetic fields.

In time varying fields, metallic implants may perturb the induced electric field within the body leading to localised regions of strong fields. In addition, metallic implants may be

inductively heated, resulting in heating and consequent thermal injury to surrounding tissues. Ultimately this may lead to failure of the implant.

There are few data on which to base an assessment of risk to those wearing passive implants. One factor to consider is the frequency of the EMF as penetration of the field into the body decreases with increasing frequency, so that there may be little of no interaction between high frequency fields and the majority of implants, which are located within a mass of surrounding tissue.

Inductive heating sufficient to cause thermal injury to surrounding tissues will depend on the extraction of sufficient power from the field. This will be influenced by the dimensions and mass of the implant as well as the strength and frequency of the accessible field. However, compliance with Council Recommendation 1999/519/EC would normally be expected to provide adequate protection, whilst stronger fields may be justifiable in some circumstances.

E.2.3 Workers with Medical Devices Worn on the Body

Body worn medical devices fall within the scope of the Medical Devices Directive (93/42/EEC as amended). Hence, in the absence of more specific information the assessment considerations are the same as for interference with other medical electronic equipment discussed in SectionE1.1.

However, in general body-worn devices would not be expected to be any more sensitive than AIMD and devices that are not designed to sense physiological parameters may be less sensitive than some AIMD. Hence it is always advisable to contact the manufacturer to request information about immunity to interference.

E.2.4 Pregnant Workers

There have been reports of adverse effects resulting from maternal exposure to low frequency magnetic fields. However, overall the evidence of an association between such effects and exposure to low frequency fields is considered to be very weak (ICNIRP, 2010). Nevertheless, an expert group has considered that the developing nervous system *in utero* could be potentially susceptible to induced time varying electric fields (NRPB, 2004). The same group concluded that limiting induced electric field strengths to around 20 mV/m should provide adequate protection to the developing nervous system *in utero*. It was calculated that this could be achieved by compliance with the reference levels for low frequency fields specified in Council Recommendation 1999/519/EC.

There is compelling evidence that raised maternal body temperature adversely affects pregnancy outcome, with the central nervous system apparently particularly susceptible. It has been concluded that limiting average whole body SAR to 0.1 W/kg in pregnant women should provide adequate protection (NRPB, 2004). This is similar to the basic restriction for radiofrequency exposure of 0.08 W/kg specified in Council Recommendation 1999/519/EC.

Hence for most employers a pragmatic approach would be to limit exposures of pregnant workers using the reference levels contained in Council Recommendation 1999/519/EC. This should provide adequate protection at both low and high frequencies.

E.2.5 Unspecified workers at particular risk

Employers should be aware that there may be currently unspecified groups of workers who may be at particular risk, such as workers taking specific medications for recognised medical conditions.

APPENDIX F. GUIDANCE ON MRI

Magnetic resonance imaging (MRI) is an important medical technology that has become essential to the diagnosis and treatment of disease and is a valuable tool in medical research. The technique is widely used throughout the European Union with tens of millions of scans each year and involves the deliberate exposure of patients or volunteers to strong electromagnetic fields in order to generate detailed images including mapping brain metabolism and activity. Although complementary to other imaging technologies such as computed tomography (CT), MRI has the advantage that it does not involve exposure to ionising radiation and has no known long-term health effects.

Electromagnetic field exposures of patients and volunteers within the scanner fall outside the scope of the EMF Directive. The electromagnetic field distribution in the scanner is primarily dictated by considerations of scan efficiency and image quality. In addition, manufacturers endeavour to minimise the extent of stray fields outside the scanner, thereby reducing exposures to staff working around the equipment. Static magnetic fields may exceed the action levels (ALs) for indirect effects (see Chapter 6). Moreover, under some circumstances workers may still be exposed to fields in excess of an exposure limit value (ELV) (see Table F1). However, the derivation of the ELV includes a margin of safety, which means that exposure above the ELV may not elicit effects in workers. It is considered safe to routinely expose patients and volunteers to the intense fields inside an MRI scanner (ICNIRP 2004, 2009).

The value of MRI as an essential technology in the healthcare sector is well recognised and Article 10 of the EMF Directive grants a conditional derogation from the requirement to comply with the ELVs. This guidance has been prepared in consultation with stakeholders from the MRI community in order to provide practical guidance to employers on achieving compliance with these conditions, should this be necessary. Healthcare providers offering MRI will have access to expert radiography, radiology and medical physics experts who should all be consulted in relation to achieving compliance. Manufacturers and research institutes will have equivalent experts and should similarly consult them.

F.1 Design and Construction of MRI Equipment

MRI scanners are designed to generate a complex electromagnetic environment within the bore of the equipment, with three main components:

- static magnetic fields — the majority of systems in clinical use operate at either 1.5 or 3 T, although open systems favoured for interventional procedures normally operate at lower magnetic flux densities (0.2 — 1 T) and there are also a small number of high field scanners operating at up to 9.4 T that are used mainly for research purposes
- low frequency switched gradient magnetic fields — scanners use three orthogonal gradients that are switched on and off rapidly in order to generate positional information relating to the MR signals measured. These are complex pulsed waveforms that vary with the type of scan being undertaken. The pulsed waveforms are equivalent to frequencies in the region of 0.5 — 5 kHz
- radiofrequency fields applied at the Larmor frequency, which depends on the static magnetic flux density (62 — 64 MHz and 123 — 128 MHz for 1.5 T and 3 T scanners respectively).

Table F1 — Comparison of worker exposures from MRI with limit values and resulting effects

Example worker exposures*	Limit Values	Reported effects
Static magnetic field		
1.0 T, 1.5 T, 3.0 T, 7.0 T	2 T, 8 T	Vertigo in absence of motion
< 2 m/s equivalent to < 3 T/s 0.3 V/m (pk) in brain or 2 V/m (pk) in body	0.05 V/m (rms) (sensory effects ELV) 0.8 V/m (rms) (health effects ELV)	Vertigo and nausea
Switched gradient fields		
100-1500 Hz Limited by patient PNS values, which correspond to estimated values for dB/dt and induced rms E-fields in brain and trunk At normal patient locations <40 T/s (rms) = 4 V/m in brain <40 T/s (rms) = 8 V/m in trunk At worst case accessible locations for interventional workers <120 T/s (pk) = 8 V/m in brain <40 T/s (pk) = 2 V/m in trunk	0.8 V/m (rms)	tingling sensation, pain or muscular contraction if PNS controlled mode limits are exceeded. CNS effects have never been reported by MRI workers, known reports are from TMS at values > 500 T/s or > 50-100 V/m
Radiofrequency fields		
42, 64, 128, 300 MHz WB SAR limited to < 4 W/kg in isocentre correspond to WB SAR < 0.4 W/kg halfway inside << 0.1 W/kg at aperture	0.4 W/kg	Heat sensations and sweating at exposures > 2 W/kg

Data supplied by COCIR — further data on worker exposures available in Stam, 2014.

All MRI scanners intended for diagnosis and/or therapy of people and placed on the market or put into service in the European Union since 30 June 2001 have had to conform to the *essential requirements* of the Medical Devices Directive (93/42/EEC), which includes a general requirement that they should not compromise the safety and health of users, or where applicable, other persons. Manufacturers are required to select state of the art design and construction solutions that will eliminate or reduce risks so far as possible. In order to assist manufacturers to achieve conformity with the essential requirements and acting under a mandate provided by the European Commission, the European Committee for Electrotechnical Standardisation (CENELEC) has published a product standard for magnetic resonance equipment for medical diagnosis (EN60601-2-33).

The current version of EN60601-2-33 includes a requirement for manufacturers to provide information on the spatial distribution of fields and this is normally to be found in the scanner manuals. This information is available for all MR systems and should assist employers in identifying those areas where the ELVs may be exceeded. In addition, scanners are required to provide information about the gradient output and radiofrequency specific energy absorption rate (SAR) prior to initiating each scan. Scanners are also required to incorporate safeguards to provide protection from excessive exposures. It is possible that the requirements referred to in this paragraph may not apply in the case of older so-called 'legacy' equipment.

F.2 Worker Exposure During Operation of MRI in the Healthcare Sector

MRI scanners are designed to generate strong, but carefully controlled fields within the bore of the scanner whilst minimising stray fields outside the footprint of the equipment. Hence fields fall very rapidly with distance from the scanner aperture, typically resulting in high spatial field gradients close to the scanner and much weaker fields at greater distances. The available evidence suggests that only work within the bore of the scanner or in the immediate vicinity of the aperture will lead to exposures in excess of the ELVs.

As exposures of workers who do not need to approach close to the scanner aperture will always be compliant there is no necessity to assess them. The assessment of exposure for workers who have to approach close to the aperture or enter the bore of the scanner will be complex. It requires a detailed knowledge of the spatial distribution of fields within and outside the scanner together with an understanding of how staff move in relation to the scanner whilst carrying out their work, something that will be strongly dependent on the tasks to be completed. In addition, assessments should ideally be based on numerical modelling techniques so that exposures can be compared directly with the ELVs. Such assessments are beyond the capability of most institutions carrying out routine MRI procedures.

In order to provide information on worker exposures resulting from a range of typical procedures and different types of equipment, the European Commission funded an assessment at four magnetic resonance facilities in different countries. This detailed project assessed staff movements and positions during different procedures, together with field mapping and computational dosimetry (Capstick et al., 2008). The results from this and earlier studies (reviewed in Stam, 2008) are informative, although the detailed conclusions need to be treated with some caution. The results relate to the previous EMF Directive and use different exposure metrics. Moreover they are limited to a relatively small number of scanners and exposure scenarios. Recent analyses suggests that the ELVs may be exceeded under some circumstances (Stam, 2014; McRobbie, 2012).

The measurement data for switched gradient fields need to be treated with particular caution since in many cases the action levels in the current EMF Directive are less restrictive than those discussed in earlier exposure studies. In general, comparison with action levels results in a conservative assessment relative to the use of ELVs, so that the latter is preferable, but generally requires expertise in complex computational dosimetry.

F.2.1 Exposures Relative to ELVs

F.2.1.1 Static magnetic fields

For all low field scanners (operating at less than 2 T) and the majority of routine procedures with scanners operating above 2 T, static magnetic field exposures will be compliant with the sensory ELV. For all other procedures using scanners operating at up to 8 T static magnetic field exposures will be compliant with the health effects ELV.

F.2.1.2 Movement through static magnetic fields

Movement through the strong static magnetic fields produced by MRI scanners will induce electric fields within the tissues of the body and these may exceed the ELVs specified in the EMF Directive. At normal movement speeds this will only happen in the bore of the scanner and within a short distance from the aperture (generally no more than 1 m on the basis of available information). This is a particular issue during patient set up, which may involve complex rotational movements of the operator's head.

F.2.1.3 Switched gradient fields

For the majority of routine procedures switched gradient field exposures will not exceed either the sensory or health effects ELVs. However, for a minority of procedures, where workers have to approach close to the scanner aperture (normally less than 1 m), there may be potential to exceed the ELVs, whilst for a very small number the ELVs are very likely to be exceeded, particularly if the worker has to lean into the scanner. Actual exposures will depend on a number of factors including the number of gradients that are simultaneously active and the gradient characteristics, with high speed imaging generally resulting in higher exposures. Table F2 illustrates examples of procedures falling into each category.

F.2.1.4 Radiofrequency fields

Radiofrequency ELVs are time-averaged over a six minute period and exposures will generally be compliant where a worker has to lean into a scanner (to monitor a patient for example) provided this only lasts a few minutes. Longer exposures are also often compliant.

F.3 MRI Derogation

The importance of MRI as an essential technology in the healthcare sector is well recognised and Article 10 of the EMF Directive grants a non-discretionary but conditional derogation from the requirement to comply with ELVs. This derogation applies to worker exposures associated with installation, testing, use, development, maintenance of, or research related to MRI provided the following conditions are met:

(i) the risk assessment carried out in accordance with Article 4 has demonstrated that the ELVs are exceeded

(ii) given the state of the art, all technical and/or organisational measures have been applied

(iii) the circumstances duly justify exceeding the ELVs

(iv) the characteristics of the workplace, work equipment, or work practices have been taken into account

(v) the employer demonstrates that workers are still protected against adverse health effects and against safety risks, including by ensuring that the instructions for safe use provided by the manufacturer in accordance with the Medical Devices Directive (93/42/EEC) are followed.

Table F2 — Risk of exceeding the relevant ELV for gradient field exposures during different MRI investigations

Risk of exceeding ELV	Procedure
High	Guide wire placement (with real time scanning) Interventional techniques such as interventional cardiovascular MRI Functional MRI (in-scanner physical stimulation of patient) Adjustment of EEG electrodes (research activity)
Medium	General anaesthesia (close monitoring of patient condition during scanning) Cardiac stress test (close monitoring of patient condition during scanning) Cleaning / infection control inside scanner (no scanning) Comforting child during scanning (comforter remains outside scanner, but within 1 m of aperture)
Low	Routine scans (no staff present in scanner room) Biopsy (patient not in scanner/ no scanning) Manual administration of contrast agent (no scanning)

It should be noted that the derogation applies only in respect of ELVs, which are intended to prevent the direct effects of electromagnetic fields on people. Other hazards may arise from the operation of MRI equipment that could give rise to safety risks with potentially severe outcomes. Operators should ensure that these are managed appropriately. These other hazards may include interference with:

- active or passive implanted medical devices
- body-worn medical devices
- medical electronic equipment
- cosmetic or medicinal implants

Other hazards also include:

- projectile risk from movement of ferromagnetic materials in the strong magnetic field
- noise
- liquid helium.

F.4 Meeting the Conditions of the Derogation

This section provides guidance to employers in assessing whether they are compliant with the conditions of the derogation.

F.4.1 Risk assessment to determine if ELVs are exceeded

Specific guidance on undertaking risk assessments in the context of the EMF Directive is given in Chapter 5. Magnetic resonance imaging equipment employs strong fields in order to produce images and hence there will often be the potential to exceed the ELVs. However, in general electric field strengths will only exceed the ELVs within the scanner or very close to the aperture (see Section F1) and the majority of MRI procedures (estimated to be around 97 %) do not require staff to be present at these positions during scanning.

As the assessment of exposures is likely to be beyond the capability of most institutions carrying out routine MRI procedures, it will normally be acceptable to rely on published data, together with information on predicted exposure provided by scanner systems.

The key to assessing the risk will thus be to determine whether staff have to enter those areas where ELVs may be exceeded (normally within 1 m of the aperture). During routine operation and patient care, operators will access this, but not normally whilst the system is scanning. Where staff have to approach within 1m of the aperture, moving slowly should be sufficient to keep electric fields induced by the movement below the relevant ELV. Examination of Table F2 and published exposure data (see Section F2) should assist employers in deciding what, if any, procedures could give rise to exposures in excess of the ELV from the switched gradient fields.

Staff should avoid entering the bore of the scanner if possible (see Section F6.4). However, it should be noted that where staff do have to enter the bore of the scanner for activities such as infection control, this will be done with the switched gradient and RF fields off so that only exposures resulting from the static magnetic field have to be considered. As discussed in Section F2, for scanners operating at magnetic flux densities up to 8 T, the health effects ELV will not be exceeded. If measures to inform workers and prevent safety risks are taken, it is acceptable to exceed the sensory effects ELV temporarily.

F.4.2 Application of State of the Art Technical and Organisational Measures

F.4.2.1 Technical measures

Technical measures to constrain fields within the bore of the scanner are inherent in its design and construction along with operating modes to restrict output. Manufacturers continuously develop and improve their equipment, including measures to constrain fields as part of achieving compliance with the requirements of the Medical Devices Directive. It follows from these compliance requirements that at the time of manufacture and installation the technical measures incorporated into scanners will represent the state of the art. Post-installation modification of MR equipment would be technically difficult and would normally require re-assessment in relation to compliance with the Medical Devices Directive, which is generally beyond the capabilities of operating institutions.

In principle it would be possible to select operating parameters (such as gradient characteristics or radiofrequency field strength) to reduce exposures when staff have to be present within the bore or close to the scanner aperture. However, in practice the selection of scanner operating parameters is driven primarily by clinical need and procedures that involve staff leaning into the scanner (such as interventional procedures) will often be those that require fast scans resulting in high exposures. Hence there is unlikely to be much scope to reduce exposures through this approach, but where there is flexibility, radiographers should select slower scans and lower radiofrequency exposures if staff are likely to approach close to the scanner. Nevertheless, the selection of appropriate scanner settings must remain a matter for clinical judgement.

F.4.2.2 Organisational measures

Employers operating MRI scanners should follow the recommendations given in Sections F5 and F6 below.

F.4.3 Circumstances Duly Justify Exceeding the ELV

Circumstances duly justifying the exceeding the ELV depend on particular applications. For diagnosis and treatment, the requirement to carry out particular procedures will always be a matter for clinical judgement. Where procedures involve workers entering the region around the aperture identified on the plan (see Section F5.3 below) then the employer should consult the relevant healthcare professionals to consider if there is any other acceptable means of achieving the desired end, taking account of the clinical needs and patient safety.

Manufacturers should take similar considerations into account when organising their work, particularly the need to ensure that equipment will generate images of appropriate quality for clinical use. Research institutions should follow an analogous process to that followed in direct patient care, taking into account the quality of the data obtained and the safety of volunteers.

F.4.4 Characteristics of the Workplace, Work Equipment, or Work Practices

Employers should note the contents of Section F1 above, and follow the recommendations given in Sections F5 and F6 below.

F.4.5 Worker Protection and Safe Use

As explained in Section F1, MRI equipment conforming to EN60601-2-33 incorporates safeguards to protect against excessive exposures. Nevertheless, where ELVs are exceeded there is a risk that workers who are most sensitive to the fields may experience effects. For this reason it is important that workers required to enter the Controlled Access Area (see Section F5.1) are given information about the possible consequences of exposure so that they can recognise if these occur and take action to limit their exposure appropriately. All such events should be reported to the unit manager or responsible person who should take appropriate action.

MRI scanners are complex and highly technical items of medical or research equipment and operators are extensively trained. The equipment incorporates numerous safety systems including safeguards to protect against excessive exposures and automated warning systems. Provided employers have systems in place to ensure that operators use the equipment according to the manufacturer's instructions and heed the automated warning systems the equipment should be safe for patients and workers as required by the Medical Devices Directive (93/42/EEC).

F.4.6 Pregnant Workers

Once a worker declares that they are pregnant, the employer should review the existing risk assessment to see if it is fit for purpose. If changes are required then a specific risk assessment should be carried out. Further guidance is available in Chapter 5 and Appendix E of this guide.

F.5 Organisation of MRI Facility

Institutions can minimise worker exposure by adopting a structured approach to the organisation of the MRI facilities and in particular by dividing the area according to the magnitude of the fields likely to be encountered. This facilitates the restriction of access into areas where the risk of exposure in excess of the ELVs is higher. In general, most

MRI facilities already operate a system of access restriction based on other hazards (see bulleted list in Section F3). The approach described below is based on proposals for good practice published elsewhere and develops existing approaches in the context of the EMF Directive.

F.5.1 Controlled Access Area

EN60601-2-33 defines the concept of the Controlled Access Area and specifies that this will be required for any MRI equipment that generates a stray field exceeding 0.5 mT outside its permanently attached cover and/or does not comply with the electromagnetic interference level specified in EN60601-1-2. Hence the designation of the Controlled Access Area is already standard practice in the healthcare sector.

Within the Controlled Access Area there will be a risk of interference with active implanted medical devices and other medical equipment. There will also be risks from attraction of ferromagnetic materials or torques acting on such materials.

Access into the area will need to be restricted, ideally through a controlled access door, with appropriate signage. Suitable organisational arrangements will be required to control entry into the area (see Section F6 below).

F.5.2 Scanner Room

Entry into the scanner room should be limited to workers with an operational need to be there. Those who enter the room should not remain in the room longer than necessary to perform their duties.

The magnetic spatial field gradient is maximal in the area immediately around the scanner aperture. Switched gradient fields in this area may also be sufficiently strong that there is a risk of exceeding the ELV when the scanner is operating. This area should therefore be identified on a plan displayed in the scanner room. The identified area will be based on the most restrictive of the spatial gradient and switched gradient fields and will normally be advised by the manufacturer. Where this specific information is not available (for an old scanner, for example)the default should be to identify an area within 1 m of the aperture (as measured from the central axis) as this will normally be adequate. The plan should serve to alert workers to the greater risks when working in this area. Workers should not enter the identified area unless necessary to discharge their duties and should not remain in the area any longer than is necessary. Any staff having to enter the identified area should ensure that they move sufficiently slowly to avoid adverse effects.

F.5.3 Layout of Scanner Room

The layout of the scanner room should be designed to avoid the need for staff to work close to the scanner so far as possible. Hence anaesthetic and other moveable equipment should be positioned as far away from the scanner as possible providing this is consistent with good medical practice. Similarly, administration of medications and contrast agents should be automated where possible, although it is recognised that it may not always be safe to do this: this is a matter of clinical judgement. In particular, manual infusion is often considered to be a safer alternative for young or very ill patients and this will always be a matter for clinical judgement.

F.6 Organisation of Work

F.6.1 Controlled Access Area

The Controlled Access Area should be subject to appropriate organisational arrangements, which should be documented. There should be direct supervision of work activities in the area by a member of staff in a position of authority, such as the lead radiographer for the day.

Medical staff and visitors in the controlled access area should be continuously supervised by an MR worker.

A key element of the arrangements will be screening to identify those at risk due to the presence of active or passive implants, or other risk factors such as body piercings or tattoos with high iron content. These will be the same screening criteria used for patients and carers.

Arrangements will also need to be in place to control access outside normal working hours (e.g. by cleaners, security staff, firefighters and building maintenance workers).

Screening should also extend to items brought into the area to ensure that ferromagnetic articles are marked as either MR safe of MR conditional as appropriate. This should be covered by local procedures.

F.6.2 Staff Training

Staff required to work in the Controlled Access Area should receive training in relation to MRI safety. Training should cover:

- Awareness of possible effects of movement in a strong static magnetic field
- Awareness of the effects of strong switched gradient fields
- Awareness of the effects of radiofrequency fields
- Awareness of the projectile risk from attraction of ferromagnetic materials and of the risks from torques acting on those materials
- Awareness of the risk of interference with active implanted medical devices
- Awareness of the risks of interference with medical electronic equipment
- The importance of access restrictions and screening of people or items entering the Controlled Access Area
- The importance of moving slowly around and inside the scanner
- Awareness of the spatial distribution of fields around the scanner
- Awareness of other hazards including noise and cryogenic gasses
- Evacuation procedures in the event of a superconducting magnet quench
- Awareness of procedures in case of an emergency event.

Training should normally be tailored to the particular facility and will therefore be delivered in house by someone with appropriate knowledge and experience. Further guidance on training requirements is expected to be produced by the relevant European professional bodies.

Where other staff such as cleaners, security staff, firefighters and building maintenance workers may have to access the Controlled Access Area, they should also receive

awareness training appropriate to the areas they may need to enter, although this need not be as detailed as for MR staff.

F.6.3 Scanner Room

Staff who have to enter the area around the aperture identified on the plan will need to ensure that they move slowly enough to make any transitory effects acceptable for the individual. Further guidance on restricting movement in static magnetic fields has been published (ICNIRP, 2014) and is discussed further in Section D4. Staff will need to be aware of the effects of the switched gradient fields and the importance of not approaching within the area identified on the plan unless required for the procedure being undertaken and then not remaining in the area any longer than necessary.

When active scanning is performed with workers near or inside the bore, they may experience peripheral nerve stimulation. Modern scanners are designed to limit peripheral nerve stimulation for most people, but the most sensitive individuals may still experience some effects and should be aware of the symptoms so that action can be taken to limit these effects. Should workers experience effects from exposure these should be reported to the facility management, who should, if necessary, update the risk assessment and prevention measures.

Direct effects on workers may result in safety risks to others. For example, vertigo or visual disturbances experienced by workers as a result of rapid movement through the static field could affect their ability to provide appropriate patient care.

F.6.4 Entry into the Scanner

Staff should not be instructed to enter the bore of the scanner unless absolutely essential. Entry into the bore of the scanner, for example to clean the scanner or comfort a patient, should be kept to the minimum necessary to complete the task. Staff should consider whether the procedure is necessary or whether it would be possible to achieve the same objective without entry. Staff who are not familiar with the effects of movement in strong static magnetic fields may be at increased risk.

In many cases simple approaches such as remote viewing (using a mirror, for example) can be used for activities such as monitoring of patients during scanning or inspection of the bore of the scanner. Similarly long-handled tools may be adequate for some cleaning procedures. Sensible use of these approaches will minimise the need for workers to enter the scanner.

If it is essential for staff to enter the scanner then the radiofrequency and switched gradient fields should be disabled unless absolutely required. If switched gradient fields are required they should, if possible, be limited to a single gradient and slow scan acquisition speed to limit the magnitude of exposures. Similarly, if radiofrequency fields are required they should be kept to the minimum power consistent with achieving the work objective.

F.7 MRI in the Research Environment

It is recognised that in the research environment work is likely to be less routine and may of necessity involve a higher degree of worker activity close to the scanner. Nevertheless, in general it should be possible to follow the general principles outlined above for scanning of patients adapting them as necessary to meet the specific requirements of the research. Detailed advice on the safe operation of MRI in the research environment has been developed by the International Society of Magnetic Resonance in Medicine (Calamante et al., 2014).

APPENDIX G. REQUIREMENTS OF OTHER EUROPEAN TEXTS

G.1 Legal basis for European Legislation

European law is shaped by three fundamental treaties:

- Treaty on European Union (TEU)
- Treaty on the Functioning of the European Union (TFEU)
- Treaty Establishing the European Atomic Energy Community.
- The TFEU (formerly the Treaty of Rome) provides the legislative basis for the Directives discussed below.

G.2 Health and Safety Directives

The TFEU sets an objective to encourage improvements in the working environment regarding the health and safety of workers. To help achieve this objective it allows for the introduction of Directives to set minimum requirements.

G.2.1 Framework Directive

In 1989 the Framework Directive (89/391/EEC) was introduced as an overarching Directive in this area. The Framework Directive sets out general principles of prevention and protection of workers in relation to occupational accidents and disease. It places obligations on employers in relation to:

- assessment of risks (see Chapter 5)
- prevention of risks (see Chapter 9)
- arrangements for first aid, firefighting, evacuation and actions in the event of serious and imminent danger
- keeping records of accidents
- worker information, participation and training
- health surveillance according to national custom and practice
- protection of particularly sensitive risk groups.

The Framework Directive also places duties on workers to:

- make correct use of equipment, substances and personal protective equipment
- inform the employer of any situation presenting a serious and imminent danger and of any shortcomings in the protection arrangements
- cooperate with the employer implementing measures for protection of health and safety.

The Framework Directive provides for the introduction of individual Directives, which essentially give additional detail on how to achieve the objectives of the Framework Directive in specific situations. The EMF Directive is just one of many individual Directives that supplement the general requirements of the Framework Directive. Some of these other Directives may have relevance to work with EMF and are briefly discussed below. For definitive information on any of these Directives, please refer to the Directives themselves, the national legislation that implements them and any official guides that may be available.

G.2.2 Work Equipment Directive

The Work Equipment Directive (2009/104/EC) places obligations on employers to ensure that work equipment provided to workers is safe and appropriate for the workplace in which it is to be used. It also places a duty on employers to ensure that work equipment is adequately maintained so that it remains compliant throughout its working life. The employer must carry out inspection and/or testing to ensure equipment is correctly installed and operating properly, and must record the results.

Where work equipment is likely to give rise to specific risks, the employer is required to restrict its use to those required to use it and ensure that repairs, modifications, maintenance or servicing is only carried out by designated personnel.

Employers are required to provide employees with information on the conditions of use of work equipment, foreseeable abnormal situations and dangers relevant to them. Workers should also receive adequate training.

G.2.3 Workplace Directive

The Workplace Directive (89/654/EEC) places obligations on employers to provide a workplace that is safe, clean and properly maintained.

G.2.4 Safety and/or Health Signs Directive

The Safety and/or Health Signs Directive (92/58/EEC) places obligations on employers to ensure that safety and/or health signs are displayed where hazards cannot be avoided or reduced. Workers and their representatives have to be provided with instruction about the meaning of signs and the actions that should be taken when they are displayed.

Minimum requirements for these signs are detailed in the annexes to the Directive.

G.2.5 Pregnant Workers Directive

The Pregnant Workers Directive (92/85/EEC) places obligations on employers to assess risks to safety and health from exposure to a range of physical, biological and chemical agents, including non-ionising radiations. The results of the assessment and any measures to be taken must be made available to workers who are pregnant, have recently given birth, or who are breastfeeding, and to workers who are likely to be in one of these situations. Where risks are identified, the employer is required to avoid them by adjusting the working conditions, moving the worker to another job, or granting leave.

The Directive also gives pregnant workers protection from having to work night shifts when medically indicated, grants rights to maternity leave, and provides protection from dismissal due to pregnancy or maternity leave.

G.2.6 Young Workers Directive

The Young Workers Directive (94/33/EC) establishes a system of protection for anyone under the age of 18 years. With certain defined exceptions, Member States are required to prohibit children in compulsory full-time education (and in any event children under the age of 15) from working.

Employers are required to carry out a risk assessment that takes particular account of risks arising from lack of experience, absence of awareness of existing or potential risks, and the fact that young people have not fully matured. Employers are then required to put in place measures to protect the safety and health of young people. The assessment must be made before young people begin work and when there is any major change in working conditions. Young workers and their representatives must be informed of the outcome of the assessment and the measures adopted.

G.2.7 Use of Personal Protective Equipment Directive

The Use of Personal Protective Equipment Directive (89/656/EEC) places an obligation on employers to ensure that personal protective equipment is used where risks cannot be avoided or sufficiently limited by technical or organisational means. Any personal protective equipment provided must meet EU provisions on design and manufacture and must:

- be appropriate for the risks, without leading to any increased risk itself
- correspond to existing conditions at the workplace
- take account of ergonomic requirements and the worker's state of health
- fit the wearer correctly after any necessary adjustment.

Personal protective equipment must be provided to workers free of charge, in good working order and hygienic condition. The employer must carry out an assessment to ensure it is suitable and, if necessary, compatible with other personal protective equipment.

Workers must be appropriately trained in the use of any PPE issued to them.

G.3 Product Directives

The TFEU prohibits quantitative restrictions on trade between Member States of the European Union, or measures having similar effect. Case law has established that restrictions on the free movement of products within the European Union can only be justified on the basis of non-conformity with *essential requirements*. This in turn led to a need to be able to define *essential requirements* and to standardise the assessment of conformity.

These issues were initially addressed through adoption of the *New Approach* to product regulation, which laid down the following principles:

- legislative harmonisation should be limited to the essential requirements that products placed on the EU market must meet if they are to benefit from free movement within the EU
- the technical specifications for products to meet the essential requirements should be laid down in harmonised standards
- products manufactured in conformity with harmonised standards benefit from a presumption of conformity with the corresponding essential requirements

- the application of harmonised or other standards remains voluntary; manufacturers can always apply other technical specifications to meet the requirements, but will then need to demonstrate that they have done so.

The New Approach has now been replaced by the New Legislative Framework, which revised and strengthened aspects of the earlier system.

This system of product legislation allows for regulation of broadly-based groups of products that share common essential requirements. To date 27 directives have been passed under this system, but only a few are likely to have any relevance to EMF safety in the workplace and these are discussed below.

G.3.1 Electrical equipment

Electrical equipment made available on the market in the European Union is subject to the requirements of the Low Voltage Directive (2006/95/EC). This directive was recast in 2014, with Member States required to introduce national legislation to implement the new Low Voltage Directive (2014/35/EU) by 20 April 2016. With specific exceptions, the Low Voltage Directives apply to electrical equipment designed to operate at AC voltages between 50 and 1 000 V or DC voltages between 75 and 1 500 V.

It is a requirement of the Low Voltage Directives that equipment should not endanger the health and safety of people, domestic animals or property when properly installed, maintained and used as intended. Of particular relevance to this guide, there is a requirement to use technical measures to ensure that equipment does not produce radiations that would cause a danger.

G.3.2 Machinery

Machinery made available on the market in the European Union is subject to the requirements of the Machinery Directive (2006/42/EC). In broad terms the Directive applies to any assembly of linked parts of components, at least one of which moves, and that is fitted or intended to be fitted with a drive system. With the exception of lifting machinery, equipment powered solely by human or animal effort is excluded from the scope of the Directive. There are a number of specific exclusions and additions to this broad scope.

The Machinery Directive exists to ensure that machinery does not present a risk to health or safety. There are specific requirements to ensure that undesirable emissions of radiations are eliminated or reduced to levels that do not have hazardous effects on people. Non-ionising radiation emissions during setting, operation and cleaning must be limited to levels that do not have adverse effects on people.

Manufacturers of machinery are required to provide information on residual risks in the instructions supplied with machinery. Manufacturers are also required to provide information on likely emissions of non-ionising radiations where these may cause harm to people, including those with implanted medical devices.

G.3.3 Radio equipment

Radio equipment placed on the market within the European Union is subject to the requirements of the Radio Equipment and Telecommunications Terminal Equipment Directive (1999/5/EC). However, from 13 June 2016, this Directive will be repealed and replaced with the Radio Equipment Directive (2014/53/EU). Under transitional arrangements, radio equipment complying with Directive 1999/5/EC can still be placed on the market until 13 June 2017. The Radio Directive applies to any equipment that is designed to intentionally emit and/or receive radio waves for the purposes of radio

communication and/or radiodetermination (using radio waves to determine the position, velocity or other characteristics of an object, or information about these properties). The Radio Equipment and Telecommunications Terminal Equipment Directive has a broader scope and, for example, also includes any equipment intended for connection to a public network.

Both directives incorporate the same requirements in respect of health and safety as the Low Voltage Directives (see Section G3.1), but without any restriction on voltage limits.

G.3.4 Medical equipment

Medical electronic equipment placed on the market within the European Union is subject to the requirements of either the Medical Devices Directive (93/42/EEC) or the Active Implantable Medical Devices Directive (90/385/EEC). Both directives are discussed further in Sections E2.1.1 (Active Implanted Medical Devices Directive) and E2.3 (Medical Devices Directive).

G.3.5 Personal protective equipment

Personal protective equipment placed on the market within the European Union is subject to the requirements of the Personal Protective Equipment Directive (89/686/EEC). Subject to specific exclusions, personal protective equipment is broadly defined as any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards.

The Personal Protective Equipment Directive requires that personal protective equipment shall be placed on the market and brought into service only if it preserves the health and ensures the safety of users when properly maintained and used for its intended purpose. Personal protective equipment may not compromise the health or safety of other people, animals or goods.

G.3.6 General product safety

The purpose of the General Product Safety Directive (2001/95/EC) is to ensure the safety of products intended for consumer use. Where such products fall within the scope of one of the new approach or new legislative framework directives the requirements of the specific directive will normally take precedence over those of the General Product Safety Directive. Although the purpose of the General Product Safety Directive is to protect consumers, it applies to products purchased for use by a business provided the product is intended for use by consumers.

The General Product Safety Directive requires that products should present either no risk, or only minimum risks compatible with its intended use and considered to be acceptable (consistent with a high level of protection of health and safety). These requirements apply under all reasonably foreseeable conditions of use, including installation, putting into service, and maintenance.

G.3.7 Electromagnetic compatibility

Equipment likely to cause electromagnetic disturbance or liable to be affected by such disturbance and either placed on the market or put into service in the European Union is subject to the requirements of the Electromagnetic Compatibility Directive (2004/108/EC). This Directive has recently been recast, with the new Electromagnetic Compatibility Directive (2014/30/EU) coming into force on the 20 April 2016 and the existing Directive repealed from the same date. Any equipment placed on the market prior to 20 April 2016 and compliant with Directive 2004/108/EC may continue to be

made available on the market after that date. There are specific exceptions to the scope of the Directives, including equipment falling within scope of the Radio Equipment and Telecommunications Terminal Equipment Directive (see G3.3) and aeronautical equipment. Electromagnetic compatibility requirements for aircraft are covered by Regulation (EC) 216/2008, whilst four and more wheeled vehicles are covered by Regulation (EC) 661/2009.

The Electromagnetic Compatibility Directives do not contain any provisions specifically relating to ensuring health and safety of people. However, they do contain requirements to limit electromagnetic disturbance so as to prevent interference with other equipment, and for equipment to exhibit a level of immunity to disturbance that will ensure it can operate in its intended environment without unacceptable degradation. These requirements may have implications for safety in relation to some indirect effects.

G.4 European Council Recommendation

In order to protect members of the general public the Council of the European Union passed a Recommendation on limiting exposure of the general public to electromagnetic fields (1999/519/EC). The Recommendation provides a framework to protect members of the general public from the established adverse health effects that may result from exposure to electromagnetic fields. It does not address the protection of workers.

The Council Recommendation is non-binding, but sets out a system of basic restrictions, which are quantities that should not be exceeded and are conceptually equivalent to the ELVs used in the EMF Directive.

As the basic restrictions are mostly set in terms of internal quantities within the body that cannot be readily measured, the Council Recommendation also sets out a system of reference levels set in terms of external field quantities that can be more readily assessed. The reference levels are derived from the basic restrictions using conservative approaches such that provided the reference level is not exceeded, then the underlying basic restriction will not be exceeded. However, as the derivation of the reference levels is based on worst case assumptions, it is often possible to exceed the reference levels and still not exceed the basic restrictions. In this respect the reference levels are conceptually equivalent to the action levels used in the EMF Directive.

In applying the systems of basic restrictions and reference levels, Member States were recommended to consider the risks and benefits of technologies producing electromagnetic fields. Member States were also recommended to provide information to the general public and to promote and review research relevant to the health effects of electromagnetic fields.

The Council Recommendation also invites the European Commission to contribute to the protection of the general public. The commission was invited to work towards the establishment of European Standards to support the system of protection described, to encourage research into long- and short-term effects of exposure, to promote the establishment of international consensus in this area, and to keep the matters covered by the Recommendation under review.

The system of protection described in the Council Recommendation has been widely adopted as a framework for protection of the general public. In particular, the reference levels specified in the Council Recommendation have been used as a basis for managing exposures in many publicly accessible areas. In addition, the reference levels have been used to inform the development of standards for the electromagnetic immunity of active implanted medical devices.

APPENDIX H. EUROPEAN AND INTERNATIONAL STANDARDS

EMF technical standards have been developed by bodies such as the International Electrotechnical Commission (IEC), the European Committee for Electrotechnical Standardization (CENELEC) and other standardisation authorities.

CENELEC has already developed a range of occupational exposure standards relating to EMF assessment. However, these standards were developed to establish compliance in relation to the previous EMF Directive. Hence, standards dated 2013 or earlier should not be used to assess compliance with the current EMF Directive.

However, some existing standards allow for compliance to be assessed against the Council Recommendation (1999/519/EC). Under Article 4(6) of the EMF Directive employers do not need to carry out exposure assessments for workplaces that are open to the public and for which an evaluation shows that it is compliant with the Council Recommendation (1999/519/EC). This clause is conditional on worker exposures respecting those for the public and the absence of health and safety risks.

CENELEC also publish product standards that are harmonised to various product directives (see Section G.3). Lists of standards harmonised to each product directive are published on the enterprise area of the European Commission website. These standards may be used by manufacturers and suppliers to demonstrate compliance with EMF safety requirements. Where equipment is intended for public use and complies with the stricter safety levels required of such equipment, then provided no other equipment is in use, the workplace is deemed to comply with the Council Recommendation (1999/519/EC).

As indicated above, where standards are developed, these will generally fall into one of two types: emission standards and exposure standards.

- emission standards relate to emissions from equipment and provide a means for manufacturers to demonstrate that the field emitted by a product will not exceed a certain limit. The limit will usually be either the EMF Directive ALs or ELVs, or the values in the Council Recommendation (1999/519/EC). Importantly these assessments will be based on use of equipment as intended. If equipment is not used as intended by the manufacturer then the assessment may not be valid.

- exposure assessment standards generally provide a standardised means of assessing exposures in particular industries or for particular types of technology. Workplace assessments should consider how equipment is used and should cover all aspects of work with the equipment including cleaning and maintenance.

In general, emission standards aim to ensure that aggregate exposure to the emission from a device will be sufficiently low that use, even in proximity to other EMF emitting devices, will not cause exposure limits to be exceeded.

It should be noted that these standards relate to assessment of individual items of equipment, whereas the EMF Directive relates to exposure of workers from all sources. It is possible that exposure to more than one source that is just compliant by itself, could result in a combined personal exposure that exceeds an AL or ELV. However, in general fields fall rapidly with distance so that where equipment is widely spaced the resultant fields will normally be compliant.

Work is on-going within CENELEC to develop new technical standards that will be focussed on achieving compliance with the current EMF Directive. These standards will be published as they are agreed, but it is likely to be some time before a comprehensive set of standards is developed. Nevertheless, anyone needing to undertake an assessment should check to see if a standard relevant to the current EMF Directive is available.

Within CENELEC, work on the development of new exposure assessment standards is carried out by Technical Committee CLC/TC106X: electromagnetic fields in the human environment. Progress on the development of new standards can be checked on the TC106X area of the CENELEC website.

APPENDIX I. RESOURCES

I.1 Advisory/Regulatory

I.1.1 European Union

Country	Organisation	Website
Austria	Bundesministerium für Arbeit, Soziales und Konsumentenschutz	www.bmask.gv.at/site
Belgium	Federal Public Service Employment, Labour and Social Dialogue	www.employment.belgium.be
Bulgaria	National Center of Public Health and Analyses	ncphp.government.bg/en
Croatia	Ministry of Labour and Pension System	www.mrms.hr
Cyprus	Ministry of Labour and Social Insurance	www.mlsi.gov.cy
Czech Republic	Ministry of Labour and Social Affairs	www.mpsv.cz/cs
Denmark	Danish Working Environment Authority	www.at.dk
Estonia	Labour Inspectorate of Estonia	www.ti.ee
Finland	Ministry of Social Affairs and Health	www.riskithaltuun.fi
France	Ministère du Travail, de l'Emploi, et du Dialogue social	www.travail.gouv.fr
Germany	Federal Ministry of Labour and Social Affairs	www.bmas.bund.de
Greece	Ministry of Labour and Social Affairs	www.mathra.gr
Hungary	National Research Institute for Radiobiology	www.osski.hu
Ireland	Health and Safety Authority	www.hsa.ie
Italy	National Institute for Insurance against Accidents at Work	www.inail.it
Latvia	State Labour Inspectorate of the Republic of Latvia	www.vdi.gov.lv
Lithuania	Labour Department, Ministry of Social Security and Labour	www.socmin.lt/en
Luxembourg	Inspection du Travail et des Mines	www.itm.lu/de/home.html
Malta	Occupational Health and Safety Authority	www.ohsa.org.mt
Netherlands	National Institute for Public Health and the Environment (RIVM)	www.rivm.nl
Poland	Central Institute for Labour Protection	www.ciop.pl
Portugal	Autoridade para as Condiçôes de Trabalho	www.act.gov.pt
Romania	The National Research and Development Institute on Occupational Safety	www.protectiamuncii.ro
Slovakia	Ministry of Labour, Social Affairs and Family	www.employment.gov.sk/en
Slovenia	Ministry of Labour, Family and Social Affairs	www.gov.si
Spain	National Institute of Safety and Hygiene at Work	www.meyss.es
Sweden	Swedish Work Environment Authority	www.av.se
United Kingdom	Health and Safety Executive Public Health England	www.hse.gov.uk www.gov.uk/government/organisations/public-health-england

I.1.2 International organisations

Organisation	Website
International Commission on Non-Ionizing Radiation Protection	www.icnirp.de
World Health Organisation	www.who.int
European Trade Union Confederation	www.etuc.org
European Public Health Alliance	www.epha.org
The European Agency for Health and Safety at Work	osha.europa.eu
International Commission on Occupational Health	www.icohweb.org

I.2 Trade Associations

Organisation	Website
Council of European Employers of the Metal, Engineering and Technology-Based Industries	www.ceemet.org
European Automobile Manufacturers Association	www.acea.be
Euro Chlor	www.eurochlor.org
European Network of Transmission System Operators for Electricity — ENTSO-E	www.entsoe.eu
European Coordination Committee of the Radiological Electromedical and Healthcare IT Industry (COCIR)	www.cocir.org
Union of the Electricity Industry — EURELECTRIC	www.eurelectric.org

I.3 National Guidance Documents

Country	Documents
Belgium	Ordinance No 7 for the minimal requirements for safety and health at work, State gazette No 88, 1999
Denmark	The executive order no. 559 on 'The Performance of Work' The executive order no. 513 amending the executive order no. 559 on 'The Performance of Work' Ikke-ioniserende stråling, Vejledning om ikke-ioniserende stråling med frekvenser under 300 GHz D.6.1.1, Maj 2002 At-VEJLEDNING, ARBEJDSSTEDETS INDRETNING — A.1.8, Gravide og ammendes arbejdsmiljø
Estonia	Töökeskkonna füüsikaliste ohutegurite piirnormid ja ohutegurite parameetrite mõõtmise kord
Finland	Toimintamalli RF-kenttien aiheuttamissa tapaturmaisissa ylialtistumistilanteissa, Tommi Alanko, Harri Lindholm, Soile Jungewelter, Maria Tiikkaja, Maila Hietanen (2013), ISBN 978-952-261-349- 3 (PDF, FI), ISBN 978-952-261-393-6 (PDF, EN) Sydäntahdistimen häiriötön toiminta työympäristön sähkömagneettisissa kentissä, Maria Tiikkaja, Maila Hietanen, Tommi Alanko, Harri Lindholm (2012), ISBN 978-952-261-212-0 (print) ISBN 978-952-261-213-7 (pdf, FI), ISBN 978-952-261-295-3 (pdf, EN) Turvallinen työskentely tukiasemien lähellä, Tommi Alanko, Maila Hietanen (2006), ISBN (vihko) 951-802-707-2, ISBN (PDF) 951-802-708-0 Sähkömagneettiset kentät työympäristössä — Opaskirja työntekijöiden altistumisen arvioimiseksi, Maila Hietanen, Patrick von Nandelstadh, Tommi Alanko, ISBN 951-802-614-9, ISSN 1458-9311 Työntekijöiden altistuminen tukiasemien radiotaajuisille kentille, Tommi Alanko, Maila Hietanen, Patrick von Nandelstadh (2006), ISBN 951-802-667-X, ISSN 1458-9311 Sydäntahdistinpotilaan työhön paluun tukeminen — Sähkömagneettisten häiriöriskien hallinta, Maria Tiikkaja, Maila Hietanen, Tommi Alanko ja Harri Lindholm (2012), ISBN 978-952-261-204-5 (nid.) ISBN 978-952-261-205-2 (PDF)
France	Hygiène et sécurité du travail no 233 Décembre 2013 (Resistance Welding) INRS, Exposition des travailleurs aux risques dus aux champs électromagnétiques, Guide d'évaluation des risques
Germany	BGV B11, Unfallverhütungsvorschrift, Elektromagnetische Felder BGR B11, Berufsgenossenschaftliche Regel, Elektromagnetische Felder BGI 5011, Beurteilung magnetischer Felder von Widerstandsschweißeinrichtungen BGI/GUV-I 5111, Beeinflussung von Implantaten durch elektromagnetische Felder IFA Report 4/2013, Elektromagnetische Felder an handgeführten Mittelfrequenz-/Inverter-Punktschweißzangen IFA-Report 5/2011, Elektromagnetische Felder an Anlagen, Maschinen und Geräten IFA-Report 2/2009, Electromagnetic fields at handheld spot-welding guns Hannah Heinrich (2007). Assessment of non-sinusoidal, pulsed, or intermittent exposure to low frequency electric and magnetic fields, *Health Physics*, 92, (6) BMAS-Forschungsbericht FB 400-E, Electromagnetic fields at workplace, ISSN 0174-4992

Greece	ΜΕΤΡΗΣΕΙΣ ΣΤΑΤΙΚΟΥ ΜΑΓΝΗΤΙΚΟΥ ΠΕΔΙΟΥ ΣΤΑ ΠΛΑΙΣΙΑ ΤΗΣ ΑΣΦΑΛΕΙΑΣ ΠΡΟΣΩΠΙΚΟΥ ΣΤΟΥΣ ΧΩΡΟΥΣ ΤΟΥ ΠΥΡΗΝΙΚΟΥ ΜΑΓΝΗΤΙΚΟΥ ΣΥΝΤΟΝΙΣΜΟΥ (NMR), 5^{ο} Τακτικό Εθνικό Συνέδριο Μετρολογίας, Εθνικό Ίδρυμα Ερευνών, Αθήνα, 9-10 Μαΐου 2014
Latvia	Atgādne par elektromagnētisko lauku, Aktualizēts 2011.gada jūnijā
Lithuania	Lithuanian Hygiene Norm (HN) 110: 2001 Electromagnetic field of 50 Hz frequency in work places. Permissible values of the parameters and measuring requirements' and labour No 660/174 of 21 December 2001 Lithuanian Hygiene Norm (HN) 80: 2011 Electromagnetic field in working places and living environment. Permissible values of the parameters and measuring requirements in the 10 kHz to 300 GHz radiofrequency zone, approved by the order of minister of health and No V-199 of 2 March 2011 Rules on determining electrostatic field strength permitted levels in working places approved by the order of minister of health and No 28 of 18 January 2001
Luxembourg	Conditions d'exploitation pour les émetteurs d'ondes électromagnétiques à haute fréquence, ITM-CL 179.4
Poland	EU Directive, ICNIRP Guidelines and Polish Legislation on Electromagnetic Fields, *International Journal of Occupational Safety and Ergonomics (JOSE),* 12(2), 125–136 Exposure of Workers to Electromagnetic Fields. A Review of Open Questions on Exposure Assessment Techniques, *International Journal of Occupational Safety and Ergonomics (JOSE)*, 15(1), 3–33
Romania	MONITORUL OFICIAL AL ROMANIEI Anul 175 (XIX) — Nr. 645, Vineri, 21 septembrie 2007

I.4 Industry Guidance Documents

Organisation	Guidance document
Euro Chlor	Electromagnetic Fields in the Chlorine Electrolysis Units: Health Effects, Recommended Limits, Measurement Methods and Possible Prevention Actions. HEALTH 3. 3rd edition, 2014

APPENDIX J. GLOSSARY AND ABBREVIATIONS

J.1 Glossary

Administrative measures	Safety measures of a non-engineering type such as: key control, safety training, and warning notices
Bridge-wire devices	A detonator that uses an electric current to vaporize a wire: the resulting shock and heat leading to the detonation of the surrounding explosive material
Contact Current	The electric current that flows within a person when they touch a conducting object within an electromagnetic field
Current Density	The electric current or flow of electric charge through a conducting medium, such as tissue, per unit cross-sectional area. Unit: ampere per square metre. Symbol: A/m^2
Derogation	The partial revocation of a law or regulation in particular circumstances
Dielectric	An electrical insulator that can be polarised by an applied electric field
Dipole	An aerial consisting of a conducting rod with the connecting wire at its centre
Dosimetry	The calculation or assessment of the deposition of energy within a human body
Electromagnetic Radiation	Electromagnetic radiation is a form of radiation with both electric and magnetic field components, which can be described as waves propagating at the speed of light. Under some circumstances electromagnetic radiation can be considered to exist as particles called photons
Electromagnetic Spectrum	The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. The spectrum ranges from short wavelengths such as x-rays, through visible radiation to longer wavelength radiations of microwaves, television and radio waves
Engineering control	Safety measures of a deliberate engineering design which should be used as the fundamental method of reducing exposure to radiation. A physical means of preventing access to radiation
Exposure index	The observed exposure divided by the limit value. If the exposure index is less than one the exposure is compliant
Fail-Safe	A fail-safe component is one whereby its failure does not increase the hazard i.e. it fails in a safe condition. In the failure mode the system is rendered inoperative or non-hazardous
Frequency	The number of cycles per unit time of an oscillation. Symbol: f Unit: Hz
Hazard	Something with the potential to cause harm. The hazard can be to people, property or the environment
Induction	Induction (electromagnetic) is the production of voltage across an electrical conductor when exposed to a time varying magnetic field
Industrial Electrolysis	A process used on a large scale where an electric current stimulates an otherwise non-spontaneous chemical reaction
Interlock (see Safety Interlock)	A mechanical, electrical or other type of device, the purpose of which is to prevent the operation of equipment under specified conditions
International Commission on Non-Ionising Radiation Protection (ICNIRP)	A body of independent scientific experts that aims to disseminate information and advice on the potential health hazards of exposure to non-ionizing radiation
Joule	The unit of energy, equivalent to work done by a force of one newton moving an object through one metre. Symbol: J
Magnetic particle inspection	A method of detecting cracks and other defects in a magnetic material using magnetic powder and magnetic fields

Magnetic resonance imaging	A medical imaging technique that uses strong magnetic fields and high frequency electromagnetic fields to produce detailed images within the body
Non-Ionising Radiation	Radiation that does not produce ionisation in biological tissue. Examples are ultraviolet radiation, light, infrared radiation and radiofrequency radiation
Orthogonal	At right angles (90 degrees)
Phosphenes	Light flashes experienced by a person without light being incident on their eyes
Power density	Power of radiation incident on a surface unit of area (Wm^2)
Product Standard	Document specifying essential characteristics of a product allowing uniformity of manufacture and interoperability
Radiofrequency Radiation	Electromagnetic radiation often defined as having frequencies between 100 kHz and 300 GHz
Reasonably Foreseeable Event	The occurrence of an event which under given circumstances can be predicted fairly accurately, and the occurrence probability or frequency of which is not low or very low
Risk	The probability of injury, harm or damage
Risk factor	The product of the likelihood of a hazardous event occurring and the outcome or harm that arises as a result
Safety Interlock	A mechanical, electrical or other type of device, the purpose of which is to prevent the operation of equipment under specified conditions
Sinusoidal	Varying in a way that can be represented by the trigonometrical sine function
Technical Standard	Document specifying a standardised approach to a process
Transmission	The passage of radiation through a medium. If not all radiation is absorbed, that which passes through is said to be transmitted. Dependent upon wavelength, polarisation, radiation intensity and transmitting material
Voltage	The unit of electrical potential difference, symbol: V
Walkie-talkie	A hand held two-way communication device that operates in unlicensed radio frequency bands. More formally known as a hand-held transceiver
Watt	The unit of power, equivalent to one joule of energy per second. Symbol: W
Wavelength	The distance between similar points on successive cycles of a wave. Unit metre, symbol: m
Wi-Fi	A system for connecting electronic equipment such as computers to a local area network using radiofrequency communication

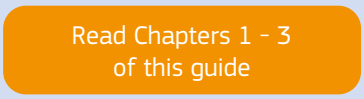
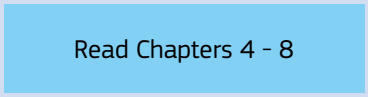
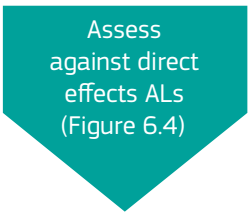
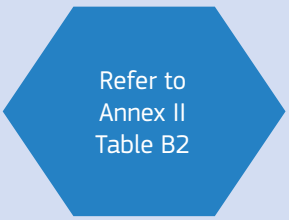
J.2 Abbreviations

AIMD	Active implanted medical device
AL	Action level
AM	Amplitude modulation
BSS	Basic safety standards
CENELEC	European committee for electrotechnical standardization
CNS	Central nervous system
DECT	Digital enhanced cordless telecommunications
DVD	Digital versatile disc
EI	Exposure indices
ELF	Extremely low frequency
ELV	Exposure limit value
EMF	Electromagnetic fields

ERP	Effective radiated power
FD	Finite difference
FDTD	Finite difference in the time domain
FEM	Finite element method
HF	High frequency
ICNIRP	International commission on non-ionizing radiation protection
IR	Infrared
IT	Information technology
LF	Low frequency
MF	Medium frequency
MFR	Multiple frequency rule
MRI	Magnetic resonance imaging
NMR	Nuclear magnetic resonance
OiRA	Online interactive risk assessment
RC	Resistor capacitor
RF	Radiofrequency
RFID	Radiofrequency identification
RMS	Root-mean-square
SA	Specific absorption
SAR	Specific energy absorption rate
SHF	Super high frequency
SPFD	Scalar-potential finite-difference
STD	Shaped time domain
TETRA	Terrestrial trunked radio
TV	Television
UHF	Ultra high frequency
UV	Ultraviolet
VHF	Very high frequency
VLF	Very low frequency
WBSAR	Whole-body averaged SAR
WLAN	Wireless local area network
WPM	Weighted peak method

J.3 Flow Chart Symbols

Table J3 — Flow chart symbols used in the guide

Symbol	Description	Meaning in this guide
	Terminator	Indicates start and finish of procedure
	Decision	Poses a question to guide the user down one of two alternative paths, labelled yes and no
	Process	Indicates the process to be undertaken in order to progress
	Off-page connector	Used to link to another flow chart. These are colour coded to indicate the points of entry and exit.
	Preparation	Identifies to the user that they need to undertake preparatory work for this section of the flow chart. Relates to a colour coded box.

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APPENDIX L.
DIRECTIVE 2013/35/EU

I

(Legislative acts)

DIRECTIVES

DIRECTIVE 2013/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 26 June 2013

on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty on the Functioning of the European Union, and in particular Article 153(2) thereof,

Having regard to the proposal from the European Commission,

After transmission of the draft legislative act to the national parliaments,

Having regard to the opinion of the European Economic and Social Committee [1],

After consulting the Committee of the Regions,

Acting in accordance with the ordinary legislative procedure [2],

Whereas:

(1) Under the Treaty, the European Parliament and the Council may, by means of directives, adopt minimum requirements for the encouragement of improvements, in particular of the working environment, to guarantee a better level of protection of the health and safety of workers. Such directives are to avoid imposing administrative, financial and legal constraints in a way which would hold back the creation and development of small and medium-sized undertakings.

(2) Article 31(1) of the Charter of Fundamental Rights of the European Union provides that every worker has the right to working conditions which respect his or her health, safety and dignity.

(3) Following the entry into force of 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) [3], serious concerns were expressed by stakeholders, in particular those from the medical community, as to the potential impact of the implementation of that Directive on the use of medical procedures based on medical imaging. Concerns were also expressed as to the impact of the Directive on certain industrial activities.

(4) The Commission examined attentively the arguments put forward by stakeholders and, after several consultations, decided to thoroughly reconsider some provisions of Directive 2004/40/EC on the basis of new scientific information produced by internationally recognised experts.

(5) Directive 2004/40/EC was amended by Directive 2008/46/EC of the European Parliament and of the Council [4], with the effect of postponing, by four years, the deadline for the transposition of Directive 2004/40/EC, and subsequently by Directive 2012/11/EU of the European Parliament and of the Council [5], with the effect of postponing that deadline for transposition until 31 October 2013. This was to allow the Commission to present a new proposal, and the co-legislators to adopt a new directive, based on fresher and sounder evidence.

(6) Directive 2004/40/EC should be repealed and more appropriate and proportionate measures to protect workers from the risks associated with electromagnetic fields should be introduced. That Directive did not address the long-term effects, including the possible carcinogenic effects, of exposure to time-varying

[1] OJ C 43, 15.2.2012, p. 47.
[2] Position of the European Parliament of 11 June 2013 (not yet published in the Official Journal) and decision of the Council of 20 June 2013.
[3] OJ L 159, 30.4.2004, p. 1.
[4] OJ L 114, 26.4.2008, p. 88.
[5] OJ L 110, 24.4.2012, p. 1.

electric, magnetic and electromagnetic fields, for which there is currently no conclusive scientific evidence establishing a causal relationship. This Directive is intended to address all known direct biophysical effects and indirect effects caused by electromagnetic fields, in order not only to ensure the health and safety of each worker on an individual basis, but also to create a minimum basis of protection for all workers in the Union, while reducing possible distortions of competition.

(7) This Directive does not address suggested long-term effects of exposure to electromagnetic fields, since there is currently no well-established scientific evidence of a causal relationship. However, if such well-established scientific evidence emerges, the Commission should consider the most appropriate means for addressing such effects, and should, through its report on the practical implementation of this Directive, keep the European Parliament and Council informed in this regard. In doing so, the Commission should, in addition to the appropriate information that it receives from Member States, take into account the latest available research and new scientific knowledge arising from the data in this area.

(8) Minimum requirements should be laid down, thereby giving Member States the option of maintaining or adopting more favourable provisions for the protection of workers, in particular by fixing lower values for the action levels (ALs) or the exposure limit values (ELVs) for electromagnetic fields. However, the implementation of this Directive should not serve to justify any regression in relation to the situation already prevailing in each Member State.

(9) The system of protection against electromagnetic fields should be limited to a definition, which should be free of excessive detail, of the objectives to be attained, the principles to be observed and the fundamental values to be applied, in order to enable Member States to apply the minimum requirements in an equivalent manner.

(10) In order to protect workers exposed to electromagnetic fields it is necessary to carry out an effective and efficient risk assessment. However, this obligation should be proportional to the situation encountered at the workplace. Therefore, it is appropriate to design a protection system that groups different risks in a simple, graduated and easily understandable way. Consequently, the reference to a number of indicators and standard situations, to be provided by practical guides, can usefully assist employers in fulfilling their obligations.

(11) The undesired effects on the human body depend on the frequency of the electromagnetic field or radiation to which it is exposed. Therefore, exposure limitation systems need to be exposure-pattern and frequency dependent in order to adequately protect workers exposed to electromagnetic fields.

(12) The level of exposure to electromagnetic fields can be more effectively reduced by incorporating preventive measures into the design of workstations and by giving priority, when selecting work equipment, procedures and methods, to reducing risks at source. Provisions relating to work equipment and methods thereby contribute to the protection of the workers involved. There is, however, a need to avoid duplication of assessments where work equipment meets the requirements of relevant Union law on products that establishes stricter safety levels than those provided for by this Directive. This allows for simplified assessment in a large number of cases.

(13) Employers should make adjustments in the light of technical progress and scientific knowledge regarding the risks related to exposure to electromagnetic fields, with a view to improving the safety and health protection of workers.

(14) Since this Directive is an individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work [1], it follows that Directive 89/391/EEC applies to the exposure of workers to electromagnetic fields, without prejudice to more stringent and/or specific provisions contained in this Directive.

(15) The physical quantities, ELVs and ALs, laid down in this Directive are based on the recommendations of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and should be considered in accordance with ICNIRP concepts, save where this Directive specifies otherwise.

(16) In order to ensure that this Directive remains up-to-date, the power to adopt acts in accordance with Article 290 of the Treaty on the Functioning of the European Union should be delegated to the Commission in respect of purely technical amendments of the Annexes, to reflect the adoption of regulations and directives in the field of technical harmonisation and standardisation, technical progress, changes in the most relevant standards or specifications and new scientific findings concerning hazards presented by electromagnetic fields, as well as to adjust ALs. It is of particular importance that the Commission carry out appropriate consultations during its preparatory work, including at expert level. The Commission, when preparing and drawing-up delegated acts, should ensure a simultaneous, timely and appropriate transmission of relevant documents to the European Parliament and to the Council.

[1] OJ L 183, 29.6.1989, p. 1.

(17) If amendments of a purely technical nature to the Annexes become necessary, the Commission should work in close cooperation with the Advisory Committee for Safety and Health at Work set up by Council Decision of 22 July 2003 [1].

(18) In exceptional cases, where imperative grounds of urgency so require, such as possible imminent risks to workers' health and safety arising from their exposure to electromagnetic fields, the possibility should be given to apply the urgency procedure to delegated acts adopted by the Commission.

(19) In accordance with the Joint Political Declaration of 28 September 2011 of Member States and the Commission on explanatory documents [2], Member States have undertaken to accompany, in justified cases, the notification of their transposition measures with one or more documents explaining the relationship between the components of a directive and the corresponding parts of national transposition instruments. With regard to this Directive, the legislator considers the transmission of such documents to be justified.

(20) A system including ELVs and ALs, where applicable, should be seen as a means to facilitate the provision of a high level of protection against the adverse health effects and safety risks that may result from exposure to electromagnetic fields. However, such a system may conflict with specific conditions in certain activities, such as the use of the magnetic resonance technique in the medical sector. It is therefore necessary to take those particular conditions into account.

(21) Given the specificities of the armed forces and in order to allow them to operate and interoperate effectively, including in joint international military exercises, Member States should be able to implement equivalent or more specific protection systems, such as internationally agreed standards, for example NATO standards, provided that adverse health effects and safety risks are prevented.

(22) Employers should be required to ensure that risks arising from electromagnetic fields at work are eliminated or reduced to a minimum. It is nevertheless possible that in specific cases and in duly justified circumstances, the ELVs set out in this Directive are only temporarily exceeded. In such a case, employers should be required to take the necessary actions in order to return to compliance with the ELVs as soon as possible.

(23) A system ensuring a high level of protection as regards the adverse health effects and safety risks that may result from exposure to electromagnetic fields should take due account of specific groups of workers at particular risk and avoid interference problems with, or effects on the functioning of, medical devices such as metallic prostheses, cardiac pacemakers and defibrillators, cochlear implants and other implants or medical devices worn on the body. Interference problems, especially with pacemakers, may occur at levels below the ALs and should therefore be the object of appropriate precautions and protective measures,

HAVE ADOPTED THIS DIRECTIVE:

CHAPTER I

GENERAL PROVISIONS

Article 1

Subject-matter and scope

1. This Directive, which is the 20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC, lays down minimum requirements for the protection of workers from risks to their health and safety arising, or likely to arise, from exposure to electromagnetic fields during their work.

2. This Directive covers all known direct biophysical effects and indirect effects caused by electromagnetic fields.

3. The exposure limit values (ELVs) laid down in this Directive cover only scientifically well-established links between short-term direct biophysical effects and exposure to electromagnetic fields.

4. This Directive does not cover suggested long-term effects.

The Commission shall keep under review the latest scientific developments. If well-established scientific evidence on suggested long-term effects becomes available, the Commission shall consider a suitable policy response, including, if appropriate, the submission of a legislative proposal to address such effects. The Commission shall, through its report referred to in Article 15, keep the European Parliament and the Council informed in this regard.

5. This Directive does not cover the risks resulting from contact with live conductors.

6. Without prejudice to the more stringent or more specific provisions in this Directive, Directive 89/391/EEC shall continue to apply in full to the whole area referred to in paragraph 1.

Article 2

Definitions

For the purposes of this Directive, the following definitions shall apply:

(a) 'electromagnetic fields' means static electric, static magnetic and time-varying electric, magnetic and electromagnetic fields with frequencies up to 300 GHz;

[1] OJ C 218, 13.9.2003, p. 1.
[2] OJ C 369, 17.12.2011, p. 14.

(b) 'direct biophysical effects' means effects in the human body directly caused by its presence in an electromagnetic field, including:

(i) thermal effects, such as tissue heating through energy absorption from electromagnetic fields in the tissue;

(ii) non-thermal effects, such as the stimulation of muscles, nerves or sensory organs. These effects might have a detrimental effect on the mental and physical health of exposed workers. Moreover, the stimulation of sensory organs may lead to transient symptoms, such as vertigo or phosphenes. These effects might create temporary annoyance or affect cognition or other brain or muscle functions, and may thereby affect the ability of a worker to work safely (i.e. safety risks); and

(iii) limb currents;

(c) 'indirect effects' means effects, caused by the presence of an object in an electromagnetic field, which may become the cause of a safety or health hazard, such as:

(i) interference with medical electronic equipment and devices, including cardiac pacemakers and other implants or medical devices worn on the body;

(ii) the projectile risk from ferromagnetic objects in static magnetic fields;

(iii) the initiation of electro-explosive devices (detonators);

(iv) fires and explosions resulting from the ignition of flammable materials by sparks caused by induced fields, contact currents or spark discharges; and

(v) contact currents;

(d) 'exposure limit values (ELVs)' means values established on the basis of biophysical and biological considerations, in particular on the basis of scientifically well-established short-term and acute direct effects, i.e. thermal effects and electrical stimulation of tissues;

(e) 'health effects ELVs' means those ELVs above which workers might be subject to adverse health effects, such as thermal heating or stimulation of nerve and muscle tissue;

(f) 'sensory effects ELVs' means those ELVs above which workers might be subject to transient disturbed sensory perceptions and minor changes in brain functions;

(g) 'action levels (ALs)' means operational levels established for the purpose of simplifying the process of demonstrating the compliance with relevant ELVs or, where appropriate, to take relevant protection or prevention measures specified in this Directive.

The AL terminology used in Annex II is as follows:

(i) for electric fields, 'low ALs' and 'high ALs' means levels which relate to the specific protection or prevention measures specified in this Directive; and

(ii) for magnetic fields, 'low ALs' means levels which relate to the sensory effects ELVs and 'high ALs' to the health effects ELVs.

Article 3

Exposure limit values and action levels

1. Physical quantities regarding exposure to electromagnetic fields are indicated in Annex I. Health effects ELVs, sensory effects ELVs and ALs are set out in Annexes II and III.

2. Member States shall require that employers ensure that the exposure of workers to electromagnetic fields is limited to the health effects ELVs and sensory effects ELVs set out in Annex II, for non-thermal effects, and in Annex III, for thermal effects. Compliance with health effects ELVs and sensory effects ELVs must be established by the use of relevant exposure assessment procedures referred to in Article 4. Where the exposure of workers to electromagnetic fields exceeds the ELVs, the employer shall take immediate action in accordance with Article 5(8).

3. For the purpose of this Directive, where it is demonstrated that the relevant ALs set out in Annex II and III are not exceeded, the employer shall be deemed to be in compliance with the health effects ELVs and sensory effects ELVs. Where the exposure exceeds the ALs, the employer shall act in accordance with Article 5(2), unless the assessment carried out in accordance with Article 4(1), (2) and (3) demonstrates that the relevant ELVs are not exceeded and that safety risks can be excluded.

Notwithstanding the first subparagraph, exposure may exceed:

(a) low ALs for electric fields (Annex II, Table B1), where justified by the practice or process, provided that either the sensory effects ELVs (Annex II, Table A3) are not exceeded; or

(i) the health effects ELVs (Annex II, Table A2) are not exceeded;

(ii) the excessive spark discharges and contact currents (Annex II, Table B3) are prevented by specific protection measures as set out in Article 5(6); and

(iii) information on the situations referred to in point (f) of Article 6 has been given to workers;

(b) low ALs for magnetic fields (Annex II, Table B2) where justified by the practice or process, including in the head and torso, during the shift, provided that either the sensory effects ELVs (Annex II, Table A3) are not exceeded; or

(i) the sensory effects ELVs are exceeded only temporarily;

(ii) the health effects ELVs (Annex II, Table A2) are not exceeded;

(iii) action is taken, in accordance with Article 5(9), where there are transient symptoms under point (a) of that paragraph; and

(iv) information on the situations referred to in point (f) of Article 6 has been given to workers.

4. Notwithstanding paragraphs 2 and 3, exposure may exceed:

(a) the sensory effects ELVs (Annex II, Table A1) during the shift, where justified by the practice or process, provided that:

(i) they are exceeded only temporarily;

(ii) the health effects ELVs (Annex II, Table A1) are not exceeded;

(iii) specific protection measures have been taken in accordance with Article 5(7);

(iv) action is taken in accordance with Article 5(9), where there are transient symptoms under point (b) of that paragraph; and

(v) information on the situations referred to in point (f) of Article 6 has been given to workers;

(b) the sensory effects ELVs (Annex II, Table A3 and Annex III, Table A2) during the shift, where justified by the practice or process, provided that:

(i) they are exceeded only temporarily;

(ii) the health effects ELVs (Annex II, Table A2 and Annex III, Table A1 and Table A3) are not exceeded;

(iii) action is taken in accordance with Article 5(9), where there are transient symptoms under point (a) of that paragraph; and

(iv) information on the situations referred to in point (f) of Article 6 has been given to workers.

CHAPTER II

OBLIGATIONS OF EMPLOYERS

Article 4

Assessment of risks and determination of exposure

1. In carrying out the obligations laid down in Articles 6(3) and 9(1) of Directive 89/391/EEC, the employer shall assess all risks for workers arising from electromagnetic fields at the workplace and, if necessary, measure or calculate the levels of electromagnetic fields to which workers are exposed.

Without prejudice to Article 10 of Directive 89/391/EEC and Article 6 of this Directive, that assessment can be made public on request in accordance with relevant Union and national laws. In particular, in the case of processing the personal data of employees in the course of such an assessment, any publication shall comply with Directive 95/46/EC of the European Parliament and of the Council of 24 October 1995 on the protection of individuals with regard to the processing of personal data and on the free movement of such data [1] and the national laws of the Member States implementing that Directive. Unless there is an overriding public interest in disclosure, public authorities that are in possession of a copy of the assessment may refuse a request for access to it or a request to make it public, where disclosure would undermine the protection of commercial interests of the employer, including those relating to intellectual property. Employers may refuse to disclose or make public the assessment under the same conditions in accordance with the relevant Union and national laws.

2. For the purpose of the assessment provided for in paragraph 1 of this Article the employer shall identify and assess electromagnetic fields at the workplace, taking into account the relevant practical guides referred to in Article 14 and other relevant standards or guidelines provided by the Member State concerned, including exposure databases. Notwithstanding the employer's obligations under this Article, the employer shall also be entitled, where relevant, to take into account the emission levels and other appropriate safety-related data provided, by the manufacturer or distributor, for the equipment, in accordance with relevant Union law, including an assessment of risks, if applicable to the exposure conditions at the workplace or place of installation.

3. If compliance with the ELVs cannot be reliably determined on the basis of readily accessible information, the assessment of the exposure shall be carried out on the basis of measurements or calculations. In such a case, the assessment shall take into account uncertainties concerning the measurements or calculations, such as numerical errors, source modelling, phantom geometry and the electrical properties of tissues and materials, determined in accordance with relevant good practice.

[1] OJ L 281, 23.11.1995, p. 31.

4. The assessment, measurement and calculations referred to in paragraphs 1, 2 and 3 of this Article shall be planned and carried out by competent services or persons at suitable intervals, taking into account the guidance given under this Directive and taking particular account of Articles 7 and 11 of Directive 89/391/EEC concerning the necessary competent services or persons and the consultation and participation of workers. The data obtained from the assessment, measurement or calculation of the level of exposure shall be preserved in a suitable traceable form so as to permit consultation at a later stage, in accordance with national law and practice.

5. When carrying out the risk assessment pursuant to Article 6(3) of Directive 89/391/EEC, the employer shall give particular attention to the following:

(a) the health effects ELVs, the sensory effects ELVs and the ALs referred to in Article 3 and Annexes II and III to this Directive;

(b) the frequency, the level, duration and type of exposure, including the distribution over the worker's body and over the volume of the workplace;

(c) any direct biophysical effects;

(d) any effects on the health and safety of workers at particular risk, in particular workers who wear active or passive implanted medical devices, such as cardiac pacemakers, workers with medical devices worn on the body, such as insulin pumps, and pregnant workers;

(e) any indirect effects;

(f) the existence of replacement equipment designed to reduce the level of exposure to electromagnetic fields;

(g) appropriate information obtained from the health surveillance referred to in Article 8;

(h) information provided by the manufacturer of equipment;

(i) other relevant health and safety related information;

(j) multiple sources of exposure;

(k) simultaneous exposure to multiple frequency fields.

6. In workplaces open to the public it is not necessary for the exposure assessment to be carried out if an evaluation has already been undertaken in accordance with the provisions on the limitation of exposure of the general public to electromagnetic fields, if the restrictions specified in those provisions are respected for workers and if the health and safety risks are excluded. Where equipment intended for the public use is used as intended and complies with Union law on products that establishes stricter safety levels than those provided for by this Directive, and no other equipment is used, these conditions are deemed to be met.

7. The employer shall be in possession of an assessment of the risks in accordance with Article 9(1)(a) of Directive 89/391/EEC and shall identify which measures must be taken in accordance with Article 5 of this Directive. The risk assessment may include the reasons why the employer considers that the nature and the extent of the risks related to electromagnetic fields make a further detailed risk assessment unnecessary. The risk assessment shall be updated on a regular basis, particularly if there have been significant changes which could render it out of date, or if the results of the health surveillance referred to in Article 8 show this to be necessary.

Article 5

Provisions aimed at avoiding or reducing risks

1. Taking account of technical progress and the availability of measures to control the production of electromagnetic fields at the source, the employer shall take the necessary actions to ensure that risks arising from electromagnetic fields at the workplace are eliminated or reduced to a minimum.

The reduction of risks arising from exposure to electromagnetic fields shall be based on the general principles of prevention set out in Article 6(2) of Directive 89/391/EEC.

2. On the basis of the risk assessment referred to in Article 4, once the relevant ALs, referred to in Article 3 and in Annexes II and III, are exceeded and unless the assessment carried out in accordance with Article 4(1), (2) and (3) demonstrates that the relevant ELVs are not exceeded and that safety risks can be excluded, the employer shall devise and implement an action plan that shall include technical and/or organisational measures to prevent exposure exceeding the health effects ELVs and sensory effects ELVs, taking into account, in particular:

(a) other working methods that entail less exposure to electromagnetic fields;

(b) the choice of equipment emitting less intense electromagnetic fields, taking account of the work to be done;

(c) technical measures to reduce the emission of electromagnetic fields, including, where necessary, the use of interlocks, shielding or similar health protection mechanisms;

(d) appropriate delimitation and access measures, such as signals, labels, floor markings, barriers, in order to limit or control access;

(e) in the case of exposure to electric fields, measures and procedures to manage spark discharges and contact currents through technical means and through the training of workers;

(f) appropriate maintenance programmes for work equipment, workplaces and workstation systems;

(g) the design and layout of workplaces and workstations;

(h) limitations of the duration and intensity of the exposure; and

(i) the availability of adequate personal protection equipment.

3. On the basis of the risk assessment referred to in Article 4, the employer shall devise and implement an action plan that shall include technical and/or organisational measures to prevent any risks to workers at particular risk, and any risks due to indirect effects, referred to in Article 4.

4. In addition to providing the information set out in Article 6 of this Directive, the employer shall, pursuant to Article 15 of Directive 89/391/EEC, adapt the measures referred to in this Article to the requirements of workers at particular risk and, where applicable, to individual risks assessments, in particular in respect of workers who have declared the use of active or passive implanted medical devices, such as cardiac pacemakers, or the use of medical devices worn on the body, such as insulin pumps, or in respect of pregnant workers who have informed their employer of their condition.

5. On the basis of the risk assessment referred to in Article 4, workplaces where workers are likely to be exposed to electromagnetic fields that exceed the ALs shall be indicated by appropriate signs in accordance with Annexes II and III and with Council Directive 92/58/EEC of 24 June 1992 on the minimum requirements for the provision of safety and/or health signs at work (ninth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) ([1]). The areas in question shall be identified and access to them limited, as appropriate. Where access to these areas is suitably restricted for other reasons and workers are informed of the risks arising from electromagnetic fields, signs and access restrictions specific to electromagnetic fields shall not be required.

6. Where Article 3(3)(a) applies, specific protection measures shall be taken, such as the training of workers in accordance with Article 6 and the use of technical means and personal protection, for example the grounding of work objects, the bonding of workers with work objects (equipotential bonding) and, where appropriate and in accordance with Article 4(1)(a) of Council Directive 89/656/EEC of 30 November 1989 on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace (third individual directive within the meaning of Article 16(1) of Directive 89/391/EEC) ([2]), the use of insulating shoes, gloves and protective clothing.

7. Where Article 3(4)(a) applies, specific protection measures, such as controlling movements, shall be taken.

8. Workers shall not be exposed above the health effects ELVs and sensory effects ELVs, unless the conditions under either Article 10(1)(a) or (c) or Articles 3(3) or (4) are fulfilled. If, despite the measures taken by the employer, the health effects ELVs and sensory effects ELVs are exceeded, the employer shall take immediate action to reduce exposure below these ELVs. The employer shall identify and record the reasons why the health effects ELVs and sensory effects ELVs have been exceeded, and shall amend the protection and prevention measures accordingly in order to prevent them being exceeded again. The amended protection and prevention measures shall be preserved in a suitable traceable form so as to permit consultation at a later stage, in accordance with national law and practice.

9. Where paragraphs 3 and 4 of Article 3 apply and where the worker reports transient symptoms, the employer shall, if necessary, update the risk assessment and the prevention measures. Transient symptoms may include:

(a) sensory perceptions and effects in the functioning of the central nervous system in the head evoked by time varying magnetic fields; and

(b) static magnetic field effects, such as vertigo and nausea.

Article 6

Worker information and training

Without prejudice to Articles 10 and 12 of Directive 89/391/EEC, the employer shall ensure that workers who are likely to be exposed to risks from electromagnetic fields at work and/or their representatives receive any necessary information and training relating to the outcome of the risk assessment provided for in Article 4 of this Directive, concerning in particular:

(a) measures taken in application of this Directive;

(b) the values and concepts of the ELVs and ALs, the associated possible risks and the preventive measures taken;

(c) the possible indirect effects of exposure;

(d) the results of the assessment, measurement or calculations of the levels of exposure to electromagnetic fields, carried out in accordance with Article 4 of this Directive;

(e) how to detect adverse health effects of exposure and how to report them;

(f) the possibility of transient symptoms and sensations related to effects in the central or peripheral nervous system;

([1]) OJ L 245, 26.8.1992, p. 23.
([2]) OJ L 393, 30.12.1989, p. 18.

(g) the circumstances in which workers are entitled to health surveillance;

(h) safe working practices to minimise risks resulting from exposure;

(i) workers at particular risk, as referred to in Article 4(5)(d) and Article 5(3) and (4) of this Directive.

Article 7

Consultation and participation of workers

Consultation and participation of workers and/or their representatives shall take place in accordance with Article 11 of Directive 89/391/EEC.

CHAPTER III

MISCELLANEOUS PROVISIONS

Article 8

Health surveillance

1. With the objective of the prevention and the early diagnosis of any adverse health effects due to exposure to electromagnetic fields, appropriate health surveillance shall be carried out in accordance with Article 14 of Directive 89/391/EEC. Health records and their availability shall be provided for in accordance with national law and/or practice.

2. In accordance with national law and practice, the results of health surveillance shall be preserved in a suitable form that allows them to be consulted at a later date, subject to compliance with confidentiality requirements. Individual workers shall, at their request, have access to their own personal health records.

If any undesired or unexpected health effect is reported by a worker, or in any event where exposure above the ELVs is detected, the employer shall ensure that appropriate medical examinations or individual health surveillance is provided to the worker(s) concerned, in accordance with national law and practice.

Such examinations or surveillance shall be made available during hours chosen by the worker, and any costs arising shall not be borne by the worker.

Article 9

Penalties

Member States shall provide for adequate penalties applicable in the event of infringements of national legislation adopted pursuant to this Directive. These penalties must be effective, proportionate and dissuasive.

Article 10

Derogations

1. By way of derogation from Article 3 but without prejudice to Article 5(1), the following shall apply:

(a) exposure may exceed the ELVs if the exposure is related to the installation, testing, use, development, maintenance of or research related to magnetic resonance imaging (MRI) equipment for patients in the health sector, provided that all the following conditions are met:

(i) the risk assessment carried out in accordance with Article 4 has demonstrated that the ELVs are exceeded;

(ii) given the state of the art, all technical and/or organisational measures have been applied;

(iii) the circumstances duly justify exceeding the ELVs;

(iv) the characteristics of the workplace, work equipment, or work practices have been taken into account; and

(v) the employer demonstrates that workers are still protected against adverse health effects and against safety risks, including by ensuring that the instructions for safe use provided by the manufacturer in accordance with Council Directive 93/42/EEC of 14 June 1993 concerning medical devices [1] are followed;

(b) Member States may allow for an equivalent or more specific protection system to be implemented for personnel working in operational military installations or involved in military activities, including in joint international military exercises, provided that adverse health effects and safety risks are prevented;

(c) Member States may allow, in duly justified circumstances and only for as long as they remain duly justified, for the ELVs to be temporarily exceeded in specific sectors or for specific activities outside the scope of points (a) and (b). For the purposes of this point, 'duly justified circumstances' shall mean circumstances in which the following conditions are met:

(i) the risk assessment carried out in accordance with Article 4 has shown that the ELVs are exceeded;

(ii) given the state of the art, all technical and/or organisational measures have been applied;

(iii) the specific characteristics of the workplace, work equipment, or work practices have been taken into account; and

(iv) the employer demonstrates that workers are still protected against adverse health effects and safety risks, including using comparable, more specific and internationally recognised standards and guidelines.

[1] OJ L 169, 12.7.1993, p. 1.

2. Member States shall inform the Commission of any derogation under points (b) and (c) of paragraph 1 and shall state the reasons that justify them in the report referred to in Article 15.

Article 11

Technical amendments of the Annexes

1. The Commission shall be empowered to adopt delegated acts in accordance with Article 12 amending, in a purely technical way, the Annexes, so as to:

(a) take into account the adoption of regulations and directives in the field of technical harmonisation and standardisation with regard to the design, building, manufacture or construction of work equipment or workplaces;

(b) take into account technical progress, changes in the most relevant standards or specifications, and new scientific findings concerning electromagnetic fields;

(c) make adjustments to the ALs where there is new scientific evidence, provided that employers continue to be bound by the existing ELVs set out in Annexes II and III.

2. The Commission shall adopt a delegated act, in accordance with Article 12, to insert into Annex II the ICNIRP guidelines for limiting exposure to electric fields induced by movement of the human body in a static magnetic field and by time-varying magnetic fields below 1 Hz as soon as they are available.

3. Where, in the case of the amendments referred to in paragraphs 1 and 2, imperative grounds of urgency so require, the procedure provided for in Article 13 shall apply to delegated acts adopted pursuant to this Article.

Article 12

Exercise of the delegation

1. The power to adopt delegated acts is conferred on the Commission subject to the conditions laid down in this Article.

2. The power to adopt delegated acts referred to in Article 11 shall be conferred on the Commission for a period of five years from 29 June 2013. The Commission shall draw up a report in respect of the delegation of power not later than nine months before the end of the five-year period. The delegation of power shall be tacitly extended for periods of an identical duration, unless the European Parliament or the Council opposes such extension not later than three months before the end of each period.

3. The delegation of powers referred to in Article 11 may be revoked at any time by the European Parliament or by the Council. A decision to revoke shall put an end to the delegation of the power specified in that decision. It shall take effect the day following the publication of the decision in the *Official Journal of the European Union* or at a later date specified therein. It shall not affect the validity of any delegated acts already in force.

4. As soon as it adopts a delegated act, the Commission shall notify it simultaneously to the European Parliament and to the Council.

5. A delegated act adopted pursuant to Article 11 shall enter into force only if no objection has been expressed either by the European Parliament or the Council within a period of two months of notification of that act to the European Parliament and the Council or if, before the expiry of that period, the European Parliament and the Council have both informed the Commission that they will not object. That period shall be extended by two months at the initiative of the European Parliament or of the Council.

Article 13

Urgency procedure

1. Delegated acts adopted under this Article shall enter into force without delay and shall apply as long as no objection is expressed in accordance with paragraph 2. The notification of a delegated act to the European Parliament and to the Council shall state the reasons for the use of the urgency procedure which shall relate to the health and protection of workers.

2. Either the European Parliament or the Council may object to a delegated act in accordance with the procedure referred to in Article 12(5). In such a case, the Commission shall repeal the act without delay following the notification of the decision to object by the European Parliament or by the Council.

CHAPTER IV

FINAL PROVISIONS

Article 14

Practical guides

In order to facilitate the implementation of this Directive the Commission shall make available non-binding practical guides at the latest six months before 1 July 2016. Those practical guides shall, in particular relate to the following issues:

(a) the determination of exposure, taking into account appropriate European or international standards, including:

— calculation methods for the assessment of the ELVs,

— spatial averaging of external electric and magnetic fields,

— guidance for dealing with measurements and calculations uncertainties;

(b) guidance on demonstrating compliance in special types of non-uniform exposure in specific situations, based on well-established dosimetry;

(c) the description of the 'weighted peak method' for the low frequency fields and of the 'multifrequency fields summation' for high frequency fields;

(d) the conduct of the risk assessment and, wherever possible, the provision of simplified techniques, taking into account in particular the needs of SMEs;

(e) measures aimed at avoiding or reducing risks, including specific prevention measures depending on the level of exposure and the workplace characteristics;

(f) the establishment of documented working procedures, as well as specific information and training measures for workers exposed to electromagnetic fields during MRI-related activities falling under Article 10(1)(a);

(g) the evaluation of exposures in the frequency range from 100 kHz to 10 MHz, where both thermal and non-thermal effects are to be considered;

(h) the guidance on medical examinations and health surveillance to be provided by the employer in accordance with Article 8(2).

The Commission shall work in close cooperation with the Advisory Committee for Safety and Health at Work. The European Parliament shall be kept informed.

Article 15

Review and reporting

Taking into account Article 1(4), the report on the practical implementation of this Directive shall be established in accordance with Article 17a of Directive 89/391/EEC.

Article 16

Transposition

1. Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 1 July 2016.

When Member States adopt those provisions, they shall contain a reference to this Directive or be accompanied by such a reference on the occasion of their official publication. Member States shall determine how such a reference is to be made.

2. Member States shall communicate to the Commission the text of the main provisions of national law which they adopt in the field covered by this Directive.

Article 17

Repeal

1. Directive 2004/40/EC is repealed from 29 June 2013.

2. References to the repealed Directive shall be construed as references to this Directive and shall be read in accordance with the correlation table set out in Annex IV.

Article 18

Entry into force

This Directive shall enter into force on the day of its publication in the *Official Journal of the European Union*.

Article 19

Addressees

This Directive is addressed to the Member States.

Done at Brussels, 26 June 2013.

For the European Parliament	*For the Council*
The President	*The President*
M. SCHULZ	A. SHATTER

ANNEX I

PHYSICAL QUANTITIES REGARDING THE EXPOSURE TO ELECTROMAGNETIC FIELDS

The following physical quantities are used to describe the exposure to electromagnetic fields:

Electric field strength (E) is a vector quantity that corresponds to the force exerted on a charged particle regardless of its motion in space. It is expressed in volt per metre (Vm^{-1}). A distinction has to be made between the environmental electric field and the electric field present in the body (in situ) as a result of exposure to the environmental electric field.

Limb current (I_L) is the current in the limbs of a person exposed to electromagnetic fields in the frequency range from 10 MHz to 110 MHz as a result of contact with an object in an electromagnetic field or the flow of capacitive currents induced in the exposed body. It is expressed in ampere (A).

Contact current (I_C) is a current that appears when a person comes into contact with an object in an electromagnetic field. It is expressed in ampere (A). A steady state contact current occurs when a person is in continuous contact with an object in an electromagnetic field. In the process of making such contact, a spark discharge may occur with associated transient currents.

Electric charge (Q) is an appropriate quantity used for spark discharge and is expressed in coulomb (C).

Magnetic field strength (H) is a vector quantity that, together with the magnetic flux density, specifies a magnetic field at any point in space. It is expressed in ampere per metre (Am^{-1}).

Magnetic flux density (B) is a vector quantity resulting in a force that acts on moving charges, expressed in tesla (T). In free space and in biological materials, magnetic flux density and magnetic field strength can be interchanged using the magnetic field strength of H = 1 Am^{-1} equivalence to magnetic flux density of B = $4\pi\ 10^{-7}$ T (approximately 1,25 microtesla).

Power density (S) is an appropriate quantity used for very high frequencies, where the depth of penetration in the body is low. It is the radiant power incident perpendicular to a surface, divided by the area of the surface. It is expressed in watt per square metre (Wm^{-2}).

Specific energy absorption (SA) is an energy absorbed per unit mass of biological tissue, expressed in joule per kilogram (Jkg^{-1}). In this Directive, it is used for establishing limits for effects from pulsed microwave radiation.

Specific energy absorption rate (SAR), averaged over the whole body or over parts of the body, is the rate at which energy is absorbed per unit mass of body tissue and is expressed in watt per kilogram (Wkg^{-1}). Whole-body SAR is a widely accepted quantity for relating adverse thermal effects to radio frequency (RF) exposure. Besides the whole-body average SAR, local SAR values are necessary to evaluate and limit excessive energy deposition in small parts of the body resulting from special exposure conditions. Examples of such conditions include: an individual exposed to RF in the low MHz range (e.g. from dielectric heaters) and individuals exposed in the near field of an antenna.

Of these quantities, magnetic flux density (B), contact current (I_C), limb current (I_L), electric field strength (E), magnetic field strength (H), and power density (S) can be measured directly.

ANNEX II

NON-THERMAL EFFECTS

EXPOSURE LIMIT VALUES AND ACTION LEVELS IN THE FREQUENCY RANGE FROM 0 Hz TO 10 MHz

A. EXPOSURE LIMIT VALUES (ELVs)

ELVs below 1 Hz (Table A1) are limits for static magnetic field which is not affected by the tissue of the body.

ELVs for frequencies from 1 Hz to 10 MHz (Table A2) are limits for electric fields induced in the body from exposure to time-varying electric and magnetic fields.

ELVs for external magnetic flux density from 0 to 1 Hz

The sensory effects ELV is the ELV for normal working conditions (Table A1) and is related to vertigo and other physiological effects related to disturbance of the human balance organ resulting mainly from moving in a static magnetic field

The health effects ELV for controlled working conditions (Table A1) is applicable on a temporary basis during the shift when justified by the practice or process, provided that preventive measures, such as controlling movements and providing information to workers, have been adopted.

Table A1

ELVs for external magnetic flux density (B_0) from 0 to 1 Hz

	Sensory effects ELVs
Normal working conditions	2 T
Localised limbs exposure	8 T
	Health effects ELVs
Controlled working conditions	8 T

Health effects ELVs for internal electric field strength from 1 Hz to 10 MHz

Health effects ELVs (Table A2) are related to electric stimulation of all peripheral and central nervous system tissues in the body, including the head.

Table A2

Health effects ELVs for internal electric field strength from 1 Hz to 10 MHz

Frequency range	Health effects ELVs
1 Hz ≤ f < 3 kHz	1,1 Vm^{-1} (peak)
3 kHz ≤ f ≤ 10 MHz	$3{,}8 \times 10^{-4}$ f Vm^{-1} (peak)

Note A2-1: f is the frequency expressed in hertz (Hz).

Note A2-2: The health effects ELVs for internal electric field are spatial peak values in the entire body of the exposed subject.

Note A2-3: The ELVs are peak values in time which are equal to the Root-Mean-Square (RMS) values multiplied by √2 for sinusoidal fields. In the case of non-sinusoidal fields, exposure evaluation carried out in accordance with Article 4 shall be based on the weighted peak method (filtering in time domain), explained in the practical guides referred to in Article 14 but other scientifically proven and validated exposure evaluation procedures can be applied, provided that they lead to approximately equivalent and comparable results.

Sensory effects ELVs for internal electric field strength from 1 Hz to 400 Hz

The sensory effects ELVs (Table A3) are related to electric field effects on the central nervous system in the head, i.e. retinal phosphenes and minor transient changes in some brain functions.

Table A3

Sensory effects ELVs for internal electric field strength from 1 to 400 Hz

Frequency range	Sensory effects ELVs
$1 \leq f < 10$ Hz	$0{,}7/f$ Vm^{-1} (peak)
$10 \leq f < 25$ Hz	$0{,}07$ Vm^{-1} (peak)
$25 \leq f \leq 400$ Hz	$0{,}0028\ f$ Vm^{-1} (peak)

Note A3-1: f is the frequency expressed in hertz (Hz).

Note A3-2: The sensory effects ELVs for internal electric field are spatial peak values in the head of the exposed subject.

Note A3-3: The ELVs are peak values in time which are equal to the Root-Mean-Square (RMS) values multiplied by $\sqrt{2}$ for sinusoidal fields. In the case of non-sinusoidal fields, the exposure evaluation carried out in accordance with Article 4 shall be based on the weighted peak method (filtering in time domain), explained in the practical guides referred to in Article 14, but other scientifically proven and validated exposure evaluation procedures can be applied, provided that they lead to approximately equivalent and comparable results.

B. ACTION LEVELS (ALs)

The following physical quantities and values are used to specify the action levels (ALs), the magnitude of which are established to ensure by simplified assessment the compliance with relevant ELVs or at which relevant protection or prevention measures specified in Article 5 must be taken:

— Low ALs(E) and high ALs(E) for electric field strength E of time varying electric fields as specified in Table B1;

— Low ALs(B) and high ALs(B) for magnetic flux density B of time varying magnetic fields as specified in Table B2;

— ALs(I_C) for contact current as specified in Table B3;

— ALs(B_0) for magnetic flux density of static magnetic fields as specified in Table B4.

ALs correspond to calculated or measured electric and magnetic field values at the workplace in the absence of the worker.

Action levels (ALs) for exposure to electric fields

Low ALs (Table B1) for external electric field are based on limiting the internal electric field below the ELVs (Tables A2 and A3) and limiting spark discharges in the working environment.

Below high ALs, the internal electric field does not exceed the ELVs (Tables A2 and A3) and annoying spark discharges are prevented, provided that the protection measures referred to in Article 5(6) are taken.

Table B1

ALs for exposure to electric fields from 1 Hz to 10 MHz

Frequency range	Electric field strength Low ALs (E)[Vm^{-1}] (RMS)	Electric field strength High ALs (E) [Vm^{-1}] (RMS)
$1 \leq f < 25$ Hz	$2{,}0 \times 10^4$	$2{,}0 \times 10^4$
$25 \leq f < 50$ Hz	$5{,}0 \times 10^5/f$	$2{,}0 \times 10^4$
50 Hz $\leq f <$ 1,64 kHz	$5{,}0 \times 10^5/f$	$1{,}0 \times 10^6/f$

Frequency range	Electric field strength Low ALs (E)[Vm^{-1}] (RMS)	Electric field strength High ALs (E) [Vm^{-1}] (RMS)
1,64 ≤ f < 3 kHz	$5{,}0 \times 10^5/f$	$6{,}1 \times 10^2$
3 kHz ≤ f ≤ 10 MHz	$1{,}7 \times 10^2$	$6{,}1 \times 10^2$

Note B1-1: f is the frequency expressed in hertz (Hz).

Note B1-2: The low ALs (E) and high ALs (E) are the Root-Mean-Square (RMS) values of the electric field strength which are equal to the peak values divided by √2 for sinusoidal fields. In the case of non-sinusoidal fields, the exposure evaluation carried out in accordance with Article 4 shall be based on the weighted peak method (filtering in time domain), explained in the practical guides referred to in Article 14, but other scientifically proven and validated exposure evaluation procedures can be applied, provided that they lead to approximately equivalent and comparable results.

Note B1-3: ALs represent maximum calculated or measured values at the workers' body position. This results in a conservative exposure assessment and automatic compliance with ELVs in all non-uniform exposure conditions. In order to simplify the assessment of compliance with ELVs, carried out in accordance with Article 4, in specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14. In the case of a very localised source within a distance of a few centimetres from the body, the induced electric field shall be determined dosimetrically, case by case.

Action levels (ALs) for exposure to magnetic fields

Low ALs (Table B2) are, for frequencies below 400 Hz, derived from the sensory effects ELVs (Table A3) and, for frequencies above 400 Hz, from the health effects ELVs for internal electric field (Table A2).

High ALs (Table B2) are derived from the health effects ELVs for internal electric field related to electric stimulation of peripheral and autonomous nerve tissues in head and trunk (Table A2). Compliance with the high ALs ensures that health effects ELVs are not exceeded, but the effects related to retinal phosphenes and minor transient changes in brain activity are possible, if the exposure of the head exceeds the low ALs for exposures up to 400 Hz. In such a case, Article 5(6) applies.

ALs for exposure of limbs are derived from the health effects ELVs for internal electric field related to electric stimulation of the tissues in limbs by taking into account that the magnetic field is coupled more weakly to the limbs than to the whole body.

Table B2

ALs for exposure to magnetic fields from 1 Hz to 10 MHz

Frequency range	Magnetic flux density Low ALs(B)[μT] (RMS)	Magnetic flux density High ALs(B) [μT] (RMS)	Magnetic flux density ALs for exposure of limbs to a localised magnetic field [μT] (RMS)
1 ≤ f < 8 Hz	$2{,}0 \times 10^5/f^2$	$3{,}0 \times 10^5/f$	$9{,}0 \times 10^5/f$
8 ≤ f < 25 Hz	$2{,}5 \times 10^4/f$	$3{,}0 \times 10^5/f$	$9{,}0 \times 10^5/f$
25 ≤ f < 300 Hz	$1{,}0 \times 10^3$	$3{,}0 \times 10^5/f$	$9{,}0 \times 10^5/f$
300 Hz ≤ f < 3 kHz	$3{,}0 \times 10^5/f$	$3{,}0 \times 10^5/f$	$9{,}0 \times 10^5/f$
3 kHz ≤ f ≤ 10 MHz	$1{,}0 \times 10^2$	$1{,}0 \times 10^2$	$3{,}0 \times 10^2$

Note B2-1: f is the frequency expressed in hertz (Hz).

Note B2-2: The low ALs and the high ALs are the Root-Mean-Square (RMS) values which are equal to the peak values divided by √2 for sinusoidal fields. In the case of non-sinusoidal fields the exposure evaluation carried out in accordance with Article 4 shall be based on the weighted peak method (filtering in time domain), explained in practical guides referred to in Article 14, but other scientifically proven and validated exposure evaluation procedures can be applied, provided that they lead to approximately equivalent and comparable results.

Note B2-3: ALs for exposure to magnetic fields represent maximum values at the workers' body position. This results in a conservative exposure assessment and automatic compliance with ELVs in all non-uniform exposure conditions. In order to simplify the assessment of compliance with ELVs, carried out in accordance with Article 4, in specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14. In the case of a very localised source within a distance of a few centimetres from the body, the induced electric field shall be determined dosimetrically, case by case.

Table B3

ALs for contact current I_C

Frequency	ALs (I_C) steady state contact current [mA] (RMS)
up to 2,5 kHz	1,0
2,5 ≤ f < 100 kHz	0,4 f
100 ≤ f ≤ 10 000 kHz	40

Note B3-1: f is the frequency expressed in kilohertz (kHz).

Action levels (ALs) for magnetic flux density of static magnetic fields

Table B4

ALs for magnetic flux density of static magnetic fields

Hazards	ALs(B_0)
Interference with active implanted devices, e.g. cardiac pacemakers	0,5 mT
Attraction and projectile risk in the fringe field of high field strength sources (> 100 mT)	3 mT

ANNEX III

THERMAL EFFECTS

EXPOSURE LIMIT VALUES AND ACTION LEVELS IN THE FREQUENCY RANGE FROM 100 kHz TO 300 GHz

A. EXPOSURE LIMIT VALUES (ELVs)

Health effects ELVs for frequencies from 100 kHz to 6 GHz (Table A1) are limits for energy and power absorbed per unit mass of body tissue generated from exposure to electric and magnetic fields.

Sensory effects ELVs for frequencies from 0,3 to 6 GHz (Table A2) are limits on absorbed energy in a small mass of tissue in the head from exposure to electromagnetic fields.

Health effects ELVs for frequencies above 6 GHz (Table A3) are limits for power density of an electromagnetic wave incident on the body surface.

Table A1

Health effects ELVs for exposure to electromagnetic fields from 100 kHz to 6 GHz

Health effects ELVs	SAR values averaged over any six-minute period
ELVs related to whole body heat stress expressed as averaged SAR in the body	0,4 Wkg^{-1}
ELVs related to localised heat stress in head and trunk expressed as localised SAR in the body	10 Wkg^{-1}
ELVs related to localised heat stress in the limbs expressed as localised SAR in the limbs	20 Wkg^{-1}

Note A1-1: Localised SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for estimating exposure. This 10 g of tissue is intended to be a mass of contiguous tissue with roughly homogeneous electrical properties. In specifying a contiguous mass of tissue, it is recognised that this concept may be used in computational dosimetry but may present difficulties for direct physical measurements. A simple geometry, such as cubic or spheric tissue mass, can be used.

Sensory effects ELVs from 0,3 GHz to 6 GHz

This sensory effects ELVs (Table A2) is related to avoiding auditory effects caused by exposures of the head to pulsed microwave radiation.

Table A2

Sensory effects ELVs for exposure to electromagnetic fields from 0,3 to 6 GHz

Frequency range	Localised specific energy absorption (SA)
$0,3 \leq f \leq 6$ GHz	10 $mJkg^{-1}$

Note A2-1: Localised SA averaging mass is 10 g of tissue.

Table A3

Health effects ELVs for exposure to electromagnetic fields from 6 to 300 GHz

Frequency range	Health effects ELVs related to power density
$6 \leq f \leq 300$ GHz	50 Wm^{-2}

Note A3-1: The power density shall be averaged over any 20 cm^2 of exposed area. Spatial maximum power densities averaged over 1 cm^2 should not exceed 20 times the value of 50 Wm^{-2}. Power densities from 6 to 10 GHz are to be averaged over any six-minute period. Above 10 GHz, the power density shall be averaged over any $68/f^{1,05}$-minute period (where f is the frequency in GHz) to compensate for progressively shorter penetration depth, as the frequency increases.

B. ACTION LEVELS (ALs)

The following physical quantities and values are used to specify the action levels (ALs), the magnitude of which are established to ensure by simplified assessment the compliance with the relevant ELVs or at which relevant protection or prevention measures specified in Article 5 must be taken:

— ALs(E) for electric field strength E of time varying electric field, as specified in Table B1;

— ALs(B) for magnetic flux density B of time varying magnetic field, as specified in Table B1;

— ALs(S) for power density of electromagnetic waves, as specified in Table B1;

— ALs(I_C) for contact current, as specified in Table B2;

— ALs(I_L) for limb current, as specified in Table B2;

ALs correspond to calculated or measured field values at the workplace in the absence of the worker, as maximum value at the position of the body or specified part of the body.

Action levels (ALs) for exposure to electric and magnetic fields

ALs(E) and ALs(B) are derived from the SAR or power density ELVs (Tables A1 and A3) based on the thresholds related to internal thermal effects caused by exposure to (external) electric and magnetic fields.

Table B1

ALs for exposure to electric and magnetic fields from 100 kHz to 300 GHz

Frequency range	Electric field strength ALs(E) [Vm^{-1}] (RMS)	Magnetic flux density ALs(B) [μT] (RMS)	Power density ALs(S) [Wm^{-2}]
100 kHz ≤ f < 1 MHz	$6{,}1 \times 10^2$	$2{,}0 \times 10^6/f$	—
1≤ f < 10 MHz	$6{,}1 \times 10^8/f$	$2{,}0 \times 10^6/f$	—
10 ≤ f < 400 MHz	61	0,2	—
400 MHz ≤ f < 2 GHz	$3 \times 10^{-3}\ f^{½}$	$1{,}0 \times 10^{-5}\ f^{½}$	—
2 ≤ f < 6 GHz	$1{,}4 \times 10^2$	$4{,}5 \times 10^{-1}$	—
6 ≤ f ≤ 300 GHz	$1{,}4 \times 10^2$	$4{,}5 \times 10^{-1}$	50

Note B1-1: f is the frequency expressed in hertz (Hz).

Note B1-2: $[ALs(E)]^2$ and $[ALs(B)]^2$ are to be averaged over a six-minute period. For RF pulses, the peak power density averaged over the pulse width shall not exceed 1 000 times the respective ALs(S) value. For multi-frequency fields, the analysis shall be based on summation, as explained in the practical guides referred to in Article 14.

Note B1-3: ALs(E) and ALs(B) represent maximum calculated or measured values at the workers' body position. This results in a conservative exposure assessment and automatic compliance with ELVs in all non-uniform exposure conditions. In order to simplify the assessment of compliance with ELVs, carried out in accordance with Article 4, in specific non-uniform conditions, criteria for the spatial averaging of measured fields based on established dosimetry will be laid down in the practical guides referred to in Article 14. In the case of a very localised source within a distance of a few centimetres from the body, compliance with ELVs shall be determined dosimetrically, case by case.

Note B1-4: The power density shall be averaged over any 20 cm^2 of exposed area. Spatial maximum power densities averaged over 1 cm^2 should not exceed 20 times the value of 50 Wm^{-2}. Power densities from 6 to 10 GHz are to be averaged over any six-minute period. Above 10 GHz, the power density shall be averaged over any $68/f^{1,05}$-minute period (where f is the frequency in GHz) to compensate for progressively shorter penetration depth as the frequency increases.

Table B2

ALs for steady state contact currents and induced limb currents

Frequency range	Steady state contact current, $ALs(I_C)$ [mA] (RMS)	Induced limb current in any limb, $ALs(I_L)$ [mA] (RMS)
100 kHz ≤ f < 10 MHz	40	—
10 ≤ f ≤ 110 MHz	40	100

Note B2-1: $[ALs(I_L)]^2$ is to be averaged over a six-minute period.

ANNEX IV

Correlation table

Directive 2004/40/EC	This Directive
Article 1(1)	Article 1(1)
Article 1(2)	Article 1(2) and (3)
Article 1(3)	Article 1(4)
Article 1(4)	Article 1(5)
Article 1(5)	Article 1(6)
Article 2(a)	Article 2(a)
—	Article 2(b)
—	Article 2(c)
Article 2(b)	Article 2(d), (e) and (f)
Article 2(c)	Article 2(g)
Article 3(1)	Article 3(1)
Article 3(2)	Article 3(1)
—	Article 3(2)
Article 3(3)	Article 3(2) and (3)
—	Article 3(4)
Article 4(1)	Article 4(1)
Article 4(2)	Article 4(2) and (3)
Article 4(3)	Article 4(3)
Article 4(4)	Article 4(4)
Article 4(5)(a)	Article 4(5)(b)
Article 4(5)(b)	Article 4(5)(a)
—	Article 4(5)(c)
Article 4(5)(c)	Article 4(5)(d)
Article 4(5)(d)	Article 4(5)(e)
Article 4(5)(d)(i)	—
Article 4(5)(d)(ii)	—
Article 4(5)(d)(iii)	—

Directive 2004/40/EC	This Directive
Article 4(5)(d)(iv)	—
Article 4(5)(e)	Article 4(5)(f)
Article 4(5)(f)	Article 4(5)(g)
—	Article 4(5)(h)
—	Article 4(5)(i)
Article 4(5)(g)	Article 4(5)(j)
Article 4(5)(h)	Article 4(5)(k)
—	Article 4(6)
Article 4(6)	Article 4(7)
Article 5(1)	Article 5(1)
Article 5(2), introductory wording	Article 5(2), introductory wording
Article 5(2)(a) to (c)	Article 5(2)(a) to (c)
—	Article 5(2)(d)
—	Article 5(2)(e)
Article 5(2)(d) to (g)	Article 5(2)(f) to (i)
—	Article 5(4)
Article 5(3)	Article 5(5)
—	Article 5(6)
—	Article 5(7)
Article 5(4)	Article 5(8)
—	Article 5(9)
Article 5(5)	Article 5(3)
Article 6, introductory wording	Article 6, introductory wording
Article 6(a)	Article 6(a)
Article 6(b)	Article 6(b)
—	Article 6(c)
Article 6(c)	Article 6(d)
Article 6(d)	Article 6(e)
—	Article 6(f)

Directive 2004/40/EC	This Directive
Article 6(e)	Article 6(g)
Article 6(f)	Article 6(h)
—	Article 6(i)
Article 7	Article 7
Article 8(1)	Article 8(1)
Article 8(2)	—
Article 8(3)	Article 8(2)
Article 9	Article 9
—	Article 10
Article 10(1)	Article 11(1)(c)
Article 10(2)(a)	Article 11(1)(a)
Article 10(2)(b)	Article 11(1)(b)
Article 11	—
—	Article 12
—	Article 13
—	Article 14
—	Article 15
Article 13(1)	Article 16(1)
Article 13(2)	Article 16(2)
—	Article 17
Article 14	Article 18
Article 15	Article 19
Annex	Annex I, Annex II and Annex III
—	Annex IV

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The Directive 2013/35/EU lays down the minimum safety requirements regarding the exposure of workers to risks arising from electromagnetic fields (EMF). This practical guide has been prepared to assist employers, particularly small to medium sized enterprises, to understand what they will need to do to comply with the Directive. However, it may also be useful for workers, workers representations and regulatory authorities in Member States. It consists of two volumes and a specific guide for SMEs.

The practical guide volume 1 provides advice on carrying out risk assessment and further advice on the options that may be available where employers need to implement additional protective or preventive measures.

Volume 2 http://dx.doi.org/10.2767/97726 presents twelve case studies that show employers how to approach assessments and illustrate some of the preventive and protective measures that might be selected and implemented. The case studies are presented in the context of generic workplaces, but were compiled from real work situations.

The guide for SMEs http://dx.doi.org/10.2767/967378 will assist you to carry out an initial assessment of the risks from EMF in your workplace. Based on the outcome of this assessment, it will help you decide whether you need to take any further action as a result of the EMF Directive.

This publication is available in electronic format in all EU official languages.

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