SZW Ministry of Social Affairs and Employment
Working Conditions Directorate

# Electromagnetic fields in the working environment
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Ministry of Social Affairs and Employment

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rivm
National Institute for Public Health and the Environment

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## Abstract

The EU has issued Directive 2004/40/EC on the protection of workers from health and safety risks arising from exposure to electromagnetic fields in the workplace. This directive must be implemented in national legislation no later than 30 April 2008. To prepare for implementation, RIVM has, on commission of the Ministry of Social Affairs and Employment, investigated and analysed exposure in Dutch working environments.

The purpose of this report is to provide assistance to employers to assess whether compliance is being met and to carry out the inventory and evaluation of risks (RI&E) due to electromagnetic fields. Until harmonised European standards from CENELEC cover all relevant assessment, measurement and calculation situations, this report may serve as a guide. It is not mandatory to use this report.

It will be sufficient for most of the employers to confine themselves to the first two chapters.

Subsequent chapters deal with the exposure found in several working environments and provide guidelines for assessing risks and possible measures in these working environments. Costs for implementing the directive are discussed in the last chapter.

CENELEC standards, if available, are mandatory for assessing whether exposure occurs below the limits in the directive. However, these standards are not easy to use without specialist knowledge. Furthermore, not all equipment needs to be assessed to the same extent nor are the same measures needed. A flow chart and tables of relevant working environments, classified into three categories, are provided to facilitate the assessment. Each category has its own assessment path.

No measures are needed for category I, while for category IIa working environments, only brief instructions are needed, e.g. keeping one's distance. For category IIb, such technical measures as shielding the radiation source, installing a fence or hanging up warning signs are needed. Category III contains all the working environments where great efforts (e.g. factory reorganisation) will be needed to combat exposure. In categories II and III the workers need to be informed about their own situation and measures with respect to exposure. Workers at particular risk, such as workers with implanted medical devices and pregnant women, will be given special attention.

Equipment found in working environments falling into category IIb includes dielectric and inductive heaters, bus bars, arc welding equipment and equipment for short wave and microwave diathermy and electrosurgery. Category III contains large rectifiers, small induction furnaces, semi-automated spot and induction

welding machines, intervention activities using MRI scanners, large broadcasting antennas, and activities such as troubleshooting situations confronting electricians. In several of these working environments measures have been taken.

The costs of implementation of the directive are divided into administrative burdens and costs of measures. The administrative burdens consist of assessment costs including measurement and calculation, and the cost of informing the workers. The administrative burdens in the first two years amount to an estimated €8 million per year and afterwards to an estimated €4 million per year. The estimates of the costs of measures vary from some €2 to €5 million per year. These estimates are uncertain due to the large variety of possible measures and the uncertainty in the number of companies.

# PART I PRACTICAL APPLICATION OF THE DIRECTIVE

## 1 Introduction

During their work, employees may be exposed to electric, magnetic and electromagnetic fields produced by equipment they are using or which they approach. To prevent excessive exposure to these fields during work the European Union has established a Directive stating minimum requirements for the protection of workers from the health & safety risks associated with exposure to these fields [1]. See Appendix 1 for more detailed information about the Directive. The Directive may have consequences for companies and lead to additional obligations for employers that will become part of the Working Conditions Decree (*Arbobesluit*). Dutch law must implement the Directive by 30 April 2008.

### 1.1 Electromagnetic fields

The two most important health-related properties of electromagnetic fields are frequency and field strength.

Low-frequency fields can cause the generation of electric currents in the body, while high frequency fields can lead to heating up of the body or parts of the body. The higher the frequency, the less deep the penetration of the field into the body and the more superficial the heating effect. The effects of 'induction of currents' and 'heating' are generally considered to be short-term effects. When exposure ceases, the effects disappear. Long-term effects have been investigated, but for the time being it is considered that there is insufficient evidence for establishing exposure limits [2, 3].

The Directive distinguishes between exposure limit values and action values. The exposure limit values must not be exceeded and are linked to physical variables that are directly related to effects on the body, such as current density in the central nervous system (at low frequencies), the specific absorption rate of energy and the power density (at high frequencies). Because these variables are usually difficult to measure, the Directive incorporates action values for easy to measure variables, such as the electric and magnetic fields outside the body. If the action values are not exceeded then, according to the Directive, it can be assumed that the exposure limit values will not be exceeded under normal circumstances. If the action values are exceeded, the employer must ensure that exposure levels are reduced to below the action values or the employer must show that the exposure limit values are not exceeded. Incidentally, exceeding the action values (or the exposure limit values) does not necessarily result in an unsafe situation.

Additional explanation of the action values, exposure limit values, various summation rules, averaging exposure over six-minutes (the ‘six-minute’ rule) and tables with the precise figures are included in Appendix 1 and Section 4.3.

## 1.2 Purpose of this report

This report is intended as a guide to help employers assess whether their workers are being subjected to excessive exposure levels. This report may be used for guidance until harmonised European standards covering all relevant assessment, measurement and calculation situations are available from the European Committee for Electrotechnical Standardization (CENELEC). Thus the use of this report is not mandatory.

This report also contains information about what can be done in situations of exposure to excessive levels. Besides, the report contains the basis for the decisions made during the compilation of this guide and an estimation of the effect of the introduction of the Directive on companies (including the administrative burden).

## 1.3 Adaptation of the RI&E methods

### 1.3.1 RI&E general

The Working Conditions Act (*Arbowet*), Article 5, obliges companies to carry out a risk inventory and evaluation (RI&E). This RI&E must be related to all health, safety and welfare risks that the work entails, i.e. including exposure to electromagnetic fields. The Working Conditions Decree (*Arbobesluit*) contains more specific instructions regarding a number of issues. These instructions, which are a direct result of European directives, state which elements the inventory and evaluation must cover for the specific risk covered by each instruction.

The RI&E is developed on a step-by-step basis. Initially, an inventory is made of the risks that are relevant to the company. Next, these risks are evaluated. This means that an assessment of the risks takes place in relation to legislation, standards and/or directives so that the severity of the risk can be determined. Then it can be established whether measures are required to reduce the risk and what these measures should be. Finally, the employer makes an action plan describing the measures to be taken, when and by whom. A company may carry out its own RI&E.

Model RI&Es have been developed by organisations such as trade organisations to assist companies making their own RI&Es. Examples of these model RI&Es can be found on the Arbo Platform Nederland general website, www.arbo.nl, and via their specialised site, www.rie.nl. Employers and workers have reached agreement about these RI&Es. A model RI&E can consist of a collection of modules, each covering a separate subject or statutory provision. Thus there are modules for hazardous materials, for sound and for vibration. These modules generally begin with an introductory question. If the answer to this is ‘yes’ then a series of subsequent questions must be answered (Figure 1). Each question is explained in a straightforward manner. It is best that modules are formulated as efficiently as possible, using an introductory question that encourages a single straightforward answer that establishes whether or not it is necessary to continue. This is followed by short sharp questions for drawing up an inventory.

If various activities take place in a company’s production process at different workplaces, and with potentially differing levels of exposure, it may be necessary to complete modules for every such activity. An example of this is the digital RI&E for linen hire and laundry companies [4], where the modules covering Setting up workplaces, Physical demands and Physical factors must be answered for the activity ‘Finishing (drying, wringing, folding, ironing and pressing)’. These modules must be completed again for the activity ‘Sorting cleaned goods, Packing and making ready for despatch’.

### 1.3.2 RI&E module for electromagnetic fields

The government is aiming for as much self-direction as possible (subsidarity principle) within industry & commerce. Employers and workers are responsible for compliance with legal requirements, but employer and employee organisations may agree what companies in their sector must do to meet the law. They can modify a generic module to fit their sector-specific equipment and circumstances. After all, it is considered that the sectors will be more aware of the current situation and future technological developments within their companies than outsiders.

A generic ‘electromagnetic field module RI&E’ has been developed, inspired by the various RI&E models for industries including rubber and plastics, laundries, the SME trade organisation, the providers of mobile telecommunications (MoNet) and the installation branch (UNETO-VNI). In this, the requirements in the Directive were translated into the most important questions to be answered in the RI&E. The electromagnetic field module was set up in a similar way to existing modules for other subjects such as sound, climate, vibrations and hazardous materials. Companies can use this module as an aid when they are setting up their own RI&Es for electromagnetic fields. Trade organisations can include this RI&E in www.rie.nl if they wish.

To keep the administrative load on employers to a minimum, an introductory question must be asked that excludes as many sections of the company as possible.

A provisional version of the generic module is included in Appendix 2.

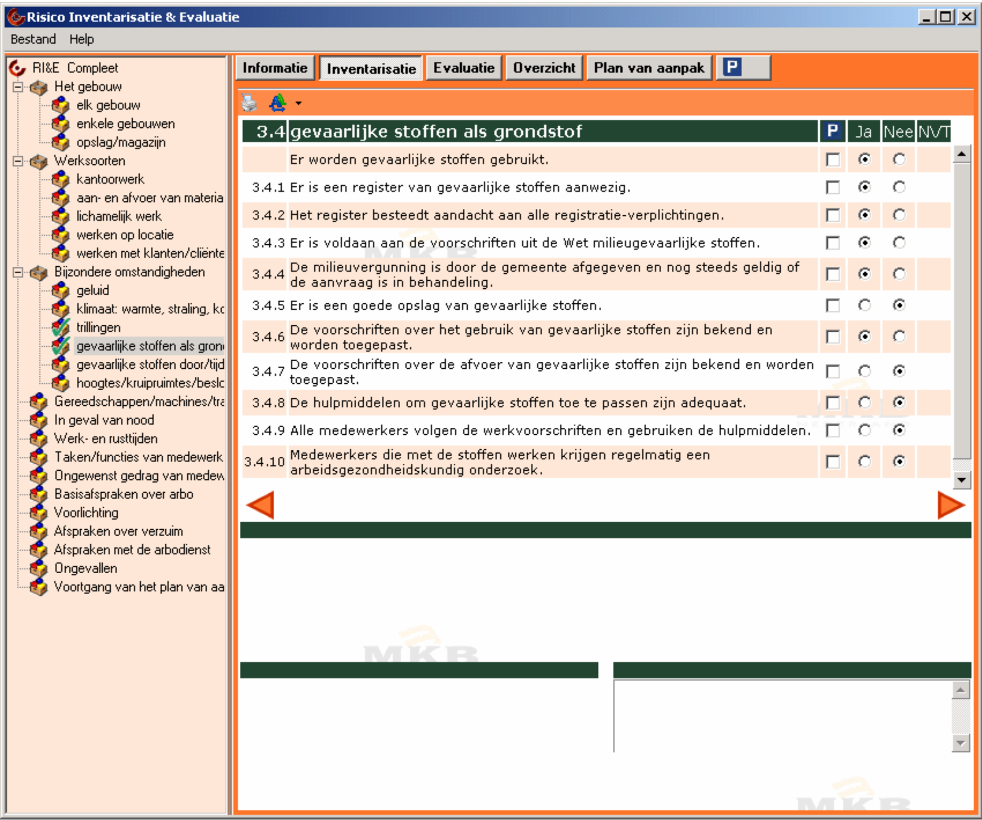


*Figure 1 A screen-shot from the generic digital RI&E used in the Netherlands for small and medium sized enterprises (SMEs). The left hand column summarises the entire RI&E and categorises buildings, types of work, special circumstances, equipment/machinery etc. The right hand column shows the inventory question list for 'special circumstance': 'hazardous raw materials'. It establishes that hazardous raw materials are used and asks a further 10 questions about how these are managed, including whether there are regular health checks on employees.*

Considering the limited time available it is not possible, within the scope of this investigation, to develop an exhaustive list of all types of equipment and the associated specific RI&E modules. No pretence is made that all equipment that might lead to exceeding action values or exposure limit values is included. The employer concerned is responsible for demonstrating that the Directive is met for all employees. Also, even if the analysis in this report indicates that it is not known that action values have been exceeded, companies still bear the responsibility for any potential exposure of their employees.

## 1.4 How to use this report

This section indicates which parts of the report are important for the employer. It is not actually necessary for each individual company to read this report in its entirety.

*General*

This Introduction and Chapter 2 are important for all employers. In Chapter 2 a flow chart is used to explain the assessment process. This chart can be compared to a tax form with various questions requiring a yes/no answer and with references to aids that can be used to help answering these questions. After the first step in the process, identifying which working environments are potentially important, it is possible that reading the remaining detailed chapters will not be necessary. Chapter 2 explains the division of working environments into three categories.

*From simple to more complex situations*

According to the flow chart, employers with working environments in only category I will just need to assess potentially non-standard situations (Section 4.5) to complete the exercise.

Employers with working environments in category II must assess the field strengths and in the first instance make use of the summary of useful 'rules of thumb' (Section 2.5). In some specific instances, summarised in Chapter 2, it is important to read the background information for the specific working environments in Chapter 3. For these types of working environment, Chapter 4 provides additional calculation rules. These mostly require more knowledge and effort and employers may need to call in expert assistance. Chapter 5 contains more information about control measures for these working environments.

Employers with working environments in category III must assess exposure levels. The specific information in Chapters3 to 5 is important for them.

*Effect on companies*

Finally, Chapter 6 is a chapter, which in connection with the implementation of the Directive, is mainly of importance to the Ministry of Social Affairs and Employment. It contains an estimation of the effect on companies (the administrative burden) that will be involved with both the assessment and taking measures.

# 2 Assessment process

By the time the Directive is converted into national legislation employers must have assessed the levels of electromagnetic fields to which workers are exposed in their working environment. This assessment is a part of the RI&E and must take place in conformity with harmonised CENELEC standards. While these standards are not available there is, on the one hand, a need for information about the potential exposure in equivalent working environments and, on the other, for basic rules of thumb and methods to be used for carrying out the assessment. This report can be used as a guide.

This chapter contains the proposed assessment process. As an introduction to the description of the process, the term ‘working environment’ will be explained. Working environments are divided into three categories. Next, the assessment process will be discussed with the assistance of a flow chart.

This assessment process is intended to be a guide. Once the harmonised European standards are available from CENELEC, the procedures described in them will be obligatory.

## 2.1 The term ‘working environment’

The exposure of the employee takes place at the location where that employee carries out his or her work. The equipment at the workplace combined with its use is called the ‘working environment’ in this report. To carry out a comprehensive assessment, the following information about this working environment must be available: the type of equipment that generates the electromagnetic fields, the type of work carried out by the worker and the circumstances under which the equipment is used.

## 2.2 Working environment categories

The working environments are divided into three categories: see Figure 2. Category II is further divided into two subcategories IIa and IIb. Each category has its own assessment process. No measures need be taken for category I. Only brief instructions are needed for category IIa working environments, e.g. keeping a safe distance. For category IIb, such technical measures as shielding the radiation source, placing a fence or placing warning signs will be required. Category III contains all the working environments where extensive measures will be needed (e.g. factory reorganisation). For all categories, workers will need to be informed about the Directive and the local exposure situation.

The division into the three categories is intended to simplify the assessment process for employers. The category into which a working environment is placed becomes the starting point for the assessment process (see Section 2.4). Identifying in advance the category into which working environments fall avoids the need to subject all working environments to the same extensive RI&E assessment.

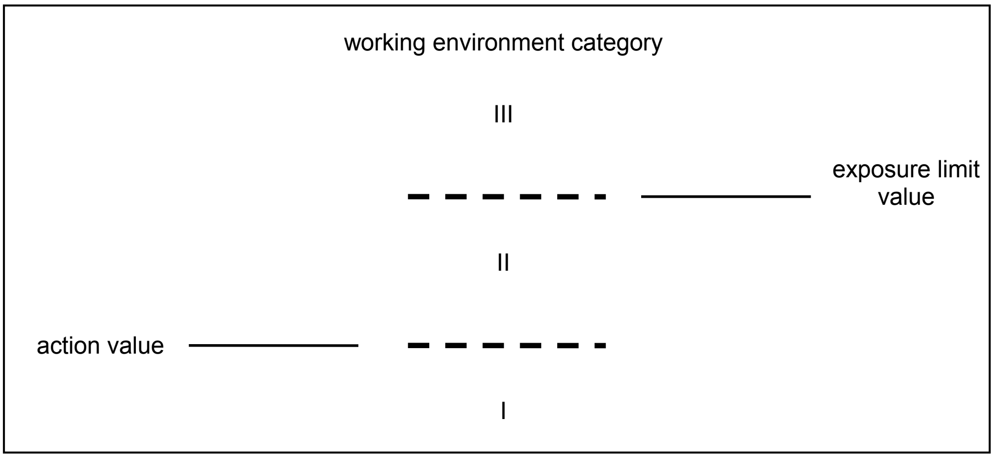


*Figure 2 Checking action values and exposure limit values leads to division of working environments into three categories.*

## 2.3 Overview of working environments

This section includes overviews of working environments split into the three categories: see Table 1 to Table 4. In the categorisation, no account has been taken of any additional provisions present for minimising exposure levels. Firstly in Table 1 (green) those working environments are listed for which it can be assumed a priori that action values will not be exceeded. Table 2 (green), Table 3 (yellow/orange) and Table 4 (red) successively list working environments that have been divided into categories I, II and III following the inventory. The tables are coloured similarly to traffic lights, depending on the severity of the measures to be taken: green: none; yellow: simple instructions; orange: technical measure; and red: extensive measures. Table 1 and Table 2 were drawn up using information obtained during the international workshop *Electromagnetic Fields in the Workplace* (held in Warsaw in September 2005) and using the CENELEC draft generic standard, version 6.4, Copenhagen, September 2005.

The assessments of the equipment investigated from literature and the practical research (see Section 3.1) finally led to an overview of working environments divided into categories I, II and III. The working environments are grouped by type of equipment. Please refer to Chapter 3 for background information about the classification of working environments into the three categories. This describes the method used and provides the details per equipment group.

*Table 1 Working environments for which it can be assumed a priori that the action values will not be exceeded.*

| | equipment and use |
|---|---|
| - | offices<br>(incl. computer equipment, cable networks, radio communication equipment; exc. tape erasers) |
| - | hand-held motor-operated electric tools (NEN 60745) |
| - | transportable motor operated electric tools (NEN 61029)<br>(incl. electrically operated garden appliances) |
| - | household and similar electrical appliances (NEN 60335)<br>(incl. mobile equipment fitted with heating elements; battery chargers; heaters; vacuum cleaners for dirt and water; cookers, ovens and cooking elements for industrial and commercial use; heating elements for waterbeds; microwave ovens for industrial and commercial use) |
| - | electrical installations<br>- low voltage network < 1000 V<br>- low voltage components with power less than 200 kVA<br>- at least 60 cm distance from low voltage components with power not exceeding 1000 kVA<br>- power transformers connected to low voltage networks (<1000 V between phases) with power up to 200 kVA<br>- at least 60 cm from power transformers connected to low voltage networks (< 1000 V between phases) with power not higher than 1000 kVA |
| - | electric motors and electric pumps, subject to<br>- the power being lower than 200 kVA<br>- there being at least 60 cm distance and the power not exceeding 1000 kVA |
| - | testing instruments<br>(exc. non-destructive magnetic testing) |
| - | mobile telephones |
| - | battery-powered radio equipment with output power less than 100 mW |
| - | audio and video equipment |
| - | lighting equipment<br>(exc. radio frequency and microwave lighting) |

*Table 2 Working environments in category I*

| group | equipment and use |
|---|---|
| 1 | installation and maintenance<br>- electrical hand-held tools (exc. welding equipment) |
| 2 | detection of articles and people<br>- EAS 0.8 – 2.5 GHz (non-linear microwaves)<br>- RFID 1 Hz - 500 kHz<br>- RFID 2 - 30 MHz (transmission power < 2 W and duty cycle < 0.05)<br>- RFID 850 - 950 MHz (transmission power < 2 W and duty cycle < 0.05)<br>- RFID 2.45 and 5.8 GHz (transmission power < 2 W and duty cycle < 0.05)<br>- hand-held metal detectors<br>- EAS-deactivators |
| 4 | electricity production and distribution<br>- bus bars/conductor rails in substations<br>- above ground high voltage cables<br>- electricity substations<br>- switch gear |
| 6 | induction heating<br>- automated systems |
| 7 | welding<br>- automated systems |
| 8 | medical applications<br>- shallow hyperthermia<br>- pain control, stimulation of bone growth etc.<br>- incubators, lamps for phototherapy, wireless communication systems etc. |
| 11 | transport and traction systems<br>- rail transport powered by direct current<br>- vehicles, ships, aircraft<br>- (large) electric motors |
| 12 | transmitters<br>- beam transmitters (small, at GSM base stations, < 1 W)<br>- telephones and hand portables<br>- radar systems (speed checks, weather radar) |
| 13 | other working environments<br>- induction hobs in hotel & catering industry (food preparation) |

*Table 3 Working environments in category II.*

| group | equipment and use | |
|---|---|---|
| 1 | installation and maintenance | |
| | - equipment that is being installed or maintained | b |
| | - equipment in the vicinity of the equipment being maintained | a/b |
| 2 | detection of articles and people | |
| | - EAS 0.01 - 20 kHz (magnetic) | a |
| | - EAS 20 - 135 kHz (resonant inductive) | a |
| | - EAS 1 - 20 MHz (radio frequency resonant inductive) | a |
| | - metal detectors | a |
| | - RFID – systems (transmitting power> 2 W or duty cycle > 0.05) | a |
| 3 | dielectric heating | |
| | - plastic sealers | b |
| | - wood gluing equipment | b |
| 4 | electricity production and distribution | |
| | - power stations | b |
| | - air cooled coils in capacitor banks | b |
| 5 | electrochemical processes | |
| | - current supply systems (bus bars) | b |
| | - electrolysis hall | b |
| 6 | induction heating | |
| | - with open coils | b |
| | - larger furnaces | b |
| 7 | welding | |
| | - arc welding - cable | b |
| | - arc welding – electrode holder | a |
| 8 | medical applications | |
| | - MRI - scanning | b |
| | - short wave and microwave diathermy | b |
| | - deep hyperthermia | a |
| | - electrosurgery | a |
| 9 | microwave drying | |
| | - use of - 'open magnetron' | b |
| 10 | research applications | |
| | - difficult to itemise | a/b |
| 11 | transport and haulage systems | |
| | - rail transport powered by alternating current (50 Hz; HSLs) | a |
| 12 | transmitters | |
| | - base stations for mobile telephony (GSM, UMTS) | a |
| | - TETRA transmitters in masts | a |
| | - TETRA transmitters on vehicles, power 10 W | a |
| | - WLL systems | a |
| | - beam transmitters | a |
| | - small broadcasting transmitters (on roofs) | b |
| | - amateur radio transmitters | b |
| | - radar systems (navigational) | b |
| 13 | Other working environments | |
| | - tape erasers | a |
| | - radio frequency and microwave lighting | a/b |
| | - non-destructive magnetic testing | b |

*Table 4 Working environments in category III.*

| group | equipment and use |
|---|---|
| 1 | installation and maintenance<br>- troubleshooting work |
| 5 | electrochemical processes<br>- rectifiers |
| 6 | induction heating<br>- smaller smelting furnaces (alloying) |
| 7 | welding<br>- spot and induction welding, semi-automated |
| 8 | medical applications<br>- MRI – intervention activities |
| 12 | transmitters<br>- large broadcasting transmitters |

## 2.4 The process

Figure 3 is a schematic indication of the process an employer can follow when carrying out the assessment in accordance with the Directive. This diagram, similar to a tax form in some respects, contains a start and a finish plus three types of symbol: rectangles, diamonds and 'frames' (rectangle with a wavy line at the bottom). The rectangles contain actions and the diamonds questions that must be answered with 'yes' (continue downwards) or 'no' (go to the right). The 'frames' contain information necessary for carrying out the actions in the rectangles. Each 'frame' contains the number of the section in this report in which the information, insofar as currently available, can be found.

The diagram is used as follows.

1. Take the overview of working environments (see Section 2.3) and look up the working environments that are present in the work situations to be assessed. As a first estimate, use the category from the overview for each working environment.
2. Check whether each category I working environment meets the description 'non-standard situations'. Non-standard situations can occur due to the presence of medical equipment, medical aids or inflammable materials for example, or due to simultaneous exposure to two or more sources of electromagnetic fields. If circumstances are considered to be standard, then the safety levels can be deemed acceptable and no further action will be needed for this working environment. If there are non-standard situations, then measures must be taken. For example a warning sign such as 'Forbidden for employees with a pacemaker' might be sufficient. The situation must then be assessed once again to establish that safety levels are acceptable; if so then no further action is required for this working environment.

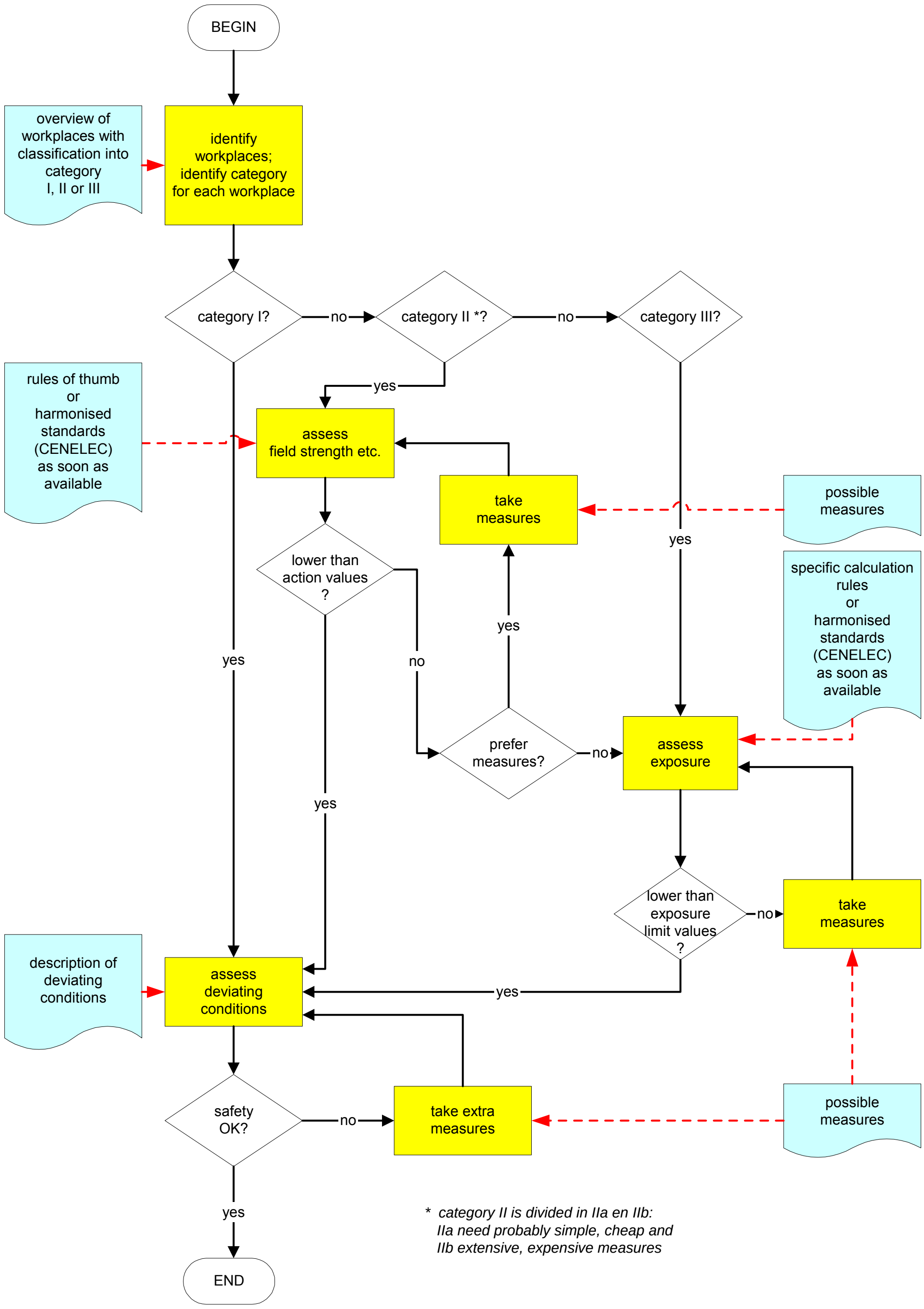


*Figure 3 Flow diagram of the process for establishing whether measures are required in practice.*

3. Per category II working environment, verify whether action values are being exceeded by carrying out a simple calculation using rules of thumb and tables (Section 2.5). If no action values are being exceeded, the non-standard situations must still be assessed for this working environment. This is analogous to the process for category I working environments.
   If action values are being exceeded, a choice must be made between taking measures (Chapter 5) to ensure that the action values are no longer exceeded (making the situation equivalent to category I), or carrying out further analysis to establish that the exposure limit values are not being exceeded (Chapter 4). If that is the case the situation is equivalent to category I. If it turns out that exposure limit values are being exceeded then measures must be taken that are equivalent to the measures for category III working environments.
   If the employer decides to take measures to ensure that the action values are no longer being exceeded, these may be simple (category IIa; e.g. instructions) or comprehensive (category IIb: enclosure or modifications to equipment).
4. Per category III working environment, undertake a more detailed analysis by carrying out extensive calculations to establish whether or not the exposure limit values are being exceeded. These calculations may have to be supported by measurements. If exposure limit values are not being exceeded the situation is equivalent to category I. If exposure limit values are being exceeded then measures must be taken.

When taking measures, account must be taken of current technological developments and the options available for managing the risk at the source, particularly regarding:

- other working methods that entail less exposure to electromagnetic fields;
- the choice of equipment emitting less electromagnetic fields, taking account of the work to be done;
- technical measures to reduce the emission of electromagnetic fields, including where necessary the use of interlocks, shielding or similar health protection mechanisms;
- appropriate maintenance programmes for work equipment, workplaces and workstation systems;
- the design and layout of work places and workstations;
- limitation of the duration and intensity of the exposure; and
- the availability of adequate personal protection equipment.

## 2.5 Summary of rules of thumb and measures for category II

This section summarises the rules of thumb that can be applied to assess whether action values are being exceeded for category II working environments. No rules of thumb are required for category I working environments. Category III working environments require tailor-made measures and each situation must be assessed individually (see for instance Chapter 4). The substantiation of the rules of thumb is included in the corresponding sections of Chapter 3. These rules of thumb are generally conservative. Thus you should be aware that if a rule of thumb is not met, this does not necessarily mean that action values are being exceeded or that the situation is unsafe.

CENELEC is developing workplace standards: harmonised standards for specific working environments. As soon as these become available they will take precedence over the rules of thumb in this section.

### 2.5.1 Installation and maintenance

The working environments of employees in the installation branch are generally characterised by the diversity of the equipment with which these workers come into contact. Large installation companies get involved with just about all groups of equipment mentioned and can find the rules of thumb that apply to these equipment groups in the following relevant subsections. In particular equipment that workers may get close to (by chance or otherwise) deserves extra attention. It is possible that installation and maintenance workers can be encouraged to avoid areas where action values are exceeded by adequate training or use of information materials.

### 2.5.2 Detection of articles and people.

There is a wide variety of equipment for anti-theft gates (EAS systems) - moreover these are specifically designed for the situation at the shop or museum concerned. The field strengths vary considerably and as a rule of thumb it can be assumed that the action values will not be exceeded at a distance of more than 1 m from the gates.

For gates used for detecting metal objects, for example at airports and in clubs, action values will not be exceeded if employees remain outside the gateway and do not lean against the gate housings.

### 2.5.3 Dielectric heating

There are no general rules of thumb available for equipment for synthetic or plastic sealers, or for wood gluing equipment. Peak values occur that exceed the action values within the operating distance of this type of equipment. The exposure is not permanent and all SAR values are to be averaged over any six-minute period (the 'six-minute' rule). If shielding is not a practical option and the exposure period cannot be restricted, then it is advisable to maintain a distance that can be determined using straightforward measurements.

### 2.5.4 Electricity production and distribution

Action values may be exceeded in power stations near generators, transformers, rectifiers and conductors. Testing must be carried out to determine where enclosures must be located.

Capacitor banks with air cooled coils are used in some substations. The action values for magnetic fields are exceeded up to 2 to 5 m from these coils. The positions of barriers preventing employees entering the hazardous areas can be established using simple testing equipment.

### 2.5.5 Electrochemical processes

Action values may be exceeded in the vicinity of bus bars (current carrying systems). This is generally caused by direct current with a small percentage of alternating current (ripple) remaining following rectification. The rectification process also leads to higher harmonic contributions, which must be added in accordance with the summation rule (see Appendix 1). Because the frequencies are lower than 100 kHz, it is not allowable to check the average exposure with the action value where the exposure time of the employee is taken into account. Table 5 gives the distance (r) to a single current carrying wire for which the frequency dependent action value (expressed in Hz) for the magnetic flux density (in μT) is reached for three frequencies, and for four (direct) current strengths (I). In these calculations, it is (conservatively) assumed that the alternating current ripple does not amount to more than 10%.

*Table 5 Distance (r) to a single bus bar for which the action value (magnetic flux density) is reached for direct current of the indicated strength, assuming that the alternating current ripple is not more than 10%.*

| current strength (direct current) I (A) | 300 Hz action value 250 μT r (m) | 600 Hz action value 83 μT r (m) | 900 Hz action value 30.7 μT r (m) |
|---|---|---|---|
| 100 | 0.02 | 0.05 | 0.07 |
| 300 | 0.07 | 0.14 | 0.2 |
| 1000 | 0.2 | 0.5 | 0.7 |
| 3000 | 0.7 | 1.4 | 2.0 |

Such a rule of thumb is not available for an electrolysis hall for example, where multiple conductors are located at varying distances from the worker. This also applies to situations where there may be a system of cables in a three-phase system. In this type of situation measurements must be carried out or calculations done using computer models.

### 2.5.6 Induction heating

Action values for magnetic fields are exceeded in the vicinity of induction heating equipment with open coils and in the vicinity of induction furnaces. In addition to the wide ranges of frequencies and powers that are used, the working procedure is also very important. Often work need not be carried out at locations where the action values are exceeded. For determining the distances outside which the action values are not exceeded, it is generally necessary to carry out (simple) measurements. This is partly due to the diversity of equipment.

### 2.5.7 Welding

During manual arc welding there are two locations where the action values may be exceeded. These are close to the cable and the electrode holder. As a rule of thumb it can be assumed that the action values will not be exceeded if the distances from the cable shown in Table 6 are maintained. If it is not possible to stay this distance away from the cable then it must be demonstrated by measurements that the action values are not being exceeded or, alternatively, from calculation that the exposure limit values are not being exceeded. In any case the cable must be located well away from the head and spinal column. The cable must not be placed over the shoulder.

Published literature indicates that the electrode holder can cause the action values to be exceeded around the hands and lower arms. From various calculations based on current density in the central nervous system it does not appear likely that the exposure limit values will be exceeded.

*Table 6 Distance to a single cable for which the action value (magnetic flux density) is reached for alternating current of the stated strength and for two frequencies.*

| current strength (direct current) I (A) | 50 Hz action value 500 μT r (m) | 100 Hz action value 250 μT r (m) |
|---|---|---|
| 100 | 0.04 | 0.08 |
| 300 | 0.12 | 0.2 |

### 2.5.8 Medical applications

*MRI*
For MRI scanners it can be assumed that the action values will not be exceeded if a distance of at least a few metres is maintained during scanning. This condition really cannot be met in troubleshooting situations in the development and production phases or during maintenance and repair phases, nor in the case of intensive patient care or during intervention activities.

*Diathermy*
For short wave and microwave diathermy equipment the distance at which fields can exceed the action values is up to 2 m. Exceeding the action values can be prevented by keeping a safe distance and minimising the time spent close to the equipment. Testing on location is required for more accurate determination of distances and times.

*Hyperthermia*
Deep hyperthermia is used at two locations in the Netherlands. Measurements have been carried out at both locations. As a rule of thumb it can be assumed that at distances in excess of 1 m no action values will be exceeded. If it does happen that work must be carried out closer, exceeding of the action values can be prevented by minimising the time spent at the location (using the 'six-minute' rule; see Appendix 1).

*Electrosurgery*
The hands of surgeons using electrosurgical techniques may be exposed to fields above the action values. Also, the power supply cable can be considered to be an open transmission cable. The current density can rise to close to the exposure limit values. Thus as large a distance as possible must be maintained between the cable and the body.

### 2.5.9 Microwave drying

The only practical application in the Netherlands that uses an 'open microwave oven' is for controlling the deathwatch beetle (large woodworm) in wood. The action values will be exceeded if precautionary measures are not taken. Exposure of the operating personnel can be minimised quite simply by partially shielding the magnetron with aluminium, wrapping the wooden beams to be handled in aluminium and subsequently monitoring the power density. Operators should also keep a safe distance when the equipment is switched on.

### 2.5.10 Research applications

The equipment used in research and educational institutions is very diverse. In general it can be assumed that all equipment listed in the other equipment groups may also be encountered in these institutions. That means that in the first instance use can be made of the rules of thumb in the equipment groups. It will certainly be the case that equipment in experimental set-ups will produce electromagnetic fields exceeding the action values. Due to the experimental nature of this equipment it is not possible to develop rules of thumb. It will probably be necessary to carry out measurements on site.

### 2.5.11 Transport and traction systems

The majority of the rail transport in the Netherlands is powered by direct current. Alternating current (50 Hz) will power the *Hoge-snelheidslijnen* (high-speed passenger lines) and the *Betuwelijn* (goods line between Rotterdam and the Ruhr) that are currently under construction. The working situations where the highest fields are expected are during the inspection of the overhead conductor (exposure of the head) and when walking over rails (exposure of the feet). Exceeding of action values is not expected at distances greater than 10 cm from the wire and rails.

### 2.5.12 Transmitters

*GSM/UMTS*
For registered GSM and UMTS base stations it is possible to determine per antenna via Internet in the Antenna Register the distances at which the action values are no longer exceeded. Figure 4 shows an example for a 900 MHz GSM antenna. These distances depend strongly on the direction from which the antenna is approached. At the back of the antenna this distance is in the order of tens of centimetres and at the front generally in the order of metres. If work has to be carried out closer than this then measures such as shortening the exposure time (the ‘six-minute’ rule), reducing the transmission power or shutting down the antenna can be taken.

*WLL*
As a rule of thumb a distance of 1 m from the antenna can be used for WLL systems. It is important that workers learn to identify the various types of antenna systems, particularly those who do not normally work on the antennas.

*Beam transmitters*
The limited power of just a few hundred milliwatts of small mobile communication beam transmitters situated on antenna masts means that the exposure limit value will not be exceeded, even in the beam. For beam transmitters with an input power

that exceeds 1 W the rule of thumb is that workers should remain outside the beam by not standing in front of the dish.

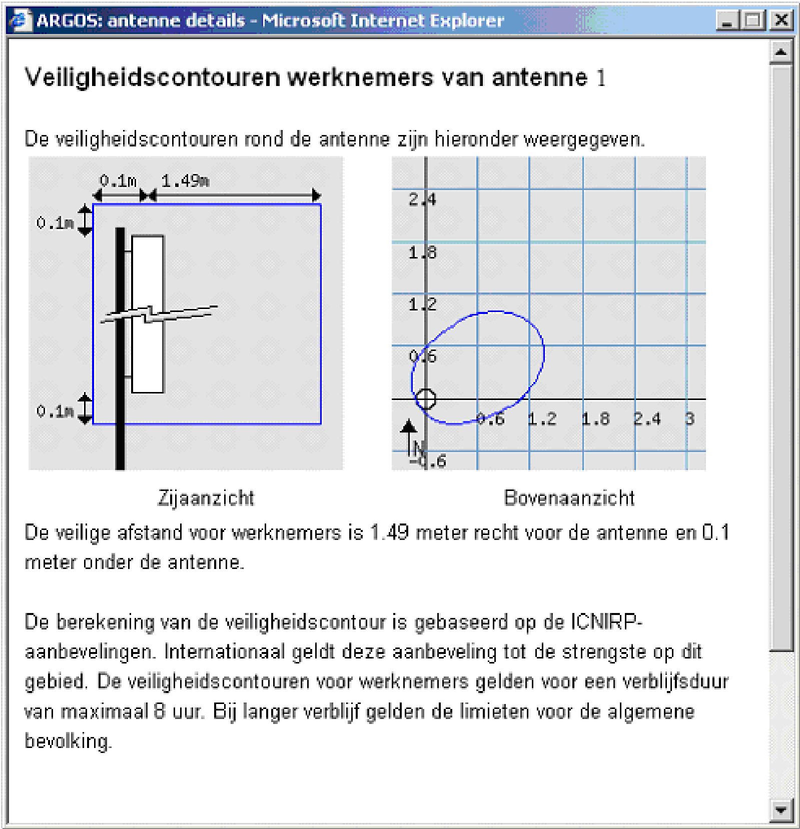


*Figure 4 An example of the information in the Antenna Register (GSM 900 MHz) about the distance at which the action values are exceeded (source: Antenna Register). The left hand diagram shows the side view of an antenna and the right hand graph the view from the top. The safe distance for workers is 1.49 m directly in front of the antenna and 0.1 m below the antenna. These contours apply to periods up to a maximum of 8 hours. For longer periods the limits for the general public are applicable. The calculations are based on the ICNIRP recommendations.*

*Broadcasting transmitters*

The *Agentschap Telecom* (AT-EZ, the regulatory body for ether frequencies in the Netherlands) differentiates between local, regional and national transmitters. Local transmitters produce a maximum of 100 W ERP and are intended to cover a radius of approx. 5 km. Regional transmitters can broadcast at power levels up to a few kilowatts ERP. Local broadcasting transmitters are generally situated on roofs or on masts, regional transmitters are on roofs, but also on antenna masts and towers, and national transmitters are usually on masts and towers. This report classifies broadcasting transmitters into large and small transmitters. ‘Small broadcasting transmitters’ means the local and regional transmitters that are situated on roofs. Both these small transmitters and the privately built amateur transmitters are located on buildings and because of their simple appearance they may not be recognised by roofing workers. Also, these transmitters have not yet been put on the Antenna Register website. It is important that workers learn to identify these and that at the start of a job they request information about whether antennas are present at the workplace.

*Radar*
Due to the high power of the radar systems used for controlling air and water traffic it is possible that for fixed radar systems, the action values in the main beam will be exceeded at distances of hundreds of metres. However for rotating radars, because of the duty cycle, the average exposure reduces by a few hundred or thousand times. It is necessary to establish the exclusion zone for workers for each radar system by means of measurements or calculations. For example, this zone can be cordoned off or indicated on the ground.

### 2.5.13 Other working environments

There are tape erasers on the market that are held in the hand during demagnetising. These cause the action values to be exceeded around the hands. To prevent the exposure limit values for current density in the head and trunk also being exceeded, these tape erasers should be kept at arm’s length from the head and trunk.

Another application in this group is non-destructive magnetic testing for detecting defects in metallic materials. Action values are exceeded around the hands, but probably not around the head and trunk. It must be ensured that a distance of an arm’s length is maintained between the equipment and the head or trunk during the magnetising of the material.

### 2.5.14 Working environments not covered here

There are no rules of thumb available for working environments that are not included in the inventory, nor for potential future working environments. In general these fall into category II.

# PART II BACKGROUND INFORMATION

# 3 Inventory of working environments

This chapter summarises the data that has been collected and how it has been analysed to reach the overview of working environments. The working environments are grouped by type of equipment. A link is also made to the industry/business sector where these working environments occur. In sections 3.2 and subsequently the results of the literature survey and practical research are presented per equipment group. Each section finishes with the conclusions relating to the classification of the working environment in one of the three categories.

During the assessment of the measurement results or calculations a check will be made against the action values and the exposure limit values in which the summation rule and the 'six-minute' rule are applied (see Appendix 1). If it is explicitly demonstrated that the basic restrictions in the EU recommendations for members of the general public [5] are being met, then it will also be true that the exposure limit values of the Directive are being met.

## 3.1 Approach

### 3.1.1 Literature survey

When drawing up the inventory of working environments and also during the development of the methodology, in the first instance information was obtained from previously published surveys [6] and from recent data from published literature. Of course, the findings were critically examined and compared with each other once again by the researchers. This involved both national and international peer reviewed literature as well as 'grey' literature, mainly from established institutes with an excellent worldwide reputation that are closely involved with policy development [7]. Information from the proceedings of recent conferences and reports from workshops has also been collected. As far as possible, the literature was selected from material published over the last 10 years. On the basis of this information, an overview of working environments was drawn up with an estimation of action values and/or exposure limit values that might be exceeded per working environment.

The search terms used when researching publications in peer reviewed literature included: 'occupational', 'exposure', 'electromagn*', 'radiation' and 'protection'. The Kleinjans and Schuurman [6] publication, which was chosen as the starting point, dates from 1995. This was why the literature survey was restricted to the period 1995-2004. Quite a number of documents relating to exposure to electrical, magnetic and electromagnetic fields appear to have been published in Eastern

Europe (particularly Poland and the former Soviet Union). Due to language difficulties, availability of the documents and available time these were put to one side for the time being and investigation was restricted to publications in Dutch, English, German, French and Spanish. From the approximately 650 publications found, 150 were selected as being relevant and were studied.

A number of overview articles were used to reach classifications for equipment groups [8, 9, 10, 11]. For the classification of the working environments and the equipment groups, the generally used Working Conditions (*arbo*) practice was followed as far as possible for the classification into business sectors. This was done due to the need to accommodate the RI&E system (see Section 1.3). To be able to estimate (see Chapter 6) the magnitude of the consequences of the implementation of the Directive (number of employers and employees) it was decided to classify companies into the same classes that are used in statistical data collection. The Labour Inspectorate in the Netherlands uses the BIK code (Company Information Code) for classifying companies. This is the code that the Chambers of Commerce use to indicate the activities of companies and establishments. According to the CBS website, the SBI code (Standard Company Classification) is the same as the BIK code used by the Chambers of Commerce [12]. In the SBI code, at the highest level, companies are classified into 17 different sectors; in turn, two of these codes are classified a level deeper: C (Mining) into two, and D (Industry) into fourteen levels (see Appendix 3).

Consideration was also given to whether a classification into occupations was of importance. Although the employee (with his/her occupation and activities) is central to the assessment of the exposure to electromagnetic fields, the decision was made to choose the employer as the main approach. After all, the employer is responsible for the protection of the employee as well as to the government for this. Also, the employer is (usually) responsible for the equipment that produces the fields. In addition the Labour Inspectorate also uses a trade and industry sector approach.

### 3.1.2 Practical research and measurements

Two approaches were taken during the contacts with the field. The first was via trade and industry sector organisations and, to a lesser extent, professional associations. The second was directly to companies and organisations, where grateful use was made of the help of members of the Consultation Group. In addition the action of the FME-CWM (trade organisation for the electro-technical industrial sector) towards the EMC-ESD association and via the NEN site led to various questions from the field. The presentations for FME-CWM and UNETO-VNI (trade organisation for the installation branch) contributed strongly to the involvement from the field [13].

In addition to telephone contacts, many visits were made to companies and organisations. During these visits the actual working situations were seen and measurement reports were obtained or viewed at the location. Obtaining relevant measurement reports turned out to be a problem, often for reasons of confidentiality. This problem was partly overcome by purchasing a report from KEMA containing a summary of the results that KEMA had obtained on commission from third parties. This KEMA report maintained the anonymity of the companies concerned [14]. This report did not include EMC measurements, rather measurements of high field strengths at user distance from the equipment. Reports containing EMC measurement results turned out to be less useful for establishing whether action values might be exceeded. This was because EMC measurements are usually made at distances that are greater than the distance the worker will normally be from the equipment.

In September 2005 RIVM participated in the international scientific Electromagnetic Fields in the Workplace workshop in Warsaw, Poland. This was the first workshop where the state of affairs relating to almost all potential working environments was discussed. A number of presentations were given about several of the working environments that are covered in this report. The findings from the literature survey and the practical research were discussed with several of the foreign specialists.

It was not possible, nor necessary, to involve all companies in the practical research. During the selection of trade and industry sectors, first to be eliminated were those sectors where field strength was expected to be low. Also eliminated were those sectors where very high strength fields are prevalent, but where it could reasonably be assumed that there would be adequate expertise available for protection of the employees. For the remaining trade and industry sectors there was some doubt about either the field strengths or the presence of adequate expertise for making specialist judgments.

To summarise, the following types of information source were used in the investigation:

A articles from (international) scientific literature (including PhD dissertations),

B international reports,

C national reports (Health Council, university reports from ‘Science shops’ (research centres for non-profit making organisations) for example or dissertations),

D national test data (TNO, KEMA, EMC type approvals, company test reports etc.),

E results or interviews with Dutch experts (technicians and health & safety specialists), F conclusions from company visits where inquiries were made about exposure at levels under normal operating conditions.

### 3.1.3 Classification criteria

In Chapter 2 the classification of working environments into three categories was mentioned. This section describes the arguments used during the categorisation of a specific working environment. The criteria used in the investigation to come to a choice of category are listed per category.

I Working environments where (in normal circumstances) action values will probably not be exceeded and where it is certain that exposure limit values will not be exceeded. No subsequent assessment will be required for these working environments to determine whether the exposure limit values will be exceeded.
Reasons for classifying a working environment in category I:
- no electrical equipment present
- equipment that has not been designed to produce electromagnetic fields outside the casing, yet meets the EMC requirements
- equipment that only creates static fields (only 0 Hz[1])
- battery-powered equipment other than equipment intended to produce radio frequency electromagnetic fields
- the working environment is also accessible to members of the public and for such working environments it has already been explicitly shown that the basic restrictions in the EU recommendations applying to members of the public have been met and the situation for employees is the same as that for members of the public (Article 4.3 of the Directive)
- there was no indication whatsoever within the scope of this project in the sources of information consulted that action values would be exceeded in the working environment concerned
- it had already been explicitly proven that in all cases the exposure limit values would not be exceeded, although action values could be exceeded.

II Working environments where action values are probably being exceeded in normal circumstances, but where, following closer analysis, it appears that

[1] Action values have been defined for static magnetic fields, but not exposure limit values. For this reason equipment that produces static fields cannot be classified in category III. If the static magnetic field exceeds the action value, attention must be paid to the risk of ferromagnetic objects flying around, to avoiding the disturbance of medical implants or life-saving aids, and avoiding excessively fast movements that can cause dizziness and nausea.

exposure limit values are probably not being exceeded. For these types of working environments a ‘light’ additional assessment is required.

Reasons for classifying a working environment in category II:

- equipment for which it has been established at least once that the action values are being exceeded and for which it is still not clear whether the exposure limit values might be exceeded
- control measures to reduce exposure levels are possible (distance, ‘six-minute’ rule, shielding, making people conscious of the hazards, education); checks must be made to ensure that these control measures have indeed been taken
- unknown equipment or equipment about which there is uncertainty (old designs, equipment still in the development phase)
- equipment not covered in this report.

III Working environments where action values are certainly being exceeded in normal circumstances and where, following closer analysis, it appears probable that exposure limit values are also being exceeded. These working environments must receive a supplementary assessment. Measures will probably have to be taken to reduce the exposure.

Reasons for classifying a working environment in category III:

- at least one article was found in the international scientific literature where proof was given of exposure limit values being exceeded
- at least one article was found in the international scientific literature where proof was given that action values were being exceeded and it was suspected that the exposure limit values were also being exceeded
- during the practical research carried out by RIVM it was evident that people were not aware of potentially high exposure levels.

Strictly speaking the categories introduced above only apply to equipment that is currently in use. The situation is different for equipment that will be newly developed in the future and also for equipment that is currently being developed, but is not yet on the market. A measurement may indicate that action values are being exceeded. In this type of situation either the equipment must be further developed to ensure that the action values cannot be exceeded, or it must be clear from calculations or reasoning that the exceeding of the action values will not have the consequence that the exposure limit values are exceeded, or the supplier must supply a ‘package of measures that are necessary to prevent the exceeding of the exposure limit values’. The latter must also be included in a manual or some type of explicit warning. If one of these three options can be followed, the equipment may bear the CE mark and be introduced to the market. Equipment developed in the future will initially be placed in category II.

The classification into categories only applies to normal circumstances. This means that properly trained persons are using the equipment as intended (this also includes students on work placement and trainees).

## 3.2 Installation and maintenance

In the above sections, attention has generally been paid to the use of equipment in normal circumstances. Table 7 shows the life phases of equipment. Exposure to electromagnetic fields can also take place during the development and testing of new equipment. During testing, equipment is often loaded excessively and this may lead to higher field strengths than during normal use. Also, during maintenance and repair it is sometimes inevitable that a mechanic must work in close proximity to the equipment when it is switched on.

*Table 7 Life phases of electromagnetic field producing equipment.*

| | phase / activity | type of company or sector | exposed employee |
|---|---|---|---|
| 1 | designing and developing | research applications | researcher |
| 2 | testing prototypes | manufacturer or EMC testing organisation | testers |
| 3 | manufacturing equipment | manufacturer | - |
| 4 | installation | installation company commissioned by future user | installation worker |
| 5 | use | user | user |
| 6 | maintenance (incl. troubleshooting) | user or external maintenance company | maintenance engineer |
| 7 | waste phase / second-hand use | scrap dealer | - |

The working environments of employees in the installation branch are generally characterised by the wide diversity of the equipment with which these workers come into contact. Large installation companies are involved with virtually all stated groups of equipment.

Partly due to these specific circumstances, the installation branch will be dealt with separately. The equipment that produces electrical, magnetic or electromagnetic fields to which workers may be exposed is classified here into three types:

- equipment operated by the worker
- equipment installed or maintained by the worker
- equipment that the worker could approach.

Ambulant workers working at a location that is not owned by their employee, e.g. maintenance workers and cleaners, remain under the responsibility of their employer. These types of employers must make agreements with the owners of workplaces for the protection of their employees from exposure above the action values, e.g. switching off an antenna when workers are busy on a roof. It is important that thorough training is given on how to work with and near equipment that generates electromagnetic fields. This must include all types of practical examples and make the consequences clear e.g. workers must not stand next to an antenna because of the risk of heating up excessively. It is also advisable to provide safety rules for working with and near electrical equipment. Examples are: 'check that the machine has been switched off' and 'keep at least 2 m away from the bench'.

## 3.3 Detection of articles and people

Electronic Article Surveillance (EAS) and Radio Frequency Identification (RFID) are generic names for remote detection and identification of marked goods and living beings. EAS systems only detect, but RFID systems also convey information. The third type of detection equipment is metal detectors. The EN50357:2001 standard [15], which was drawn up as a result of the EU recommendation, states how the exposure can be assessed for these three types of detection equipment.

*EAS systems*

EAS systems consist of detection panels, labels and deactivators. The panels are often placed in detection gates at the exits of shops, museums or libraries etc. They consist of a field-generating component, usually a current carrying coil that generates a largely magnetic detection field at low frequencies, and a field-receiving component. Sometimes there is both a receiving and a transmitting panel, but there can also be multiple, overlapping transmitting and receiving components in one panel. The labels are mostly passive i.e. they do not have their own energy source. They are metal strips or LC circuits that disturb the generated field by creating a harmonic component, a resonant pulse or a phase displacement. The alarm sounds when the receiving panel detects this disturbance. According to EN 50357:2001 the less frequently used active labels that have their own energy source generate fields that are two to three times weaker than panel fields. EAS systems only detect whether or not a label is in the gateway. The deactivators are sometimes permanent magnets, but alternating current magnets are also used.

EAS systems may be in any of four frequency ranges. These are split into four groups in accordance with EN50537:2001:

1. non-linear magnetic (10 Hz - 20 kHz; continuous wave at a specific frequency);

2. (pulsating) resonant inductive or acoustomagnetic (20 - 235 kHz, pulses at a specific frequency);
3. resonant radio frequency (1 - 20 MHz, sweeps through a frequency band); and
4. non-linear microwave (0.8 – 2.5 GHz, pulsating waves).

For the first three frequency ranges the near field is around the gate, where the magnetic field usually dominates. The action values for the electric field strength are not generally exceeded [8].

Establishing exposure levels is not easy due to the complex signals with components from various frequencies and exposure to a non-uniform field. The ICNIRP statement from 2003 [35] and the EN50357:2001 standard provide guides for assessing exposure levels for these types of signals. In any case for non-sinusoidal waves such as pulsating waves it is important not just to check the RMS value with the action value; the peak value of a pulse should also be compared with the peak action value[2]. In general the action values are conservative for non-uniform exposure and exceeding the action values does not often lead to exceeding the exposure limit values [2].

From various measurements carried out on EAS systems, it appears that the exposure levels inside the gates are close to the action value levels, but they are also occasionally exceeded. For non-linear and magnetic systems field strengths of 7 to 12 times the action values have been measured close up against the transmitting panel and in the middle up to approximately 7 times [16]. In practice, from other measurements it appears that peak field strength of 30 to 110% of the peak action values occurs between the gates [9]. For lending library systems, levels of 1.3 times the action values were found at a distance of 10 cm [10]. For resonant inductive systems, up against the transmitting panel, field strengths of 0.1 to 1.1 times the action values were measured and between the gates levels up to the action values [16]. For other types of gates peak field strengths up to 150% of the peak action values have been encountered [9]. For resonant radio frequency systems, up against the transmitting panel, field strengths of 1.2 to a maximum of 5 times the action values were measured [16, 8] and between the gates up to 1.3 times the action values. No instances of the action values being exceeded were found with microwave systems [16]. For deactivators at distances of 3-5 cm, i.e. next to the hands, field strengths of 1.8 to 10 times the action values were measured [9, 17].

From a conservative numeric dosimetric analysis of exposure levels for the systems tested by the NRPB, no cases of exceeding of the exposure limit values were found [8]. In 2001, Gandhi and Kang [18] calculated the current density in various organs

[2] The peak action values for frequencies up to 100 kHz can be calculated by multiplying the action value by $\sqrt{2}$.

using the resistance method. For this they used a model of a fictitious EAS system that operated using a current of 100 A and a frequency of 30 kHz in two coils. They calculated that for this inhomogeneous field, the maximum exposure level in the gateway was 280 μT. That level exceeds the 30.7 μT action value by a factor of 10. They calculated that for an adult male the maximum current density in the central nervous system was 17.63 $mA/m^2$ in the brain and 32.64 $mA/m^2$ in the spinal column. Both these current densities remain under the exposure limit value of 300 $mA/m^2$. For a model of a tag deactivator operating at 1 kHz, the maximum current densities, 0.48 $mA/m^2$ in the brain and 0.23 $mA/m^2$ in the spinal column, were both under the exposure limit value of 10 $mA/m^2$. The practical research indicated that calculations had also been done for the anticipated current density of various types of EAS system made in the Netherlands. Here it was established that for an 8.2 MHz deactivator with a duty cycle of 0.01 and 15 A bursts, the maximum values for the brain and spinal column respectively were less than 0.5% and 2.5% of the exposure limit value of 82,000 $mA/m^2$ at 85 cm height and 35 cm from the centre of the coil. Nor were the SAR values exceeded, whereas the action values were exceeded by more than 10 times. Using the resistance method, Gandhi calculated the current density and the SAR for a human model located at 20 cm from the transmission panel for the NEDAP EAS system with the OID45 antenna. This system transmits using a frequency of 8.2 MHz and consists of a gate with two panels, with a transmission panel consisting of two coils, each with a current of 0.1 A RMS. Gandhi found that the maximum current density was less than 7% of the exposure limit value and the maximum SAR was less than 0.002% of the exposure limit value for a maximum exposure to a non-uniform magnetic field of less than 82% of the action value [19]. Thus this specific application - NEDAP EAS OID 8.2 MHz - falls into category I.

From the measurements above, it appears that instances of action values being exceeded have been measured for various anti-theft gates of the types non-linear magnetic, resonant inductive and radio frequency interactive. At the gates in the lowest frequency range, the non-linear magnetic ones exceeded the action value to the highest degree. From calculations of the induced current density in the central nervous system, it appears that the exposure limit values are not exceeded for an inhomogeneous field with maximum measured field strength of 10 times the action value. Exposure in working situations can be avoided for these three systems by not leaning against the panels and antennas. The rule of thumb is to keep a distance of 1 m [20]. This equipment falls into category IIa because in spite of the action values being exceeded no instance of the exposure limit values being exceeded was established. In addition, straightforward measures are possible.

For non-linear microwave systems, no instances of the action values being exceeded are known of, and the same applies for the exposure limit values. Thus this application falls into category I. However the number of published test results is limited and thus also in this instance it is advisable to maintain a 1 m distance.

It appears that deactivator fields can exceed action values at the positions of hands and arms, but here too, due to the distance to the torso, exposure limit values are not exceeded. Thus deactivators fall into category I.

*Metal detectors*

There are two types of metal detector: manual detectors and gate detectors. The operation is largely the same as with EAS systems. A continuous or pulsating magnetic field is transmitted. When a metallic object enters the detection zone it creates a disturbance in the field. The transmitted field creates an eddy current in the metallic object that generates an opposing field. This disturbance is then measured. Metal detectors are used for security at airports and clubs etc., and for detecting objects in the ground.

The signals for gate detectors are continuous sinusoidal signals at one or more frequencies (630 Hz – 7.375 kHz), or low-frequency pulsating waves between 89 and 909 Hz. Hand detectors usually operate using unmodulated sinusoidal signals between 13 kHz and 1.9 MHz [21].

Hietanen *et al* [9] observed that the action values could be exceeded close to the surface of hand-held detectors, but the publication does not include test results. Boivin *et al*. [22] have carried out tests on both hand-held and gate metal detectors. At 5 cm from nine hand-held detectors operating at a single frequency between 94.8 and 132.9 kHz, they found maximum RMS values for the magnetic field between 1.06 and 2.41 A/m. The lowest action value in the frequency range, 12.1 A/m, was thus not exceeded. The ten gates operated with pulsed and modulated signals with equivalent frequencies of 0.1 – 3.5 kHz. For a system at 3.5 kHz, a field strength of 125% of the action value was measured and for a system at 0.2 kHz, this was a field strength of 106% of the action value. For hand-held detectors at 20 and 94 kHz NRPB [8] did not measure any instances of the action values being exceeded. For a gate detector, they calculated the contribution of all frequency components (peak amplitude 1 kHz) using the summation rule and ended up with exposure factors that did not exceed the limit of 1: 0.69 and 0.40 respectively.

For hand-held detectors field strengths of more than 25% of the action values have not been reported. These fall into category I.

For gate detectors, in a few instances field strengths up to 125% of the action values have been measured in the gateway. Usually, the field strength has been lower than the action value. Since the exposure is in the non-uniform near field, it is reasonable to assume that, as with the EAS systems at this frequency, the exposure limit values will not be exceeded. Gate detectors fall into category IIa. A rule of thumb for preventing exposure to levels above the action values is to keep at a distance from the source, thus in any event not stand in the gateway or lean against the gate.

*RFID systems*

RFID systems detect a disturbance in the same way as EAS systems, but they also detect specific information. An RFID system consists of a transmitter, a receiver and a label or transponder. The label receives a signal from the transmitter, identifies this and then sends a response to the receiver. Sometimes the transmitter and the receiver are placed together in a single component, as in the case of hand-held readers. Applications for RFID systems include tollgates on motorways, access gates, stock control, labelling of articles in shops and tracking goods such as cases, meat and containers during transport. The implantation of small tubes containing a chip in household pets is also finding human applications. This technique can be used to store medical records and access data stored in people. RFID systems can operate with fixed antennas, with mobile and also hand-held readers.

Table 8 shows that RFID systems operate at various frequencies, depending on the quantity of information to be transferred and the required reading speed. The more information or the higher the reading speed, the larger the bandwidth. The Dutch RFID Packaging Standards working group aims to have developed a standard by the end of 2008 [23]. RFID systems are still very much under development and the number of applications is also increasing [24].

*Table 8 RFID systems and their typical frequencies (from the standard NEN-EN 50357:2001 [15]).*

| frequency | characteristics | typical applications |
|---|---|---|
| low<br>1 Hz – 500 kHz | short to intermediate distance, low read speed | access passes, animal identification, stock control |
| intermediate<br>2 – 30 MHz | short to intermediate distance, normal read speed | access passes,<br>smart cards |
| high<br>850 – 950 MHz<br>2.45 GHz, 5.8 GHz | long distance,<br>high read speed,<br>must be in line-of-sight | railway wagon monitoring, tollgates |

For short distance applications such as access pass readers, powers vary from 100 mW to 2 W [21]. Tollgates, where the distance between the RFID chip and the reader is larger, will generally require the use of higher power. The exposure limit value above 100 kHz is a local (head and trunk) SAR of 10 W/kg. The exposure level can be assessed by use of a straightforward and conservative calculation.

The following calculation example shows when the exposure limit value for heating up can be exceeded. Suppose that all energy transmitted by an RFID apparatus is absorbed in a 10 gram cube of tissue in the head or the trunk. Then this 10 grams of tissue may not absorb more than 10 W/kg averaged over a random period of six minutes. Thus the cube may absorb 10 W/kg * 0.01 kg = 100 mW. Thus any antenna radiating less than 100 mW averaged over six minutes cannot cause the exposure limit value to be exceeded. That means that exposure to equipment that has a maximum transmission power of 2 W may last a twentieth of six minutes, i.e. 18 seconds (2 W/20 = 100 mW). Note that this calculation is very conservative. Usually the energy will be absorbed by much more than 10 g of tissue and not all transmitted energy will be absorbed by the body.

ICNIRP observed in 2004 that there are few test results known relating to exposure to RFID systems [21]. Polichetti and Vecchia [25] have tested four types of pass reader (proximity detectors). All four used a frequency of around 120 kHz. The magnetic field strengths at 10 cm from the reader varied from 5 to 10 A/m – below the action value of 13.3 A/m. For a card reader (120 kHz, at 7.5 cm), NRPB [8] observed a field strength of 1.2 times the action value, at an RFID antenna (134 kHz, 2.5 cm) a field strength of 1.7 times the action value and for a card reader (4.9 MHz, 2.5 cm) a field strength of 4 times the action value. However, an NRPB numerical analysis indicated that exposure limit values were not exceeded, both for the SAR and for the current density in the central nervous system.

Calculations on two card readers produced in the Netherlands operating at 120 kHz and at the normal reading distance of 20 cm showed that the flux density was less than 40% of the action value of 16.7 μT. The exposure was less than 1% of the exposure limit value of 1200 $mA/m^2$. Also, for a library system operating at 13.56 MHz, the SAR was 3% of the exposure limit value of 10 W/kg for head and trunk.

RFID systems are still very much in the development phase and few test results have been published. It does appear from the calculations discussed here that the exposure limit value for current density in the central nervous system is not being exceeded. At frequencies below 10 MHz, such as with a card reader, it is unlikely that the exposure limit value for current density will be exceeded. At frequencies above 100 kHz and power up to 2 W it is not likely that the exposure limit value for heating, the SAR, will be exceeded. For power levels above 2 W the 'six-minute' rule must be used to establish whether the exposure limit values could be exceeded (see Appendix 1). This usually requires a few simple calculations with the assistance of rules of thumb.

RFID systems up to 500 kHz fall into category I. RFID systems with powers up to 2 W, frequencies above 100 kHz and a maximum duration of exposure of 18 seconds per six minutes or a duty cycle of 0.05 fall into category I. RFID systems with a higher power or a longer duty cycle require a calculation, as do transmitter antennas. Thus these systems fall into category IIa.

## 3.4 Dielectric heating

Dielectric, capacitive or radio frequency (RF) heating are the names of processes that transfer heat to non-metallic objects by placing them between two capacitor electrodes, often in the form of plates. Dielectric heating is used for gluing and drying wood, drying various materials such as tobacco, ceramics, leather, fibres and paper, in plastics and rubber manufacture, and in food processing. RF plastic sealers are used in plastics manufacturing and processing. This is referred to as the welding of plastics or synthetics. Capacitive heating is used in industrial sectors (D): furniture manufacture (DN), the timber industry and the manufacture of articles made from wood, cork, basketwork (not furniture) (DD) and the manufacture of rubber and synthetic products (DH).

Different frequencies are used in the range 10 to 110 MHz. Typical frequencies are 13.56 MHz, 27.12 MHz and 40.68 MHz. The first two frequencies are Industrial, Scientific and Medical (ISM) frequencies [26]. For these frequencies the action values are 61 V/m and 0.16 A/m. For frequencies of 10 - 110 MHz the operator is in the near field and thus implicitly becomes part of the transmission system. The action values are drawn up for the uniform far field, while the operating location for dielectric equipment is generally in the non-uniform near field. Thus measurements must be carried out in accordance with a protocol, followed by calculation or analysis to establish whether the exposure limit values are being exceeded. ILO [27] states several methods; see also Section 4.4.2 for a model analysis based on information from an HSE document [11]. It is certainly not sufficient just to carry out measurements in one operating position. A radius of half a metre should be used, because small shifts in position might cause exposure to a different field strength. Also, the degree to which energy can be absorbed depends on the currents that run through the body. An operator could grab hold of a bench, the electrodes or the plastic workpiece. When an operator is standing, he or she may be operating a press. The capacitors are often located on the press plates (Figure 5). In these cases the entire body is exposed causing induction currents through areas such as the ankles. There are techniques for the direct measurement of currents through the ankles and the wrists [11]. These currents are higher when the operator is sitting at the workbench and then, as often happens, is holding the workpiece. However in the latter situation it is the hands that are often exposed to higher field strengths [28].

*Figure 5 Dielectric press for sealing synthetic materials.*

Kleinjans and Schuurman [6] published figures from foreign measurements from 1993 where the magnetic field regularly exceeded the action value by several times (up to 478%). The electric field strength varied at the operating position, typically from 10 to 300 V/m and the magnetic field strength between 0.1 and 20 A/m [9]. In 1988 and 1997, Gandhi performed calculations [29, 30] that showed that workers received an increase in the whole body SAR for specific positions of the hands between the capacitor plates. Jokela and Puranen [31] noted that equipment for dielectric heating was the most important radio frequency safety problem in the working environment. They also measured peak values of 1 kV/m and an induced current of 600 mA. They established that 194 V/m and 100 mA were not unusual. Calculations showed that at 100 mA a local SAR of 20 W/kg occurs and the whole body SAR varied from 0.12 to 2 W/kg. This exceeded the exposure limit value of 0.4 W/kg [9, 31, 32, 33].

Despite the equipment being capable of producing field strengths above the action values, an average exposure duration for the material is approximately 2-3 seconds per 30 second handling when welding plastic and 1 minute on a heating cycle of 6 minutes for gluing wood [27], so that after application of the 'six-minute' rule (see Appendix 1), the average exposure does not necessarily rise above the action values, let alone the exposure limit values, if the worker is not standing continuously at the bench. That the exposure does not necessarily rise above the action value when the quadratic field strengths are averaged was confirmed during a visit to a Dutch manufacturer. In addition measures are usually taken, or can easily be taken, to reduce the field strength. These include shielding the presses, marking off the floor, or moving the operating panel further than 2 m from the presses among many other options [27, 34].

A Dutch company produces, maintains and overhauls RF equipment that usually works at 3 MHz - 70 MHz with powers of 1 - 80 kW. Their anonymised test report about this situation showed that the maximum electric field strengths exceeded the action values. However, because the 'six-minute' rule may be used for fields with a frequency higher than 100 kHz, the operator is exposed to an average field strength below the action values for his or her normal time at the workplace. For frequencies up to 10 MHz the current density in the central nervous system must not exceed the exposure limit values. In this instance the 'six-minute' rule may not be applied prior to checking with the action values.

If the shielding is damaged, the conductor is damaged or there is a defective earth connection, exposure levels can increase to above the action values. Also, if the machines jam, the shielding is sometimes removed to make it easier to reach mechanical parts, e.g. for woodworking machinery. The practical research indicated that there were situations where it was helpful to advise companies to measure electromagnetic fields during annual maintenance. Of the approximately 300 users of around 500 high-frequency heating units in the Netherlands, 40 users regularly carry out measurements. The machines are robust and often operate for periods of 10 years and longer without breaking down. A consequence of this is that annual maintenance is generally considered to be unnecessary.

Dielectric equipment is placed in category IIb, because it has been found that with irregular maintenance, exposure levels above the action values can occur. This has been seen during careless operation and even during normal operation. Measures for protection and maintenance are available for these machines.

## 3.5 Electricity production and distribution

The production and distribution of electricity includes a wide variety of equipment that operates at 50 Hz. At this low frequency, the electric and the magnetic fields must be considered separately. The electric field can be easily shielded, but shielding of the magnetic field is virtually impossible at this frequency.

The literature shows that rectifiers, exciters, generators, bus bars and transformers produce fields that can exceed the action values at normal approach and operating distances [8, 9]. For other components such as overhead power lines, substations and switch gear, instances of the action values being exceeded have been reported, but often only at the extremities and not at the head and body, so that exposure limit values were probably not exceeded. No instances of action values being exceeded in power station and substation control rooms have been reported.

The ‘Electricity production and distribution’ industry sector primarily covers large and small units that generate electricity for supply to the public grid or for internal company use (e.g. combined heating and power stations). It also covers the transport and distribution of electricity. The ‘end stage equipment’ that finally converts the electrical energy into other forms of energy is not part of this industry sector. The transition takes place in the user’s ‘meter cupboard’.

In general, magnetic fields can be considerable at locations where the distance between three phase system cables is large and where strong, unbalanced, currents flow.

*Power stations*

Power stations generate high power at low voltage. These low voltages are subsequently transformed to voltages from 110 to 380 kV for transport via overhead power lines. Because high power generators produce low voltages and very high currents, these currents can produce strong magnetic fields. NRPB measurements at generators in several power stations indicated that the fields remained below the action values. Magnetic fields that exceed action values by a factor of approximately 10 have been reported in the vicinity of power station bus bars. But this only applies to the arms and legs. The action values for magnetic flux density for the head and trunk can be exceeded by a factor of two to six near transformers, rectifiers and conductors [8]. Due to these potential cases of the action values being exceeded power stations have been placed in category II.

*Overhead power lines*

RIVM has calculated magnetic field strengths at the pylon for typical 150 and 380 kV lines using the EFC400 computer program (*Forschungsgesellschaft für Energie und Umwelttechnology GmbH*; version 5.1): see Figure 6. It is normal practice in the Netherlands to switch off a circuit when work on it is being carried out. The other circuit then receives double the load. The calculations were carried out for an extreme situation where the maximum current flowed through one circuit. The calculations indicated that the action value of 500 μT at the crossbeam was not being exceeded. Thus overhead power lines have been placed in category I.

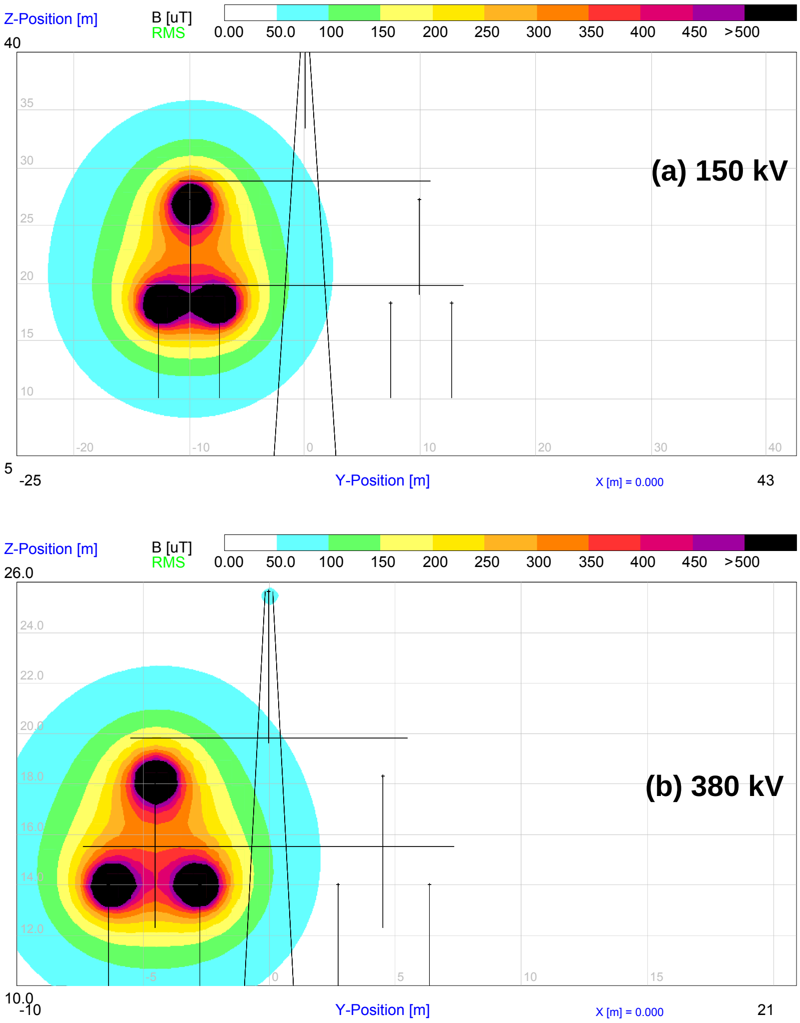


*Figure 6 Calculated field strengths near overhead power lines at pylons.*

*Substations with capacitor banks*

During the practical research, meetings took place with several grid management companies and one substation was visited that had a capacitor bank. In this substation the action value of 500 µT was never exceeded. A fence surrounded the air cooled coils and the access door was secured in such a way that it could only be opened if the capacitor bank was switched off. Because exceeding the action values is a possibility in this working environment, it is classified in category IIb.

*Small substation buildings*

During the practical research enquiries were made about measurements of magnetic field strengths in small substation buildings in the grid. The fields are strongest on the low-tension side of the transformer. On the outside wall of these substations levels of a few μT are generally measured. In the immediate vicinity (at around 1 m) of distribution substations KEMA has measured magnetic field levels of 10 to 30 A/m [14]. These values lie more than a factor of 10 below the 400 A/m action value at 50 Hz. Thus small substation buildings have been placed in category I.

## 3.6 Electrochemical processes

All processes where the energy for the chemical process is supplied by an electric current, e.g. electrolysis or surface treatment, are classed as electrochemical processes. Currents of tens of thousands of amperes are used in this type of process, so that there is a likelihood of magnetic fields exceeding the action values.

An electrolysis process works like a battery in reverse. Direct current (DC) is used to provide power for a chemical process. Examples are the electrolysis of brine (sodium chloride solutions) to produce chlorine gas and caustic soda (sodium hydroxide), and the extraction of metals such as zinc, cadmium and aluminium from ores dissolved in water and acid solutions. Also a number of surface treatment processes such as electrolytic zinc coating (zinc plating), chromium plating and tin plating can be considered to be electrolysis processes.

An electrolysis installation has three environments in which workers may be exposed to strong magnetic fields: the transformer-rectifier room, the bus bars and the electrolysis hall. Depending on the application this hall consists of a number of long parallel baths, the electroplating baths, with walkways in between. These baths consist of multiple cells in which the actual electrolysis process takes place.

Electrolysis companies have a total power consumption equivalent to that of a medium-sized town. The 50 Hz alternating current (AC) provided via an overhead power line must be rectified to produce the DC required. Usually, DC is produced from three phase AC using thyristors to switch the negative voltage of the sinusoidal 50 Hz and thus superimpose three phase-displaced positive sine waves. This provides a direct current component (DC) with an alternating current component (AC) superimposed on it. The AC component consists mainly of a 300 Hz signal with a few 50 Hz higher harmonic components. Using the summation rule, this AC component can lead to exposure levels above 1 [5, 35]. The most important components come from 300, 600 and 900 Hz. Instances of the action values being exceeded have been observed by Moen et al and others. [36]. One way of limiting the DC ripple is to smooth the ripple by using a suitable type of rectifier or by using more phases in the rectification process [37].

From measurements carried out in a zinc production factory in the Netherlands using 60 kA in the electrolysis process, it was found that after application of the summation rule the normalised exposure in rectifier rooms sometimes lay between 1 and 8 and in a few not easily accessible locations, multiples of 10. Around the conductors at working distances of more than 40 cm and in the electrolysis hall no normalised exposures above 1 were measured. Thus measures are required for the rectifier rooms. Strictly following the Directive means that workers would no longer be allowed to enter these areas and that the areas should be enclosed up to the points where the action values are no longer exceeded. It is almost certain that workers will be exposed to levels above the exposure limit values. The problem is that at least one person must enter the area on a daily basis to carry out visual inspection duties. Following a visit to the company it turned out that measures such as fencing off the rectifier room and keeping the bus bars out of reach were possible.

During the practical research, when a Dutch company producing chlorine by membrane electrolysis was visited, it was found that following application of the summation rule the normalised exposure in the rectifier room came out above 5 next to the transformers (50 kA DC at 400 V) for four electrolysers. Also, the normalised exposure could be above 5 around the bus bars (conducting 50 kA). In the electrolysis hall, between the electrolysers through which 12.5 kA was flowing, only the 300 Hz component led to values of 160% of the action value of 60 A/m. Here too, measures are necessary for the rectifier room. During a company visit no-entry areas marked by paint were seen around the bus bars. In addition the magnetic field can also be limited by running the feed and return bus bars from the rectifier to the electrolysers alongside each other in the electrolysis hall. In practice regular visual inspection must be carried out between the electrolysers to check that no leakage has occurred between compartments. These inspections are necessary to prevent the release of poisonous or explosive materials.

On the basis of company visits, KEMA measurements and published literature, the rectifier room has been classified in category III because the exposure levels there can be several tens of times higher than the action values. The conductors fall into category IIb because due to fencing in, marking and placing the feed and return conductors alongside each other over as long a distance as possible, the exposure level can be kept below the action value. The exposure in the electrolysis hall depends on the design of the hall, but the action values need not be exceeded. Thus the electrolysis hall falls into category IIb.

## 3.7 Induction heating

Induction heating is a generic name for the processes that generate heat using alternating current flowing through large coils. Induction heating is used in the manufacture of tools and machine components, forging, surface hardening, shrink fitting, bending pipes, soldering sheet metal and in vacuum furnaces for melting and processing various metals and alloys such as cast-iron, nickel, zinc, various types of steel and aluminium [8]. The industrial sectors where induction heating is used include the manufacture of various types of tools (DN) and the manufacture of metals in their primary form and of metallic products (DJ).

Although the principle of induction heating remains the same, the equipment is often tailor-made and thus there is a wide variety of types available with differing power and frequencies. Large melting furnaces often work at 50 Hz, because a large wavelength provides homogeneous heating of the material. Higher wavelengths penetrate less deeply and are used for surface treatment. According to Gabriel et al typical frequencies lie between 50 Hz and 8 MHz, with power between 300 W and 5 MW [11]. In practice, as several brochures/leaflets show, the equipment is tailor-made and power levels up to 10 MW are in use [38]. Field strengths measured for the H-field lie between 0.1 and 20,000 A/m and for the E-field between 3 – 1000 V/m. Several investigations [8, 9, 10, 37] have indicated that induction furnaces are the most powerful sources of magnetic fields in industry. At a frequency of 800 Hz Floderus et al [10] measured electric field strengths of 4000 V/m at 0.1 m and 1400 V/m at 0.5 m. This exceeds the action value of 625 V/m by several times. Chadwick [37] reported that near a steel strip processing machine operating at a frequency of 50 Hz the magnetic flux density at the left side of the bench was 0.9 mT. This is almost double the action value, which is 0.5 mT at 50 Hz. Both NRPB [39] and the Finnish Institute of Occupational Health (FIOH) [9] reported that they had measured instances of the action value being exceeded near various types of induction heating equipment. Sometimes coils are not shielded and during the production process they could be approached to distances as close as 10 cm [8, 37], making exposure to field strengths higher than the action value a possibility. Although, according to Cooper, instances of exceeding the values were mainly found at locations closer to the equipment than the operator's position. Application of the 'six-minute' rule at frequencies above 100 kHz (see Appendix 1) ensures that exposure levels actually remain below the action values.

In addition to the wide range of frequencies and powers, the working procedure is also very important. During visits to metal producing companies it was apparent that on the one hand induction furnaces were fenced, but on the other there were sometimes walkways between induction furnaces. Keeping at a distance is often a simple way of reducing exposure levels, and in the case of furnaces the radiated heat is sufficient to ensure that a safe distance is maintained. In practice with smaller induction furnaces, for example for the production of alloys, workers protected by heatproof suits can approach the open doorway to add material or carry out measurements. Measurements carried out by Chadwick [40] and Rubio

[41] indicate that for a 1 kHz furnace the worker can be exposed to field strengths of 10 times higher than the action value.

In the Netherlands, KEMA has carried out measurements at companies that use induction heating. A 1993 report indicates that action values were exceeded at a few locations in an alkane and a phosphorus factory. Locations in the phosphorus factory where the action values were exceeded by up to 3 mT at an operating current of 60 kA were measured. Measurements were carried out around the furnace fencing at a maximum of half a metre and a few other places, e.g. 1 m outside the fencing between the control room and the electrode and between the column and the electrode, within half a metre of the power supply cables and the transformer. For the record, workers did not have to remain at the aforementioned locations to carry out their work. It was shown that the magnetic field strengths at locations where workers had to remain on a permanent or semi-permanent basis were not higher than 0.04 mT.

Other measurements done by KEMA at other Dutch companies [14] indicated that exceeding of the action values was a possibility for various types of induction heating equipment, but that this could often be avoided by the use of simple measures. One induction heater for heating bearings that operated at 50 Hz consisted roughly of a hand operated coil at hip height. At a distance of 5 cm from the coil an exposure of 400 A/m was measured - four times the action value. When the distance was increased to more than 20 cm the action value was not exceeded. Cases of the action values being exceeded were also measured during semi-mechanised processes where the object to be heated was transported through the coil on a conveyor belt. For example, immediately in front of the entrance to a machine (10 kW, 3 kHz) for preheating tubes prior to the application of a coating action values were exceeded by a factor of 12, but at a distance of 20 cm the action values were no longer exceeded. A tube heater (10 kHz) caused no cases of exceeding the action values outside 50 cm. Also an induction furnace (50 Hz) for heating metallic wheels showed action values being exceeded at the wall, but not at 30 cm. With semi-mechanised processes it is often simple to keep workers at a safe distance.

A visit to a large Dutch company that maintained, repaired and overhauled various types of induction equipment showed that induction equipment had service lives of tens of years before renovation was required. This can cause problems, because in old equipment the coil is not always shielded (Figure 7). After overhaul or in the case of a new induction heater, the induction coils are usually placed in a Faraday cage such as in a furnace, or they operate fully automatically like wire heaters so that operators are not exposed to levels above the action values for electric or electromagnetic fields. A Faraday cage does not shield low-frequency magnetic fields efficiently.

*Figure 7 An induction heater with open coil - ready for overhaul.*

Induction heating equipment falls into category IIb, because of the incidences of exceeding the action values reported in the literature in EU countries and the few instances of a lack of shielding. In the Dutch situation measurements of excessive levels are also known, although these were not at locations where workers were present at all times. Simple measures like shielding the source, marking restricted areas and the use of fencing located on the basis of measurements can ensure that exposure levels remain below the action values.

Melting furnaces that must have materials added to them manually during the production process, or where measurements must be carried out through an opening in the furnace can lead to exposure levels several tens of times above the action values and thus fall into category III.

## 3.8 Welding

*General*

Welding is a technique for joining pieces of metal together. The joint is formed by heating the metal and bringing the components together. As with soldering, a joining metal is sometimes used. The websites www.nil.nl and www.dunneplaat-online.nl provide a summary of the most commonly used welding processes in the Netherlands and how they are carried out. In addition to gas welding and laser welding there are various types of electric welding that can be divided into the following main groups:

- arc welding processes (incl. MMA, TIG, plasma, MIG, MAG, powder and stud),

- resistance welding processes (incl. spot, seam, projection and flash butt),
- high frequency resistance welding processes (incl. high frequency, induction) and
- electron beam welding processes.

Welding is used in several sectors of industry such as construction and the manufacture of diverse metallic objects and vehicles.

*Types of welding process*

Arc welding involves striking an electric arc between an electrode and a workpiece to melt the materials to be joined. Direct current, pulsating direct current and alternating current are used. The AC frequency is often the mains frequency of 50 Hz. Higher frequencies are also used because they produce a better-looking weld. The resistance welding process involves firmly pressing the two components together and passing an AC current across the gap for a short period, often less than a second. High frequency resistance welding processes do not use mains frequency, but frequencies above 100 kHz (100 - 500 kHz, 50 - 1500 kW). The advantage of a higher frequency is the lower penetration of heat. The energy is concentrated more at the surface of the workpiece. This enables working at lower current strengths. Electron beam welding processes warm up metal by means of electromagnetic fields from an electron gun. This process is often carried out under a vacuum and therefore it is mechanised.

*Exposure factors and potential excessive exposure*

The exposure limit value that is likely to be exceeded is for induced current as a consequence of an alternating magnetic field. At the mains frequency of 50 Hz the action value is 0.5 mT and the exposure limit value is 10 $mA/m^2$. The most important factors that determine the exposure to magnetic fields during welding processes are:

- duration of the actual welding process,
- current strength,
- current type (DC, pulsating DC or AC),
- high frequency start pulse,
- degree of mechanisation (manual, semi-mechanised or mechanised),
- working procedure (distance from the weld and from the current carrying cables),
- shielding and protection measures.

With the exception of high frequency resistance welding, all welding processes are carried out using DC or AC with a frequency of less than 100 kHz. At frequencies lower than 100 kHz, the magnetic field strength may not be time-averaged. The time that the equipment is switched on is not a significant factor here, as it is for welding fumes.

*Current strength and type*

The current strength varies with the welding process from a few tens of amperes for plasma welding, a few hundred amperes (usually less than 350 A) for the other arc welding processes, to thousands of amperes for resistance welding. Voltage levels are usually from a few tens of volts up to mains voltage. Roughly speaking, exposure levels increase with increasing current strength. DC generates a static field, except for pulsed welding as is used for TIG welding of aluminium usually at 25 Hz (sheet metal). MIG welding can also be used with DC or pulsating DC with frequencies from 0.2 to 3 kHz [42]. Two company visits indicated that for arc welding processes there is a tendency to work more with DC, except when working with aluminium [43]. Cie VIII from the Netherlands Institute of Welding (NIL) indicates that 80% of manual arc welding consists of MIG/MAG welding and 10% manual metal arc welding using DC.

Current sources that produce square waves and pulsating signals are used for MIG/MAG and other processes. These can operate at frequencies up to 300 Hz and the square waves also produce harmonic components. Instances of exceeding the action values by a factor of 3 have been measured at a frequency of 191 Hz and a current of 420 A commonly used in practice [43]. In addition, strong electromagnetic fields are formed because during arc welding a high frequency pulse lasting a few milliseconds is used to strike the arc.

Even if only DC is used, the rectifier can cause magnetic fields of various frequencies. A three-phase transformer with diode rectifiers usually provides DC with a small ripple of approximately 4%, mainly caused by the sixth harmonic component (300-360 Hz). Adjustable current sources with thyristors provide more harmonic components because they chop off the sine wave [42]. This leads to higher frequencies and higher induced currents [44]. With single phase resistance welding using AC, higher harmonic components up to 1150 Hz appear to play a role [43]. Applying the summation rule for various frequency components indicates that the action values will be exceeded at the operator's position. Moreover measurements carried out on a frequency inverter used for resistance welding showed that at a switching frequency of 2000 Hz and currents of 5 kA and 15 kA the field was higher than the 0.03 mT action value at normal user distances.

*Degree of mechanisation*

Examples of manual welding processes are: MMA welding (only possible manually), some other types of welding process such as TIG and some spot welding processes such as projection and spot welding. During manual welding the weight of the current carrying cables is sometimes born by slinging them over the welder’s shoulder. To keep the hand steady the cable is also sometimes run along the thigh or twisted around the arm as was noted during a company visit. It can be expected that these high current levels will lead to the action values being exceeded [42, 45]. For most arc welding processes according to the Health and Safety Executive (HSE) the action values are not exceeded at a distance of more than 10 cm from the cable. For arc welding with DC the field strength is 30% of the action value at 20 cm from the cable. Although the welder's hands are exposed to levels above the action values, it is not likely that the exposure limit values will be exceeded.

For semi-mechanised welding processes, where an operator stands at a bench, the arms and hands that touch or are just a few centimetres from the cables or electrodes could be exposed to levels above the action values. Examples of semi-mechanised or fully mechanised processes are some arc welding processes (stud and powder welding), resistance welding processes (seam welding and spot welding), high-frequency welding processes and electron welding processes. HSE [43, 44], Cooper [8] and Hamnerius and Persson [46] have measured levels above the action values for spot welding processes.

The HSE measured instances of the action values being exceeded during resistance welding at 15 kA within 30 cm of the electrodes, i.e. at the welder's working position. Application of the summation rule to the higher harmonic components indicated that the action values were being exceeded by a factor of 60 at a distance of 10 cm from the electrodes. Nadeem et al [44] measured 3.7 mT at 26 cm and 1.1 mT at 42 cm (11 kA and 50 Hz), where the action value was 0.5 mT. They also calculated that up to 34 cm the induced current strength was 14 mA/m$^2$, so that the exposure limit value of 10 mA/m$^2$ was exceeded. Conversely Cooper (NRPB) considered it to be unlikely that the exposure limit values would be exceeded if only hands and limbs were exposed above the action values. After all, the Directive gives exposure limit values for current density to protect tissue in the central nervous system. See Note 2 in Table 1 of the Directive. The hands are not part of the central nervous system. Even when the exposure of the head and trunk is above the action values, non-uniform distribution of the magnetic field may mean that the exposure limit values are not exceeded.

KEMA [14] has also measured field strengths at several semi-mechanised, high frequency induction welding units (200 – 400 kHz, 1000 - 250 W) for welding tubes in the Netherlands. At distances where an operator might be working (80-110 cm), field strengths of 100 - 300% of the action values (8 - 4 A/m) were measured. The machines did not have operators, but that does not mean that people are not in the vicinity from time to time. In such situations, because of the 'six-minute' rule, keeping to a limited exposure period or keeping at a distance is sufficient to prevent exposure above the action values. However, the construction of physical barriers such as safety doors is advisable. Measurements carried out on industrial induction soldering machines (20, 25 kW, 10 kHz) indicated a maximum of 9 times the action values (24.4 A/m). No time-averaging may be carried out here and maintaining a distance of 1 m is advisable. A field of more than 2000 A/m was measured on the power supply cable. A distance of at least 1 m must be maintained when the machine is operating.

Operators of fully mechanised processes are often at more than arm's length distance, because they do not have to control the workpiece during welding. Thus the risk of exposure above the action values is reduced. Processes that can be carried out using robots in principle are spot welding, MIG/MAG welding, TIG welding, plasma welding and laser welding [47].

*Procedure for shielding and protection measures*

Contrary to normal practice for exposure to UV and infra-red radiation, neither manufacturers nor professional associations usually provide safety instructions relating to electromagnetic radiation in safety data sheets for the various types of welding equipment [48]. The NIL [49] does warn of possible issues concerning electromagnetic compatibility. It warns that during TIG welding the high frequency voltage from pulses of several thousand volts for durations of a few microseconds may result in electromagnetic fields that might disturb other equipment. The Dutch standard, NEN-EN 60974-10, also includes recommendations for reducing field strengths [50]. In addition there is a basic standard [51] and a product standard [52] for the evaluation of the exposure of the human body to electromagnetic fields from arc welding equipment and related processes.

Measures for reducing the emission of magnetic fields are [50]: shielding the cables of permanently installed arc welding equipment, maintenance, keeping the cables as short as possible, running them close together and as close as possible to the floor, equipotential connections between pieces of metal, direct earthing of the workpiece or earthing via a capacitor, and shielding the welding installation and current sources.

In addition for high frequency induction welding, reducing the time in the hazardous area and keeping a safe distance are measures that are simple to carry out. It is also advisable to shield the supply cables and to twist the cables [14].

*Category classification*

Resistance welding processes (semi-mechanised), particularly spot welding, belong in category III. Exposure above the action values at the workplace, 30 cm from the electrodes, has been established on several occasions for these welding processes during normal welding operations and set-ups. Calculations also suggest that the exposure limit values could be exceeded.

Arc welding processes fall into category IIb. Provided that a distance of 20 cm from the cable is maintained, the action values for head and torso are not usually exceeded. The common practice of running the cable along the body or leading it over the shoulders to take the weight must be avoided.

Welding processes that use pulsating current or square waves fall into category III. After the summation rule has been applied, the action values of higher harmonic components can be many times above the value 1.

## 3.9 Medical applications

It is quite usual in the case of equipment used for medical applications that the patient is exposed to field strengths above the action values. This is partly because it is an intentional part of the treatment. The medical staff carrying out the treatment may also be exposed to levels higher than the action value. The following groups of medical applications will be differentiated as follows: equipment for MRI, diathermy, hyperthermia, electrosurgery and other applications.

*MRI*

Equipment for Magnetic Resonance Imaging, also known as MRI scanners, produces three types of field: a static magnetic field, gradient magnetic fields and pulsating radio frequency fields. The static field (probably a maximum of 1 to 3 T for 'intervention MRI') is always on, the gradient (0.025 to 65 kHz) and radio frequency fields (10-400 MHz, e.g. for a 1.5 T scanner 63 MHz) only during scanning [53]. During scanning operators can keep at a safe distance but applications, such as intervention MRI, are now being developed where the doctor or other staff must work close to the equipment. Moreover there is a tendency to use increasingly stronger fields, of all three types, to improve the resolution and thus the image quality. The WHO reports that there are systems in use up to approximately 10 T [54]. MRI scanners are now in use in virtually all hospitals.

The static magnetic field will not be considered here, because the Directive gives no exposure limit values for this. However account must be taken of other effects on health such as the consequence of ferromagnetic objects present such as scissors and gas bottles flying around, attraction of metallic implants and disruption to the operation of active medical implants (Active Implanted Medical Devices, AIMD). The WHO also advises moving slowly and avoiding abrupt head movements in static magnetic fields stronger than 2 T [54, 55], the reason being that these movements can lead to dizziness and nausea.

The radio frequency fields of MRI equipment lie below the action values as a consequence of the 'six-minute' rule (see Appendix 1) [9, 11, 56, 57]. The literature suggests that the exposure of staff to gradient magnetic fields in the vicinity of current scanners will not lead to the action values being exceeded [58]. Hill *et al* [53] reported that during heart catheterisation in a 1.5 T scanner the strength of the gradient field at the head exceeded the action value of 50 μT at 500 Hz by a factor of 40.

The manufacturers and users of MRI scanners are very worried about the effect of the Directive on their use [59, 60, 53]. They cite three working environments where the action values for gradient magnetic and radio frequency fields are exceeded:

- during the development and production phases and then only in troubleshooting and other rare situations,
- during maintenance and repair, also again in troubleshooting situations where the equipment must be on to enable the cause of a malfunction to be traced, and
- during scanning, for example when supporting (nervous) patients or keeping a close watch on patients or when carrying out intervention activities.

The question now is whether the exposure limit values will be exceeded in those situations where the action values are exceeded. The practical research provided no information to confirm whether or not the local SAR values for radio frequency fields were exceeded. Hill et al state that it is improbable that the whole body SAR values will be exceeded [53]. It is not known either whether for gradient fields the exposure limit values for current density for the head and torso will be exceeded. There is an amendment pending to the IEC 60601-2-33:2002 standard written for the protection of patients, where the exposure of staff is also elaborated.

Because there is no explicit proof from measurements or calculations that exposure limit values with current equipment are not being exceeded and also because of the tendency towards increasingly stronger fields, the three stated MRI working environments have been classified in category III. The ‘use of MRI equipment for which operators only work at a distance’ working environment has been classified in category IIb.

*Diathermy*

Diathermy equipment is used for heating body parts and stimulating biological processes, generally for therapeutic purposes such as rehabilitation and pain control. A distinction is made between short wave diathermy at 27 MHz and microwave diathermy generally at 2.45 GHz. An investigation in Canada more than 20 years ago indicated that the ratio between the number of pieces of equipment for short wave diathermy and microwave diathermy was 10:1 [61]. This ratio is not known in the Netherlands, but from the practical research it appeared that microwave equipment is also used less here. Diathermy is used in hospitals and also at physiotherapy practices outside hospitals and occasionally in veterinary establishments. Because diathermy has been in use for many decades now, several measurement results are available of undesirable stray fields (also called leakage fields). The highest field strengths occur at the electrodes, power supply cables and connections [61, 62, 63, 64, 65]. The various investigators are in agreement that there is no simple formula that enables the strength of the stray fields to be calculated. Thus it seems that the development of a simple calculation rule will not be possible.

Exposure levels can be reduced significantly by keeping at a distance. Various bodies have advised values for these distances. For short wave diathermy, the advised distances vary from 0.2 to 1.1 m [65]. Shields, et al do indicate that when establishing these distances, measurements must be made on a wide range of equipment, in various configurations and operational conditions and at the highest possible output power. Shields et al carried out measurements on 10 units in Ireland, of which half were on equipment from the manufacturer that probably supplies the majority of this type of equipment in the Netherlands. They concluded that physiotherapists should maintain a distance of 2 m from equipment using the capacitive method with continuous signals, 1.5 m from equipment using the capacitive method with pulsed signals and 1 m from equipment using the inductive method. It is also necessary to make sure that no other staff, such as administrative staff working in adjoining rooms, could be within these distances. The capacitive method is the most frequently used method. Shields et al recommend that for specific equipment closer distances could be used, but only if this had been proven to be safe by reliable measurements.

Values above the action values have been reported for microwave diathermy at 2.45 GHz: to 440 W/m$^2$ at 5 cm distance [66]. At normal operator locations the action values (137 V/m at 2.45 GHz) were not exceeded: 17 - 70 V/m [67]. In 1994 Tzima et al reported that action values were exceeded up to 0.5 m at 2.45 GHz and up to 1.0 m at 434 MHz. They concluded that the action values were not exceeded when a distance of 1.0 m was maintained and the worker was prevented from approaching close to large metallic objects that might reflect the fields [63]. In 2002 Grandolfo et al came to the conclusion that modern equipment at 434 MHz did not exceed the action values, while that for 2.45 GHz could occur up to a distance of 1.0 m [68].

Manufacturers and suppliers were contacted during the practical research. The use of diathermy by 16,000 to 20,000 physiotherapists is decreasing, although accurate figures are not available. It is likely that there are still around 5000 sets of equipment for short wave diathermy in use in the Netherlands. For a few years now physiotherapist's practices have no longer been obliged to have diathermy equipment in-house. In addition to the exposure of physiotherapists, attention must also be paid to the exposure levels of maintenance staff. Contacts with the Royal Dutch Physiotherapy Association (KNGF) indicated that physiotherapists usually set levels based on subjective temperature rises. For example: 'We set the level that causes a barely noticeable temperature rise' (for a sensitive complaint) or: 'To achieve the desired affect we increase the temperature to above the pain threshold' (but below the tolerance threshold) for example to improve the elasticity of interstitial tissue. Thus physiotherapists do not measure the strength of the electric fields and subjective settings are the norm. Physiotherapists are aware of the pacemaker being a contraindication for the use of this type of equipment, although less attention is paid to this in physiotherapist training than formerly.

Because the use of diathermy equipment can cause action values to be exceeded, these are placed in category IIb. The distances within which action values may be exceeded can reach up to 2 m.

*Hyperthermia*

Hyperthermia equipment is used for cancer treatment at four locations in the Netherlands. It is used to heat tumours, the aim being to improve the therapeutic effects of chemotherapy and/or radiotherapy. There are two methods in use, shallow hyperthermia operating at 434 MHz (50 - 100 W) and deep hyperthermia at 70 MHz (800 W). Measurements reported in the literature and measurements carried out in Rotterdam showed that action values were not exceeded during shallow hyperthermia [68, 69]. The literature does indicate that deep hyperthermia can lead to action values being exceeded [8]. Measurements are available from locations in Amsterdam and Rotterdam. In Amsterdam, stray radiation was measured around two machines and it was found that electric field strengths of more than 61 V/m up to a distance of 1 m from the antennas could occur. The situation in Rotterdam was equivalent [69]. Following consultation with those responsible it emerged that measures to restrict the time staff spent in the fields and for keeping a safe distance would be possible. It also seems reasonable that the exposure limit value imposed for the whole body SAR will not be exceeded. Owing to the direction of the field (horizontal) compared to the orientation of the worker (vertical) coupling of the field is not optimal. Equipment for deep hyperthermia has been placed in category IIa and that for shallow hyperthermia in category I.

*Electrosurgery*

Radio frequency electromagnetic fields are used in two ways in surgery: for cutting and for cauterising. During cutting, the cells explode and during cauterising, the contents of the cells evaporate so that they dry out and stick to each other. Cauterising uses lower power than cutting and is mainly used for closing blood vessels. The frequencies used lie in the range 300 to 600 kHz [70]. Lower frequencies cannot be used because they cause patients to experience muscle contraction. This equipment is sometimes also called 'medical diathermy equipment' and this does sometimes lead to confusion [10]. The monopolar system uses one active electrode. The return current runs back through a plate under the patient's body to the generator. Bi-polar systems are also available where the surgeon holds two electrodes ('insulated tweezers', for example for 'peeling' the prostate). Electrosurgery is also used by dentists and in the private practices of ear, nose and throat specialists, and dermatologists. Even GPs use this technique, e.g. for wart removal. There are also applications for electric depilation that operate at frequencies of 13.5 MHz, 27 MHz or 54 MHz.

The power supply cable can be considered to be a transmitting antenna. The practical research showed that this cable, which can run close to the surgeon's body, is mostly not shielded. This is partly because current leakage could occur between the electrode and shielding that might cause the patient to receive serious burns.

According to reports in the literature the action values for exposure are exceeded [63, 71]. In 1994 Tzima and Martin in Great Britain carried out measurements and they estimated that the fields at 1 to 5 cm from the cables could reach 500-2500 V/m and 2-10 A/m. They did consider it to be unlikely that the exposure limit values for local SAR would be exceeded, partly because the equipment was only used for a small proportion of the time (the 'six-minute' rule, see Appendix 1). They considered that special precautionary measures were not required. The article did not make a case for the exposure limit values for the current density introduced never being exceeded [63].

A Swedish study in 2003 found that at a frequency of 500 kHz the surgeon's hands were exposed to typical electric and magnetic field values of 15 kV/m and 16 μT respectively. These lie above the action values of 610 V/m and 4 μT in the Directive. Liljestrand, et al reported that an earthed metallic shield for the power supply cable reduced the electric field by a factor of 10 [71]. The same Swedish group carried out calculations on the induced current density and the SAR. Current densities were found to rise to values around the exposure limit value at 500 kHz equivalent to 5 $mA/m^2$. Calculated SAR values did not come near the 0.4 W/kg (the exposure limit value for the whole body SAR at 500 kHz) [72].

During the practical research enlightenment was requested from the two main suppliers of this type of equipment. A list obtained from a university hospital indicated that these two suppliers supplied three quarters of the electrosurgical equipment in the Netherlands. The manufacturers of the equipment provided by both suppliers were located outside the Netherlands. The suppliers requested measurement reports from the manufacturers, but without success. One of the reasons given was that there was still no 100% clear definition of measurement procedures for electrosurgical equipment.

Due to its potential for exceeding the action values equipment for electrosurgery has been classified in category IIa.

*Other medical applications*

Applications such as PEMF (pulsed electromagnetic fields - for pain control and promoting bone growth for slow healing fractures) and TMS (transcranial magnetic stimulation for combating depression, where an external magnetic field is applied) belong to the other medical applications group [58, 73]. It is unknown whether and if so where, in or outside hospitals, these applications are in use in the Netherlands. The strength of fields to which operators might be exposed is also unknown. Static magnetic fields of 2 T are used for TMS. These quickly reduce in strength with increasing distance [74]. Karlström *et al* advised keeping a distance of at least 0.7 m from the equipment, and the electrodes being mounted on a mechanical arm [75].

Electrotherapy equipment with electrodes that adhere to the skin is not intended for the production of electromagnetic fields. Action values are not exceeded for applications such as electric blankets, under-floor heating, incubators, microscopes, centrifuges, lamps for phototherapy and the like [76, 77, 78].

In hospitals, an increasing number of applications are using wireless technology for monitoring patients etc. Although this is not a direct medical application of electromagnetic fields, such applications are increasingly becoming an essential part of medical practice. Measurements and calculations show that these applications do not lead to action values being exceeded [79]. The other medical applications listed here have been placed in category I.

## 3.10 Microwave drying

Microwave drying is a special application of dielectric drying. During dielectric drying the product is introduced into an electromagnetic field. That can be microwaves with a frequency of 2450 MHz or high frequency fields with a frequency of 27 MHz. Generally the product is placed in a closed room or ‘cupboard’, or on a conveyor belt run through the field. The field is produced by a microwave antenna as in a microwave oven, or in the case of high frequency fields, between two parallel plates. Stray fields can be shielded relatively simply in this type of application. However when this heating method is used in the building industry for example (SBI code F Construction industry) for drying floors, walls and ceilings this type of shielding is more difficult to achieve.

According to Hietanen et al, microwaves (915 and 2450 MHz) are in use for drying out ‘water damage to walls and floors’ [9]. They reported the use of transportable equipment with a power of 1 to 5 kW, for which the power density of the microwaves transmitted was 10 $kW/m^2$ at a distance of 20 cm. According to them a power density of more than 1 $kW/m^2$ could occur immediately behind a wall, reducing to 100 $W/m^2$ at 2 m from the wall. Fields could also be created due to scattering from other surfaces in the vicinity. According to Hietanen et al the current density of these fields can rise to above 50 $W/m^2$ at a distance of 50 cm. According to them only expert personnel should use such microwave dryers.

Enquiries were made about whether this type of equipment was in use in the Netherlands. According to the Dutch 'Drying working group' among other things this only related to experimental set-ups where 'open microwaves' were used for a few special applications such as 'disinfecting' soil [80, 81, 82]. It is important that interlock switches are used to ensure that the open microwave source can only be switched on when it is aimed at the object i.e. pointing down towards the ground. From the interviews it appeared probable that no field strengths were calculated or measured during these experiments. Also, because it involved a few experimental set-ups at the most, the power density caused by this experimental equipment was not worked out. It is the case that in July 2005 microwaves were used for the first time in the Netherlands for the destruction of the deathwatch beetle (large woodworm) in wood [83]. Because action values were exceeded and technical measures are necessary, this application has been placed in category IIb.

## 3.11 Research applications

The research applications of electromagnetic fields are particularly diverse. Highlighting all applications where action values might potentially be exceeded turned out to be beyond the scope of this report. Research applications are often closely linked to educational activities. This makes it possible that relatively inexperienced people are working with or close to this type of equipment. Nevertheless it can be supposed that researchers and other employees in R&D departments will have sufficient background knowledge about electromagnetic fields to enable them to estimate their exposure levels. It is also assumed that this group will take account of the risk and minimise their exposure by taking suitable measures. It is important to make sure of this and thus it is advisable that employers issue clear instructions about how to work with equipment and what level of risks is acceptable. It is also important to take precautionary measures in various R&D environments.

In this respect education is a special sector. In principle employees can come into contact with all the possible types of apparatus and equipment that are being used in the other trade and industrial sectors investigated. Education that takes place at companies, such as student work placement, falls under the responsibility of the employer concerned. Education that takes place at the educational establishment itself, such as practical work, does fall under the responsibility of the establishment concerned.

Partly considering the diversity of the measures that must be taken during research applications, this working environment has been classified in category IIa/b.

## 3.12 Transport and traction systems

The most important characteristics of machinery used for transport or traction systems are the supply and application of high currents and/or voltages and the use of electric motors. For DC motors the rectifiers required are potential sources of strong fields. Here a distinction is made between systems intended for transport and other systems that use electric motors.

*Rail transport*

Rail transport in the Netherlands is generally powered via cables or rails carrying direct current: trains and light railways, metros, trams and trolley buses. The *Havenspoorlijn* (Harbour railway) in Rotterdam now uses 25 kV alternating current. The *Betuwelijn* (goods line between Rotterdam and the Ruhr) and the *Hogesnelheidslijn Zuid* (linking Amsterdam and Brussels/Paris) will shortly come into operation using 25 kV AC and in the future it is possible that all railway 1500 V DC overhead lines will be changed to 25 kV DC [84].

Hietanen, et al report that the magnetic field strengths for railway workers on lines powered by 50 Hz AC can vary from 10 μT to 6 mT [9]. Most published literature reports measurements on AC systems, because most countries use these. For drivers in Switzerland instances of exceeding the action values (by a maximum of a factor of 4, for the action value 1500 μT at 16 2/3 Hz) were only found around the calf and then only for some locomotives [85, 86].

In the Netherlands the *Projectorganisatie Betuweroute* (POBR) commissioned measurements on the *Havenspoorlijn* that was used as a testing ground for the *Betuwelijn*. Measurements and calculations for this system showed that magnetic fields of more than 500 μT could only occur at short distances (in the order of 10 cm) from the overhead lines and from rails (current can also flow in tracks that are not in service, but run parallel to an operating line).

The present overhead lines in the Netherlands (1500 V DC) are fed by approximately 200 substations that in their turn are fed by 10 kV underground cables. There are rectifiers in the substations that produce AC ripples, particularly at 300 and 600 Hz. Due to the relatively low voltage of 1500 V and the high power required, currents of 4000 A can run in the overhead lines. The return current runs through the rails and not via an extra wire in the overhead lines, thus there is no extinguishing of the magnetic field. In Italy, where DC is also used, values no higher than a few μTs have been measured [87, 88]. Values measured in the Rome metro were even lower.

Sparks are formed due to non-ideal contact between overhead wires and the pantograph (current collector) on trains. These can lead to radio frequency fields above 9 kHz [89]. Due to EMC problems, the Dutch NEN-EN 50121-2, 2000 standard sets emission limits for the electric and magnetic fields in the 9 kHz and 1 GHz frequency bands. These values apply at a distance of 10 m from the centre of the outermost track and at 3 m from the fence around a substation. Because employees will often be the within these distances, the measurements as provided by the standard are not usable for checking the action values in the Directive. Neither do the typical maximum electric and magnetic field levels mentioned in Annex C of this standard give any information about potential field strengths to which employees might be exposed. A document drawn up in Italy contains a detailed description of a method for carrying out, analysing and presenting measurements carried out at the driver's workplace [90]. This method supplies an index that indicates whether the action values are being exceeded, taking account of the entire spectrum of broadcast frequencies and not limited to just the harmonic components from 50 Hz. Unfortunately it is not possible to convert this method into a rule of thumb.

The direct current system has been placed in category I. The alternating current system that uses 25 kV AC has been placed in category IIa. This applies mainly to inspecting the overhead wires (exposure of the head) and walking over rails (exposure of the feet).

*Other types of transport*

In addition to rail systems there are systems where electricity required for the functioning of the transport system is generated via petrol or diesel engines or is drawn from a battery. Examples are diesel locomotives, buses, cars, motorcycles and mopeds, cranes and breakdown lorries, forklift trucks, bulldozers, excavators, agricultural vehicles**,** boats and aircraft. Generally, only measurements in the ELF area are reported in the literature. No instances of exceeding the action values have been reported in the ELF area up to 3000 Hz [91] in transport systems including the following: lifts, cars, light lorries, electric trams, ferries, conventional buses, trolley buses and jet aircraft. Generally the measurements were not presented in such a way that a satisfactory check of all relevant frequency ranges was possible. These measurements were also often carried out over a large part of the frequency spectrum. For example Nicholas et al report measurements carried out in the cockpits of four types of passenger aircraft [92].

KEMA has measured magnetic fields of 26 A/m maximum at 50 Hz in the machine room of a diesel driven coaster (action value 400 A/m). Readings in the frequency range between 100 kHz and 3 GHz, 0.65 V/m were taken on the ship's bridge (lowest action value in this frequency range is 61 V/m) [14]. Also here no action values were exceeded.

Based on these measurements these systems have been placed in category I.

*Electric motors*

Electric motors are present in almost every machine, from household appliances such as washing machines, dryers, mixers, etc, to a variety of industrial applications, such as pumps, extractors, conveyor belts, centrifuges, mills, hoists, saws etc. It is particularly the small appliances that are used at short distances from the body, such as electric shavers, vacuum cleaners, drills and handsaws, which at a few centimetres distance can cause low frequency magnetic fields up to 1 mT [93].

Ferrari, et al have carried out EMC measurements of magnetic field strengths in the frequency range of 9 kHz to 30 MHz in the vicinity of several motors and generators with powers between 6 and 200 MW [94]. At a distance of 4 m from these installations the action values were not exceeded, but from these measurements it is difficult to ascertain whether action values would have been exceeded at shorter distances. Moreover the measurements were carried out in a test situation where parts of the shielding had been removed.

In a metal fabrication company, KEMA measured a maximum magnetic field strength of 160 A/m at 50 Hz at a distance of 5 cm from components on a production line with electric motors. This was lower than the action value of 400 A/m [14].

A few indicative measurements were all that were available in this instance. Contacts with foreign specialists indicated that they knew of no reports of field strengths in the vicinity of electric motors where the action values were exceeded [95]. Electric motors have been placed in category I.

## 3.13 Transmitters

Transmitters have been divided into three groups in this report: two-way communication transmitters, one-way broadcasting transmitters and radars. In 2004 RIVM carried out an extensive analysis of the exposure of members of the public to these transmitters [96]. At locations that are accessible to members of the public, it was shown that exposure levels were below the reference levels and basic restrictions from the EU recommendations for members of the public [5]. Sometimes work must be carried out on or in the vicinity of transmitters. This usually means that there is a possibility that the worker will be exposed to levels above the action values if he or she comes close enough to the antenna. This depends on the frequencies and powers used and the distances to the antennas.

Various standards apply to antennas, such as NEN-EN 50383:2002 'Basic Standard for the Calculation and Measurement of Electromagnetic field strength and SAR Related to Human Exposure from Radio Base Stations and Fixed Terminal Stations for Wireless Telecommunication Systems (110 MHz - 40 GHz)'. This standard must be followed using two product standards to establish whether the exposure of members of the public (EN 50385) and the labour force (EN 50384) meets the ICNIRP guidelines [2]. The latter standard directs those responsible for bringing products onto the market to provide more information about the contours within which the action values are exceeded and also to provide information about how the product should be installed so that workers can remain outside the contours. When this CENELEC standard is followed as the European Directive instructs, this means that all radio base stations fall into category IIa, because at least one contour must be indicated, with the exception of base stations that transmit at a power below 100 mW. These fall into category I (EN 50384:2002).

It is important that workers who install and maintain transmitters are well trained. During their work they must be able to measure field strengths and calculate under which circumstances, i.e. the distance, frequency and transmission power at which the field strength will exceed the action values. Based on this, measures can be taken such as shutting down the transmitter or working at a lower power, setting up shielding, keeping a safe distance or RFR protective suits that resist radio frequency fields. In addition the 'six-minute' rule applies to transmitters operating at frequencies above 100 kHz (see Appendix 1). This states that the field strength may be multiplied by the square root of the duty cycle. The duty cycle is the fraction of the exposure duration over a random six-minute period[3]. Thus sometimes reducing the exposure duration can be sufficient.

Maintenance workers who are not working on the actual transmitters but in the vicinity, such as painters and roofing workers, must be well informed about the distance that must be maintained. And also here the power can be adjusted.

The following sections briefly give the most important characteristics for each type of transmitter, such as the usual powers, frequencies and, where relevant, rules of thumb.

3 For frequencies above 100 kHz an average value of $E^2$ must be used. Thus the value of the E-field must be multiplied by the root of the duty cycle (the ratio of the used time per most unfavourable period of six minutes). After application of the six-minute rule an exposure of 30 s to a 2400 MHz field with a field strength of 200 V/m gives: $\sqrt{(30/360)} = \sqrt{(1/12)} = 0.29$. The resulting E-field is thus $0.29 * 200 = 58$ V/m. This is below the action value of 137 V/m.

*Mobile telephony: GSM and UMTS base stations*

Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) are used for mobile telephony. A macro-cellular base station transmits a beam of approximately 35 km radius and consists of a mast with a number of antennas. Additional transmitters and receivers can be added per antenna. In addition there are also micro- and picocellular base stations that provide coverage inside buildings. Macro-cellular base stations are usually fitted on the roofs of tall buildings with permission from the owners. Agreements between the government and the providers of mobile telephony about sites are laid down in the Antenna agreement (*Antenneconvenant*) [97]. The antenna usually radiates a horizontal beam pointing away from the building (Figure 8). Workers on the roof may be subjected to exposure above the action values if they approach the antennas sufficiently closely and are exposed for a sufficiently long period.

In the Netherlands, GSM transmitters operate on two frequency bands: the 900 MHz band (880-960 MHz) and the 1800 MHz band [4] (1770-1880 MHz). From *Agentschap Telecom* (AT-EZ) information (April 2003) there were 55,104 transmitters/receivers in the Netherlands, 21,669 in the 900 MHz band and 33,435 in the 1800 MHz band. At 3,339 and 8,237 specific locations[5] respectively. In total there are 11,140 specific locations. That means that there are 436 900 MHz and 1800 MHz sites that overlap[6]. The UMTS telephony network operates at frequencies between 1920 and 2170 MHz. It must be operational by 2007 in towns with more than 25,000 inhabitants, along the main roads between these towns, along the main motorways and at airports. The National Antenna Bureau reports the following on its website: 'There are approximately 16,000 GSM antenna installations and 3,500 for UMTS. An antenna installation generally consists of three antennas, which means that there are currently 58,000 antennas for Mobile telecommunication in the Netherlands…' [98]. Similar figures are stated in the *Evaluatie Nationaal Antennebeleid* (Evaluation of National Antenna Policy), February 2006 [99, page 29].

GSM and UMTS providers periodically register their GSM and UMTS masts in the *Antenneregister* [100]. The Dutch *Nationaal Antennebureau's* Antenna Register indicates these registered GSM and UMTS antennas on a map. (Figure 9) shows an

4 The correct name for the standard for mobile transmission on the 1800 MHz band is not GSM but DCS1800 (Digital Cellular System) – however in practice both systems, GSM-900 and DCS1800, are known GSM.

5 'Unique location' means here a unique combination of *x*- and *y*-coordinates (at the least accurate rounded off to 50 m).

6 Number of overlapping sites = total GSM900+GSM1800 minus total unique sites = 11,576 – 11,140 = 436.

example of the type of safety contour graph shown for each antenna in the register. This is intended for both members of the general public and workers. The register indicates that the distances at which the action values are exceeded lie between 1 and 3 m in front of the antennas. The cumulative effects of multiple transmitters are not considered. There are examples of measurements and calculations known for establishing the safety contour for simultaneous exposure to fields from multiple GSM antennas [101]. In addition the 'six-minute' rule may be applied (see Appendix 1), should the worker remain in the area within which the action values are being exceeded.

*Figure 8 Example of a roof installation of GSM antennas*

On their joint website, MoNet, the five providers of mobile telecommunications have made software available to employers and owners of roofs with antenna installations to assist them drawing up their RI&E [102]. The program helps employers inform their employees how they can work in the vicinity of mobile telecommunication antennas without being exposed to levels above the action values. According to MoNet there is no danger of the action values being exceeded for normal roof work because virtually all antennas are located above a person's height. This means that workers are not exposed because the virtually horizontal fan-shaped main beam passes over their heads. The *Antennebureau* does advise that workers remain half a metre under the antenna.

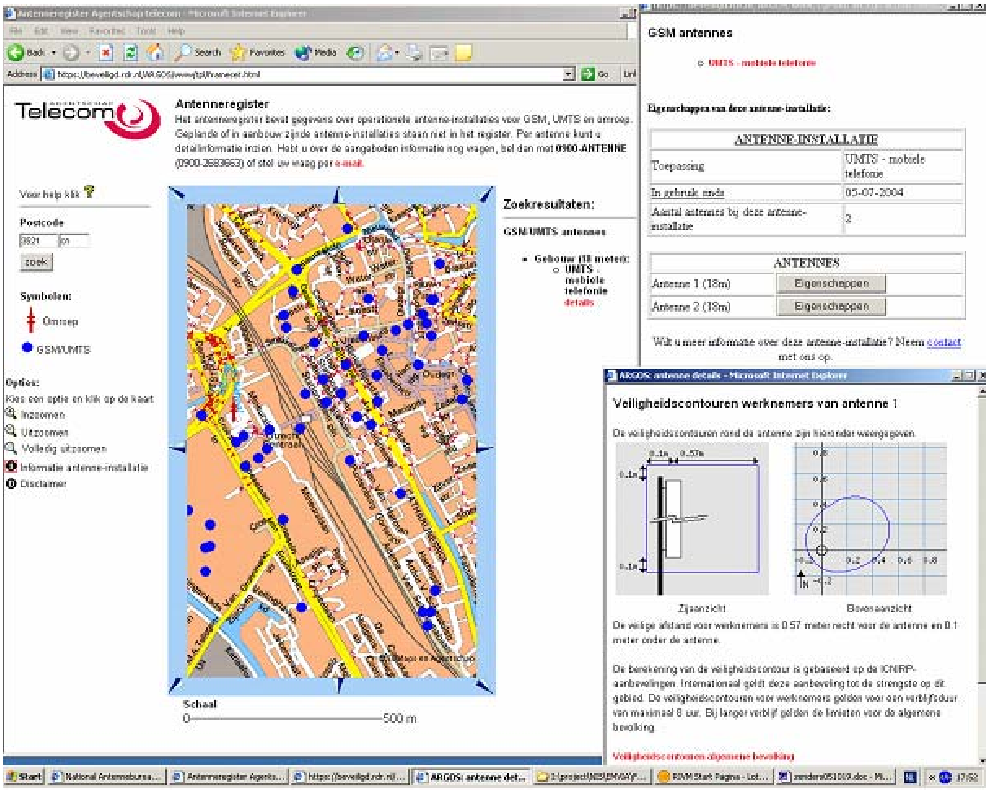


*Figure 9 Safety contours for base stations can be found in the Agentschap Telecom (AT-EZ) Antenna Register. See also Figure 4.*

As soon as workers have to come close to antennas (or a group of antennas) then measures such as disconnecting the antenna, reducing the transmission power or reducing the exposure time must be taken. Nevertheless GSM base stations and UMTS base stations have been classified in category IIa.

*Mobile telephony: TETRA transmitters*

TETRA stands for TErrestrial Trunked RAdio, an international standard for digital communication. TETRA is used both commercially and for special purposes. In the Netherlands the C2000 network was commissioned by the Ministry of the Interior and Kingdom Relations (BZK) and launched by the ITO (Information, Communication and Technology Organisation) agency [103, 104]. This is a network for mobile communication for the police, fire brigade, ambulance services and the Military Police (*Koninklijke Marechaussee*). Commercial 'DIY' networks are being advertised by the manufacturers, but in the Netherlands they are not yet in wide use.

Several frequency bands have been assigned to TETRA - between 380 and 465 MHz. The C2000 network was planned to have 390 sites: 320 new structural steel masts and 70 existing masts or roof installations [105]. At the time of the delivery of the C2000 network in July 2004 there were actually 386 sites [106]. In 2006 the C2000 website reported that there were now 450 sites [104]. They are located in the centre of cells with a radius of 1 to 6 km [107]. This enables countrywide coverage. Three or four antennas hang in a structural steel mast: two antennas for the TETRA speech and data network for mobile land communication and one for the Flexnet network (emergency and semaphony)[7]. The fourth antenna is a special antenna for airborne communication. These will only be placed in 24 of the 390 masts [108]. The height of the masts is 45, 53 or 60 m, although the antennas are not necessarily mounted at the top. On a 32 m high building the antennas are located on a 6 m high mast [104]. For underground tunnels e.g. the Metro, special installations are used. In addition to the fixed masts there are also mobile stations, for example in cars: these transmit at a maximum power of 10 W.

Communication takes place via the Time Division Multiple Access (TDMA) protocol with four time slots [109]. Base stations typically transmit at a maximum power of 25 W. Flexnet uses a frequency band of 154 to 174 MHz in combination with a transmission power of 150 W [107].

Based on TNO measurements [110], calculations published on the C2000 website [104] and measurements by the NRPB [111] the field strengths at the foot of the masts and at the location where the main beam hits the ground lie below the action values in the EU recommendations for protection of members of the public. In the horizontal plane of the beam, the distance within which the action values are exceeded is approximately two metres [111].

TETRA transmitters in masts fall into category IIa. Workers are only exposed to levels above the action values when they climb into the masts. In that case either

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7 This is also known as a paging network.

the transmitters must be switched off, the transmitting power must be reduced, the exposure must be under the exposure limit values after time-averaging or an RF protective suit must be worn. The disadvantage of protective clothing is that it is only suitable for light activities such as measuring field strengths and not for heavy exertion. The disadvantage of switching off the transmitter or reducing the transmitting power is that the coverage of the C2000 network may become insufficient, with the consequence that the communication between the emergency services may not be adequate.

*Portables/mobiles: GSM telephones*

To establish their position in the network GSM telephones keep continuous contact with a base station in the vicinity. For this they transmit short pulses of one to two seconds at intervals that vary from 20 minutes to a few hours. In doing so, the telephones transmit at their maximum power [112]. The power that a mobile telephone uses to transmit to the base station is a maximum of 2 W for the 900 MHz band and 1 W for the 1800 MHz band [113]. However, due to the use of the TDMA technique a telephone only transmits 1/8 of the time. The average transmitting powers are 0.25 W and 0.125 W respectively. Depending on the distance to the base station, the Automatic Power Control (APC) can reduce the quantity of energy transmitted by up to a factor of 1000 [114]. Besides, telephones use the DTX mode (Discontinuous Transmission), which stops the telephone transmitting when speech ceases. This can reduce the energy of the total transmitted speech signal by half, assuming that only one of the two people telephoning is speaking and the other is listening. Ultimately the average maximum transmission power varies between 29 and 240 mW and 14 to 120 mW for the 900 MHz band and the 1800 MHz band respectively [115]. However, in the case of GSM extensions for transmitting data, the so-called 2.5G applications such as GPRS (General Packet Radio Service), HSCD (High Speed Circuit Switched Data) and EDGE (Enhanced Data Rates for Global Evolution), the pulse duration changes and thus also the average power, because in these cases transmission can take place more than 1/8 of the time [114].

Because the GSM telephone transmits at wavelengths of 33.3 cm (900 MHz) or 16.7 cm (1800 MHz), the head of the person telephoning is always in the near field, and it is also possible that the local action values may be exceeded. Thus the SAR value must be calculated. That was done in 1999 in the Netherlands in the THERMIC project by the former TNO-FEL in cooperation with the former Utrecht University Teaching Hospital (AZU) [116]. A model of the head was based on 3D MRI scans. The blood vessels were also included. Besides the maximum SAR in the head as a consequence of radio frequency fields, the temperature rise was also calculated, with the effects of blood circulation being taken into account. The maximum calculated SAR for various circumstances was between 1.0 and 1.6 W/kg. Neither the basic restrictions nor the action values were exceeded. The maximum temperature rise was between 0.15 and 0.25°C. The latter is below the value of 1°C above which health could potentially be affected in the short-term.

*Portables/mobiles: UMTS telephones*

UMTS telephones operate at a power of 0.125 W maximum, time-averaged over six minutes. Since the exposure situation, except for the transmission frequency, is very similar to that of GSM telephones with a power of 0.125 W, it can be assumed that they will not lead to exposure above the exposure limit values.

*Portables/mobiles: TETRA hand portable and vehicle-mounted transmitters*

Within a TETRA network, direct contact between hand portables is possible (Direct Mode Operation, DMO) via a base station with other hand portables (Trunked Mode Operation, TMO), or with a mobile station e.g. in a car. The C2000 network will consist of around 40,000 hand portables and mobile stations [117].

The transmission power of hand portables is 1 or 3 W maximum. Because four time slots are used, the average is a quarter of these powers. The power that a hand portable uses in TMO is 1 W maximum, and in DMO 3 W maximum. In DMO, as with GSM telephones, the power is adjusted depending on the distance to the base station. Conversely, with TMO the hand portables transmit at constant power [109].

TNO calculated the maximum SAR for a TETRA hand portable that transmitted at a power of 1 W using a computer model based on an MRI scan. For two possible positions during use, the SAR was 0.24 W/kg at 2 cm from the nose, and 0.117 W/kg at 3 cm from the left ear. TNO [109] and NRPB [111] reasoned that the SARs for GSM telephones formed the upper limit for SAR compared to TETRA telephones because GSM uses a higher frequency that penetrates less deeply so that the energy is absorbed in a smaller area than with TETRA.

NRPB [111] published maximum SARs measured on an imaginary head for a hand portable that transmitted a power of 1 W, and for one that transmitted at 3 W. The maximum SARs for 1 W were 0.89 W/kg on the left ear and 0.24 W/kg for the face. For 3 W the SARs were 2.88 W/kg on the left ear and 2.33 W/kg for the face. These values are higher than those calculated by TNO. For 3 W the values were so high that they came above the basic restrictions for members of the general public. However, they remained below the exposure limit values.

Not all TETRA telephone manufacturers state the SARs on their website. Data published by Nokia indicates that the SAR for a 1 W hand portable lies typically around 0.52 W/kg [118].

TETRA installations fitted on cars usually have a transmission power between 3 and 10 W. For people in the vehicle, this power will probably not result in exceeding of the basic restrictions for members of the general public as stated in the European recommendations [5], and thus not in exceeding of the exposure limit values either, because the vehicle shields the field. For workers outside who are located close to an antenna on a vehicle, the exposure limit values could be exceeded if the head was a few centimetres from the antenna for a period of several minutes while more than one time slot is being used [111]. However, exposure levels reduce quickly with increasing distance.

All GSM and UMTS telephones and TETRA hand portables fall into category I because the exposure limit values are not exceeded. TETRA transmitters on vehicles with a power of 10 W fall into category IIa.

*Wireless communication*

There are many different techniques and standards for wireless communication. For longer distances (more than a few tens of kilometres) point-to-point (PP) beam or fixed beam transmission is used. For the intermediate distances of a hundred metres to a few kilometres in urban areas to tens of kilometres in rural areas, Wireless Local Loop (WLL) is used. For short distances of a few hundred metres Wireless Local Area Network (WLAN) is used, with the best-known standard being Wireless Fidelity (WiFi). Bluetooth is the standard for radio communication up to approximately 10 m.

*Wireless communication: WLL*

WLL is a (digital) radio system with which radio connections can be made to fixed local points from a central point. This central point is connected via a broadband connection to a fixed network, such as public telephone network or fibre-optic network. Other names are Fixed Wireless Access (FWA), Point-to-Multipoint (PMP) or Local Multipoint Distribution System (LMDS). Another form is Multipoint-to-Multipoint (MP-MP). MP-MP technology uses a mesh-like system of connections. Here, a received signal is relayed to the following antenna. In the Netherlands there are several WLL frequency bands: 2.6 GHz (2530 - 2667 MHz), 3.5 GHz (3500 - 3580 MHz) and 26 GHz [119]. Every operator using PMP systems must build at least 20 stations and each operator using MP-MP systems must build at least 300 terminals. The number of masts constructed depends on the licence holders. For example, a GSM provider can make use of existing sites. According to the Ministry of Economic Affairs website [120] WLL uses low power and '... The lower the power, the smaller the risk of damage to health...' In 1998, TNO-FEL published a report about the technical constraints such as the DS-CDMA, FH-CDMA, FDMA and TDMA transmission protocols [121]. The report indicates that the transmitting power of the antenna depends on the frequency and the transmission protocol used. The transmission power is around 2 W for the previously mentioned system or around 20 W for DS-CDMA.

In the direction of the main beam, the amplification factor of a gain antenna can lead to a higher power density at the same distance in the beam than with an isotropic antenna of the same power. For the 2600 MHz and the 3500 MHz bands, this leads to distances (maximum of 0.9 m) in the main beam within which the action values are exceeded.

WLL systems fall into category IIa because a distance from the antenna must be maintained.

*Wireless communication: beam transmitters*

Beam transmitter communication, also called fixed wireless communication, is radio communication between two points. Because it operates with strongly focussed signals, dish antennas are often used. Because of the narrow high frequency beam, two sites must have a line-of-sight connection with each other. Due to the curvature of the Earth's surface the maximum distance between transmitter and receiver is approximately 45 km. To avoid obstacles and bridge a distance of 10 km, a site at a height of 30 m is necessary. To bridge 45 km, a height of 80 m is required. Most applications use the frequency band around 25 or 38 GHz. Frequencies below 20 GHz are only used for distances larger than 20 km or for intensive data traffic, more than 140 Mbits/s. Shorter distances up to 500 m use the frequency band around 58 GHz. Sites are usually on high buildings, masts and radio towers. Permission (usually written) is normally required to get close to these beam transmitters. This is partly to check that the exposure levels do not rise above the action values. Because the purpose of beam transmitters is to focus their energy in as small a beam as possible for transmitting or receiving, the rule of thumb is that as long as people are not in the beam, i.e. standing in front of the dish, the action values will not be exceeded.

Permits are usually obligatory for fixed wireless communication systems. *Agentschap Telecom* from the Ministry of Economic Affairs determines the maximum transmission power and the height of the antenna so that sufficient signal arrives for adequate reception. ERP[8] powers vary from 0.01 W to 63 kW.

The dishes on GSM masts are familiar, easily visible and occur frequently in urban areas. They usually have a diameter of 30 cm and a power up to 130 mW. They transmit between 24 and 40 GHz, for which the far field distances are 14.4 and

8 ERP stands for Effective Radiated Power and is the power required if the transmitter transmits as a half-wavelength dipole and still achieves the same power density at the receiver. Thus for a gain antenna the ERP is larger than the actual input power.

24 m respectively. According to the Health Council of the Netherlands (*Gezondheidsraad*) [122] a beam transmitter has its maximum power density at 1/8 of the far field distance in the main beam. In the near field this is equivalent to four times the available power divided by the square of the dish diameter [123]. For a common power of 130 mW and a diameter squared of 0.09 $m^2$ this leads to 5.8 $W/m^2$, or 12% of the action value of 50 $W/m^2$. Thus even in the beam the action value cannot be exceeded.

Small beam transmitters used by GSM base stations, where the power is limited to 1 W and with a dish diameter of 30 or 60 cm, fall into category I.

Beam transmitters fall into category IIa. As long as people do not enter the beam, i.e. stand in front of the dish, the action values will not be exceeded.

*Broadcasting*

In the Netherlands the national and regional broadcasting companies use analogue AM and FM radio transmitters and TV transmitters. Work is being carried out on the introduction of digital transmitters for both radio (AM and FM) and television. According to the website of the Ministry of Economic Affairs and the 'Digital Delta' memorandum [124] the aim is to eventually replace analogue transmitters by digital transmitters. The locations of the national analogue and digital broadcasting transmitters can be found on the Antenna Register website along with additional information [100]. As with GSM and UMTS base stations, the contours within which the action values are exceeded are provided for workers. The AM transmitters and the local and regional transmitters are not included. On the *Agentschap Telecom* website it is possible to look up the frequency, location and power of any TV transmitter [125].

In March 2006, the powers of the 56 analogue television transmitters varied between 0.1 and 1000 kW ERP. There were 18 transmitters using 1 kW or less and 38 transmitters using 100 kW or less. There were four transmitters using 1000 kW. The powers of the 111 operational digital TV transmitters vary between 0.1 and 18 kW ERP - 60% of the transmitters have a power of 5 kW or less. There are also still 324 digital TV transmitters in the final stages of construction and negotiation. The digital transmitters have a lower power than their analogue counterparts and thus smaller contours within which the action values can be exceeded. Also, digital radio transmitters such as Terrestrial Digital Audio Broadcasting (T-DAB), a successor to analogue FM developed throughout Europe, and the successor to analogue AM, Digital Radio Mondial (DRM) use less power than analogue FM and AM transmitters.

*Agentschap Telecom* differentiates between local, regional and national transmitters. Local transmitters produce a maximum of 100 W ERP and are intended to cover a radius of approximately 5 km. Regional transmitters can broadcast at power levels up to a few kilowatts ERP. Local transmitters are generally located on roofs and masts, regional transmitters are on roofs, but also on antenna masts and towers. This report classifies broadcasting transmitters into large and small transmitters. Small broadcasting transmitters means the local and regional transmitters that are situated on roofs.

National FM and TV broadcasting transmitters are usually located in separate masts and radio towers or on masts on top of buildings. Mostly such sites are shared with other broadcasting antennas. Workers who climb such masts almost always pass through the contours within which the action values are exceeded. Measurements carried out in 2004 in the United Kingdom showed that workers in VHF and UHF radio masts certainly experienced peak exposures outside the range of the personal dosimeter (126% of the action value) [126]. Also in a radio/TV mast in Finland, the action values are known to have been exceeded by a factor of five at the height of the FM transmitters. For VHF-TV antennas, exposure levels are usually lower than for FM antennas, but the action values may still be exceeded. The action values were exceeded by more than 10 times by UHF antennas at the top of a mast. Not just the transmitters, but also secondary emissions from adjacent parts of the mast caused these exposure levels. For this reason, exposure levels are not easy to establish except by carrying out measurements [127]. Also, digital TV antennas with powers of 15 kW ERP can cause exposure levels several times the action values [128].

The short wave AM transmitter conglomerate site is in the Flevopolder and transmits with four transmitters of 500 kW EIRP, each at a different frequency. They use antenna arrays to transmit beams of radiation upwards at a steep angle so that they are reflected from the ionosphere. In spite of the beam being aimed up at a steep angle, the action values may be exceeded on the ground in the vicinity of the transmitter. Thus a large area is closed off to the public. Medium wave AM transmitters use high omnidirectional antennas that stand on the ground. The entire mast, typically 200 m high, acts as an antenna. There are 15 medium wave transmitters in use with powers of 3 to 3300 W EIRP. Usually, the area around the antenna is enclosed, so that outside the fencing the reference levels and thus also the action values are not exceeded. Examples of calculations by Dahme [129] on short wave AM transmitters showed that the field strength on the ground was 400 V/m at a distance of 5 m and 130 V/m at 60 m from the antenna array at a carrier wave frequency of 21.65 MHz and a power of 275 kW EIRP. These field strengths amounted to a few times the action value of 61 V/m.

In addition to action values for direct exposure to electromagnetic fields, there are also action values for contact current for frequencies up to 110 MHz. Contact currents can occur when touching metallic objects in an electromagnetic field. In 2002, reports from TNO [130] and *Agentschap Telecom* [131] with measurements carried out at an AM transmitter at Trintelhaven were published. There had been reports of burns to the hands from mast stays and the burning out of various types of equipment such as a GPS. *Agentschap Telecom* measured maximum field strengths of 48 V/m for the electric field and 0.16 A/m for the magnetic field. TNO measured a maximum electric field with a strength of 60 V/m and a maximum current in the front stay of 0.3 A. Additional measurements by TNO indicated that substantial heating did not occur until 1 A. Contact currents cannot cause shocks at the measured field strengths. Even if the recommendation made in 2000 by the Health Council of the Netherlands is followed, the measured field strengths do not exceed this value (100 V/m) [132].

Large broadcasting transmitters fall into category III. It is certain that the action values will be exceeded. It is not usually possible to take straightforward measures.

Small (local and some regional) FM transmitters are mounted on buildings and due to their ordinary appearance they may not be recognised by roof workers. These transmitters are not yet included in the Antenna Register. Until this is done, and there is clarity about the safety contour, they will fall into category IIb. Care is necessary, at least for the moment, and some extra effort such as carrying out site measurements is advisable.

For the same reason as the regional FM transmitters, amateur radio transmitters also fall into category IIb.

*Radar*

Radar is an abbreviation of Radio Detection And Ranging. It is a system for detecting and determining the position and speed of objects. It works using the transmission of radio frequency energy, usually in a pulsed waveform, and the reception and processing of the signal (echo) that is reflected back from the object. The antenna angle is a measure of the direction of the object and the time interval between transmission and reception of the pulse is a measure of the distance. The speed of a moving object can be determined from the Doppler shift. The Doppler shift is a shift in the frequency of the signal that is reflected by a moving object.

There are various types of radar. Most radar is transmitted in pulses, but there are exceptions, such as the Frequency Modulated Continuous Wave (FMCW), which transmits continuous signals. There are fixed radars that transmit a directional signal from a specific position, e.g. speed detection radars. In some instances it is preferable that the radar beam does not transmit in a circle, on the coast for example when only observations over the sea are required. In that case the radar does not transmit when it is pointing towards land, or a shield is fitted for the beam. This type of shielding is called sector blocking.

Rotating radar generally turns a couple of times per minute and transmits a narrow beam. The field strength reduces quickly outside the main beam. Some radars move in both the horizontal and vertical planes. The duty factor expresses the fraction of the total time that the beam ‘exposes’ a single object. The total duty factor is the product of the pulse duty factor (pulse duration divided by interval) and the rotation duty factor (beam width divided by 360 degrees). This duty factor multiplied by the peak power gives the average power transmitted in all directions. There are various basic restrictions for the pulsed peak power and the average power. The EU Directive states that for the peak values of pulsed electromagnetic fields, the power density averaged over the pulse width must not exceed 1000 times the equivalent power density or that field strengths must not be more than 32 times the action values that apply to the carrier frequency.

Jokela and Puranen [127] give typical values for the power density in the main beam of a radar just in front of the antenna. For fixed radars, these values are between 100 and 1000 $W/m^2$. This means that in the main beam the action value can be exceeded at distances of several hundred metres. However, for rotating radars, people are generally outside the main beam and the average power density in areas accessible to workers is rarely higher than 1 $W/m^2$. The peak power is typically 100 to 10,000 times higher than the average. For pulsed radars the pulse widths vary between 0.1 and 100 μs. It may be that when a radar beam hits the head, the exposure limit value of 100 $mJ/m^2$ for short microwave pulses (< 30 μs) is exceeded, while the action value for averaged power density is not exceeded.

Radar is used for many applications in the Netherlands. Navigation radar is used by shipping and in aviation etc. Weather radars such as precipitation radar and the wind profiler are used by weather forecasters (KNMI). The frequency range within which most radar systems operate runs from 220 MHz to 35 GHz. Since there is no complete overview of radar applications available that provides at least their number, location, frequency, transmission protocol, field strengths, beam width and duty cycle, further evaluation of radar is not possible.

Since weather radars point upwards and no people are hit and exposed by the beam, they fall into category I.

Radars such as those used by the police for speed checks in traffic, where the beam is aimed away from the operator and towards the vehicle being checked, fall into category I. Their field strengths remain under the action value.

Other radars fall into category IIb. Because of the high powers it is possible that the action values in the main beam of fixed radars are being exceeded at distances of hundreds of metres. However for rotating radars, because of the duty cycle, the average exposure reduces by a few hundred or thousand times. It is necessary to establish the exclusion zone for workers for each radar system by means of measurements or calculations. For example this zone can be cordoned off or marked on the ground. This practice is used by the Royal Netherlands Navy on ships.

## 3.14 Other working environments

Finally there is equipment that does not fit conveniently into one of the previously discussed groups. This equipment has been placed in the 'Other' group. It applies to equipment such as tape erasers, induction hobs, radio frequency and microwave lighting and non-destructive magnetic testing.

Induction hobs use frequencies between 20 and 50 kHz [25]. Induction hobs heat food by firstly passing energy to an induction coil that subsequently generates magnetic fields that in turn cause eddy currents in the pan. Ultimately, these eddy currents generate heat. Various calculations indicate that the basic restrictions in the European recommendations [5] for whole body SAR are not exceeded [25]. Tests on two types of hob at 30 cm measured electric field strengths of 4.3 to 4.9 V/m and magnetic field strengths of 0.7 to 1.6 A/m [64]. There are hobs that switch themselves off if there is no pan on the hob. Moreover, if a pan with the same diameter as that of the hotplate is used, this provides an optimal coupling with virtually no stray field [133]. Because calculations show that the basic restrictions from the European recommendation are not exceeded and also measurements have shown that action values are not exceeded, induction hobs have been placed in category I.

Non-destructive magnetic testing is used for finding flaws at or near the surface of iron and steel objects [134]. This technique is used at many industrial locations for checking welds, piping etc. Using the hand yoke method the equipment, which contains a coil, is usually pressed by hand against the material to be tested. Cooper reported that usually only hands and limbs were exposed to values higher than the action values [8]. The practical research found that measurements have been carried out in the Netherlands: when alternating current was used (50 Hz) 6000 μT was measured at the hands and at 0.5 m distance 200 μT at the operator's chest. The head and trunk are usually at arms' length from the equipment. Cooper concluded that in situations where the head or the trunk (brain and spinal cord) of the operator was exposed to magnetic fields above the action value, there was also a chance that the exposure limit values would be exceeded. This would depend on the spatial distribution of the magnetic field generated by the equipment. Non-destructive magnetic testing is classed in category IIb.

# 4 Inventory of methods

A collection of rules of thumb and calculation rules has been formulated to enable assessment of whether or not action values are being exceeded. Rules of thumb are simple tools that must be suitable for use by non-specialists. The data for the rules of thumb has, as far as possible, been derived from CENELEC/NEN standards and standard books [135, 136]. In addition, use was made of documents from various authoritative institutions such as ICNIRP [2, 35], NRPB [137], HSE [11] and ILO [27].

The methods included in the flow chart (Figure 3) are described in more detail in this chapter.

## 4.1 Rules of thumb, calculation rules and standards - general

In the ideal situation, a test report should be available for each type of equipment to provide the employer with information about the strength of fields for each possible application and setting of the equipment. The employer would then always be able to determine whether action values were being exceeded. However, this ideal situation only happens occasionally. Also, CENELEC standards are not available for every type of equipment. For example they are not yet available for dielectric heating and induction heating. To enable assessment of whether action values or exposure limit values are being exceeded, a collection of rules of thumb and calculation rules has been formulated.

During an international scientific workshop about the introduction of the Directive (Warsaw, 5-7 September 2005) it emerged that CENELEC was not going to draw up explicit rules of thumb, in spite of the fact that by no means every employer has knowledge of electromagnetic fields and calling in specialists to carry out measurements and carry out calculations could be very expensive. Several product standards do already contain rules of thumb. The chairman of CENELEC working group TC106x commented: ‘Due to the diversity of applications, including tailor-made ones, an infinite list of equipment would have to be drawn up.’ At the workshop two alternatives for rules of thumb and for carrying out own measurements emerged as the safest for the worker and the most cost effective for the employer. Firstly there was a request for building an EU database of electromagnetic field measurements per type of equipment. It would have to be agreed who would pay for this, manage it and assess which measurements were sufficiently well carried out to be included. Secondly, the initiative with the most chance of success was obliging equipment manufacturers to indicate the fields generated in a table or by a formula, and by providing a contour within which the exposure limit values might be exceeded during normal operation, plus a contour for maximum power.

*Disclaimer*
The rules of thumb given here, based on existing CENELEC standards and generally accepted scientific understanding will be dropped as soon as CENELEC publishes rules of thumb for estimating field strengths in one of its future standards (generic, workplace, basic, and product standards). Also CENELEC will probably provide a list of applications in which exceeding the exposure limit values does not occur in the general survey standard. Of course the CENELEC list will prevail over the category I list in this report.

## 4.2 Generic rules of thumb

At the end of 2005 a basic standard, prEN 50413:2005 was under development for measurement and calculation: ‘Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz - 300 GHz)’. This provides detailed methods for measurement and calculation. In addition there is the Dutch standard, NEN 50392:2004: ‘General standard for demonstrating the conformity of electronic and electrical equipment with the basic requirements for human exposure to electromagnetic fields (0 Hz - 300 GHz)’. Currently (September 2005), a generic standard for the exposure of workers is being prepared by Working Group 4 of Technical Commission TC106x. The rules cited here correspond as far as possible to existing standards, preliminary standards and the Working Group 4 draft.

*Far field and near field*

An electromagnetic field is built up from various electric and magnetic field components. These components have different directional vectors and properties. They reduce in strength to different degrees as the distance from the source increases. A part models the energy that remains in the vicinity of the source and a part models the energy that travels away from the source: the radiation. An electric field is created by a voltage difference, i.e. by a charge (difference). A magnetic field is created by a moving charge, i.e. by a current. Every current is thus accompanied by both an electric and a magnetic field. Depending on the distance to the source, field components with different directional vectors and properties dominate. In the vicinity of the source the near field dominates and further away the far field. The far field area begins when the distance to the source is large enough to form a coupled electric and magnetic field for which the field components are perpendicular to each other: an electromagnetic field. Besides, this field can be considered locally to be a plane wave, so that the exposure is uniform over the body or body part. The radiation part of the field dominates in the far field area. In the far field the following relationship between the electric field (E-field) in volts per metre (V/m) and the magnetic flux density (B-field) in tesla (T) or the magnetic field (H-field) in amperes per metre (A/m):

$$\frac{E}{H} \approx \mu_0 \frac{E}{B} \approx 377 \text{ Ohm } (\Omega),$$

where $\mu_0$ is the permeability of vacuum (= 4 $\pi$ $10^{-7}$ = 1.25664 $10^{-6}$ henries per metre (H/m)), an approximation of the permeability of air being used here. It is thus sufficient to measure only the electric field or only the magnetic field to establish that the action values are not being exceeded.

In the near field area, the magnetic and electric fields are no longer coupled and the components of each field must be evaluated separately. Exposure in the near field area is no longer uniform and the action values are conservative. This means that if the action values are exceeded it is quite possible that the exposure limit values will not be exceeded [2, page 510]. However, to be certain that the exposure limit values are not being exceeded, the current density or the SAR value must be calculated or measured instead of the action values.

The Dutch EN 50392:2004 standard provides a few formulas for calculating the far and near fields. The far field starts at a distance r from the source, for which:

$$r > \frac{2D^2}{\lambda},$$

where $D$ is the maximum dimension of the antenna and $\lambda$ the wavelength, both in metres.

*Root-Mean-Square (RMS) values*

In accordance with the Directive, the Root-Mean-Square (RMS) values of a field must be checked against the action values. The RMS value is the square root of the time-average of the square of the field strength. The RMS value of an electric field *E(t)* with period *T* is:

$$RMS = \left[ \frac{1}{T} \int_0^T E(t)^2 \, dt \right]^{\frac{1}{2}}$$

For sinusoidal fields the RMS value is approximately 71% of (exactly half the square root of two times) the maximum value.

*Uniform versus non-uniform: coupling factor*

In the near field the exposure depends on the spatial distribution of the electric or magnetic field, the frequency used, the specific conductivity of tissue $\sigma$, the dielectric permittivity of tissue $\varepsilon$, the contact of the body with the ground and the machine, and the position and thus the geometry of the exposed person.

The action values and the exposure limit values were formulated for exposure to a uniform, homogeneous field in the far field area for the exposure concerned. For exposure to non-uniform fields a coupling factor is often used that corrects for the non-uniform distribution of the field and also for the dependency on the frequency, the specific conductivity and the dielectric properties.

According to prEN 50392:2002 the coupling factor for the non-uniform magnetic fields is:

$$k(d, f, \sigma) = \frac{J_{\max}(d, f, \sigma)}{B_{\max,Sensor}(d, A_{Sensor})},$$

where $J_{max}$ is the maximum measured current density in amperes per square metre ($A/m^2$), d the distance from the middle of the circuit to the source in metres (m), $f$ the frequency in hertz (Hz) and $B_{max,\ Sensor}$ the maximum measured magnetic flux density in tesla (T). The parameter $A_{\mathrm{Sensor}}$ stands for the surface of the sensor concerned; this determines the maximum magnetic flux density measured. Besides 0.2 siemens per metre (S/m) is usually used for the specific conductivity $\sigma$ of a homogeneous body model. A value of 0.1 S/m is also used for fields that do not penetrate deeply. The standard provides a table with the specific conductivity per frequency for various tissue types. Application of this coupling factor allows a much higher field strength being measured than the action value, although the exposure limit values are still met.

Thus the coupling factor $k$ makes it possible to calculate by how much the action value may be exceeded. The weighting factor $W$ with which the measured $B_{RMS}$ must be weighted before checking on the action value $B_L$ at the frequency concerned $L$ is:

$$W = \frac{k}{J_L},$$

where $J_L$ is the exposure limit value for the current density at frequency $L$. The standard for household appliances, EN 50366:2003 gives tables with coupling factors for appliances, which were substantially changed in the prA1 EN 50366 standard issued in March 2005. The term 'coupling factor' is not always identically defined. For each standard it is advisable to check what exactly is meant by the term.

There are also coupling factors for non-uniform electric fields. HSE [11] provides an example for exposure to equipment for dielectric heating at 10, 27 and 40 MHz and also provides coupling factors.

*Generic rules of thumb*

At frequencies of 1 Hz to 10 MHz the protection is based on current induced by an electric field (E-field) or a magnetic flux density field (B-field). For frequencies from 100 kHz to 300 GHz the protection is based on heating up.

*B-field:*

- Strength of the magnetic flux density $B$ in tesla (T) and strength of the magnetic field $H$ in amperes per metre (A/m) can be expressed together as follows in vacuum:

  $B = \mu_0 H$ ,

  with $\mu_0$ being the permeability of vacuum ($= 4\ \pi\ 10^{-7} = 1.25664\ 10^{-6}$ henries per metre (H/m)).

- Finite current carrying wire:

  $$B = \frac{\mu_0 I}{4\pi r}\left(\cos(\beta) - \cos(\alpha)\right),$$

  with $I$ being the current strength in amperes (A), $r$ the distance perpendicular to the wire from the observer and $\beta$ the obtuse angle between the wire and the shortest connection to the end of the wire from the observer, and $\alpha$ the acute angle between the wire and the shortest connection of the other end of the wire from the observer. As the length of the wire approaches infinity then $\beta$ becomes 0 and $\alpha$ becomes $\pi$ (Figure 10):

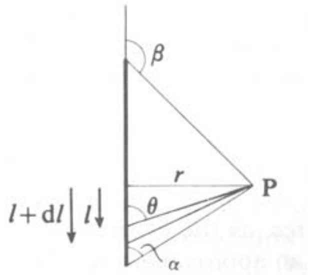


*Figure 10 B-field of a finite current carrying wire (Source: Duffin, 1980 [136])*

- Infinite current carrying wire, Ampere's law:

  $$B = \frac{\mu_0 I}{2\pi r},$$

- Current carrying parallel wires, where supply and return wires are running next to each other: B-field decreases proportionally to $1/r^2$.

- Household appliances: the B-field can be described as a magnetic dipole and decreases proportionally to $1/r^3$.

- Generic B-field loop:
  at distance $x$ on the axis of the loop with radius $a$ (Figure 11):
  $B_x = \mu_0 I a^2 / 2\left(a^2 + x^2\right)^{3/2}$.

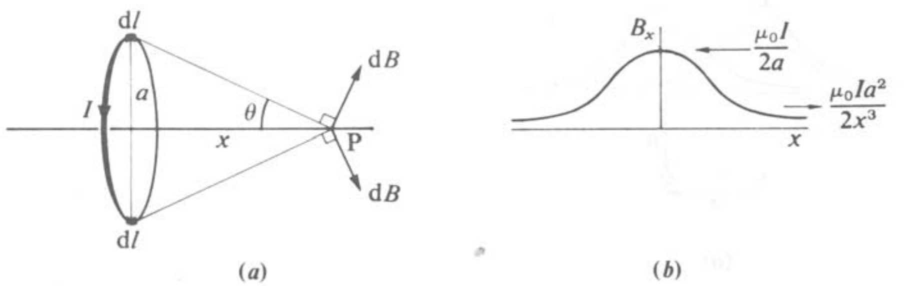


*Figure 11 B-field through a current carrying loop: (a) geometry, (b) decrease of field strength with distance along the x-axis (Source: Duffin, 1980 [136])*

- Generic B-field on the axis of a coil
  $0{,}5\mu_0 n I(\cos(\beta) - \cos(\alpha))$,
  with β = arctan(a/x) and α = arctan(a/(x-l)), with $l$ the length of the coil, $a$ the radius of the coil and the left side of the coil at x = 0 (Figure 12).

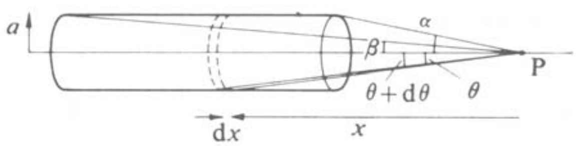


*Figure 12 B-field on the axis of a coil (Source: Duffin, 1980 [136])*

- H-field of equivalent coils: Household appliances EN 50366:2003 and prEN 50413:2005 standards.

*E-field:*
The strength of the electric field (E-field) is expressed in volts per metre (V/m).

- Field strength of a charged wire:
  $$E = \frac{\Lambda}{2\pi\varepsilon r},$$

with $\varepsilon$ the electric permittivity, the value of vacuum is $\varepsilon_0 = 8.85419\ 10^{-12}$ in farads per metre (F/m). $\Lambda$ stands for the linear charge density:

$\Lambda = Q/l$,

with $l$ the length of the wire in metres (m) and $Q$ the charge in coulombs (C).

- Field strength of a charged plate:

  $E = \dfrac{\sigma}{2\varepsilon}$,

  with σ the surface charge density:

  $\sigma = Q/A$,

  with $A$ the surface of the plate in square metres ($m^2$).

See Annex A of prEN 50413:2005 A1.1.2 for a detailed explanation of the B-field and the E-field for a number of conductors next to each other.

*Induced current*:

- As a consequence of an E-field:

  $J = kfE$,

  where $J$ is the current density in $A/m^2$, f the frequency in Hz and $k$ a coupling factor depending on dimensions, shape and specific conductivity of the body. $kf$ corresponds to the conductivity in S/m. A conservative value for $k$ is $9.6\ 10^{-9}$ Ss/m (E parallel to body, person earthed) the value is half if the E-field is perpendicular to the body, or if the body is not earthed e.g. due to wearing insulating safety footwear.
- As a consequence of a B-field:

  $J = \pi f r \sigma B$,

  where $J$ is the current density in $A/m^2$, $f$ the frequency in Hz, $r$ the radius in metres (m) of the largest circle that can be drawn on the body in a plane perpendicular to $B$, $\sigma$ the mean specific conductivity in S/m. This assumes maximum induction current density $J$ with the B-field perpendicular to the chest and minimum with the B-field along the axis of the body. A common standard measure of the mean specific conductivity σ of human tissue is 0.2 S/m.

*Contact current*

An electric field strength lower than 10,000 V/m provides a sufficient safety margin to prevent contact current effects for all possible circumstances [2, page 510].

*Heating up (100 kHz – 300 GHz)*
The exposure limit value in the range 100 kHz to 10 GHz is given by the Specific Absorption Rate (SAR), which states the quantity of absorbed energy, per unit of time, per body mass, in watts per kilogram (W/kg). The SAR is related to the Root-Mean-Square (RMS) value of the electric field $E_{RMS}$ on the basis of the following formula:

$$SAR = \frac{\sigma E_{RMS}{}^2}{\rho} = \frac{J^2}{\sigma\rho},$$

where $\rho$ is the density in kilograms per cubic metre (kg/m$^3$). This formula also shows that induced current can lead to heating up. When people are exposed to the inductive near field at a frequency of 100 kHz to 10 MHz the field is non-uniform and there is often no plane wave. In that case it is better to calculate the SAR based on current density $J$. The current density can be determined from H.

The simplest rule of thumb for checking if the exposure limit value requirements are met for the whole body SAR is:

$$\frac{P_{\max,irradiated}}{m_{body}} < SAR_{wholebody},$$

where $P_{max,irradiated}$ stands for the maximum irradiated power in watts (W) and $m_{body}$ for the mass of the exposed person in kilograms (kg). For a 16-year-old employee, the minimum standard weight has been set at 42 kg. This means that if all the irradiated power, that is always less than the maximum taken from the electricity grid, is less than 42 times 0.4 = 16.8 W, the whole body SAR cannot be exceeded. However, the local SAR can still be exceeded.

*Time-averaging for checking heating up: 'six-minute' rule*
The square of the maximum measured RMS value of the electric field with a frequency between 100 kHz and 10 GHz must also be averaged over a random time period of six minutes when it is being checked whether the SAR value for heating up is exceeded. This means that the following must be valid for each random time period:

$$\sqrt{(F_{ave}(E_{RMS})^2)} = \sqrt{F_{ave}}E_{RMS} < E_L.$$

Thus the maximum measured $E_{RMS}$ may be multiplied by the square root of the duty cycle $F_{ave}$ before checking with the action value $E_L$ at the frequency concerned.

A sample calculation is a machine that switches off for 3 minutes every 6 minutes, thus it does not radiate for half of each random six minute period. Then $F_{ave}$ = 3/6 = 0.5. Thus before checking the action value, the measured electric field strength may be multiplied by the square root of 0.5. If the worst case six minute situation is chosen, an operator standing in a field for four minutes every eight minutes will be exposed for four minutes, thus $F_{ave}$ = 4/6 = 0.67.

*Time-averaging for checking induced currents*
At frequencies up to 10 MHz, time-averaging is not allowed for checking on current density in the central nervous system.

*Peak action values and averaging in the range 10-300 GHz*
See also Appendix 1 for averaging of field strengths for frequencies between 10 GHz and 300 GHz and for the calculation of the maximum peak action values.

## 4.3 Summation rules for various signal types from one or more sources (ICNIRP statement)

The action values and exposure limit values have been established per frequency for sinusoidal signals. However, signals also exist that consist of multiple sinusoidal signals of various frequencies simultaneously, of pulses, or of non-sinusoidal phase-coherent waveforms. These signals can be generated by one piece of equipment, but can also be the result of signals coming from several pieces of equipment. Note 10 to Table 1 and Note 5 to Table 2 of the Directive state that suitable methods for the assessment of these waveforms must be developed by CENELEC. The latter because the summation rule for exposure to several frequencies (see Appendix 1 of this report) as stated in EU recommendation 1999/519/EC is not always directly applicable and can lead to an excessively conservative estimate of the exposure. This estimate is conservative because the assumption is made that the largest contribution is reached when the peaks or troughs of all sine waves occur at the same moment (i.e. are in phase). This is usually not the case.

In 2003, ICNIRP issued a statement for assessing these waveforms [35]. CENELEC also mentioned this method in the NEN-EN 50392:2004 ‘General standard for demonstrating the conformity of electronic and electrical equipment with the basic requirements for the exposure of humans to electromagnetic fields’, and in NEN-EN 50366:2003 ‘Household and a similar appliances – Electromagnetic fields - Methods for evaluation and measurement’. In addition there are publications by Jokela [20] and Chadwick [37, 137] in which exposure to various waveforms is discussed in more detail, including background theory and examples.

Roughly five wave types can be defined:
1 Rectangular pulse
2 Narrow-band sinusoidal pulse
3 Sinusoidal wave with higher harmonic components
4 Several sinusoidal waves superimposed
5 Several non-sinusoidal, phase-coherent waveforms.

*Rectangular pulse*
Here the duration $t_p$ of the pulse is considered to be half a periodic signal, so that the total period is 2 $t_p$ and the equivalent frequency for checking the action values is $1/(2\ t_p)$.

*Narrow-band sinusoidal pulse*
When series of pulses are transmitted and each pulse consists of at least five sinusoidal oscillations without higher harmonic components, then the peak value must remain below the square root of 2 times the action value for signals under 100 kHz. Above this, adjustments may be made using the duty cycle. This pulse form occurs with EAS systems under 100 kHz.

*Sinusoidal waveform with higher harmonic components*
This waveform occurs typically with rectifiers where, after rectification of the 50 Hz three-phase current, a clear 300 Hz ripple remains on the DC component. Here, after measuring the frequency spectrum, the summation rule can be simply applied (see Appendix 1). However the summation rule gives a rather conservative picture, because the relative phase of the frequency components is not included in the summation. NEN-EN50392:2004 states that the weighted peak value method may also be used if the phases of the harmonic components do not vary significantly from each other.

*Several sinusoidal waves superimposed*
As long as it involves a line spectrum, i.e. a signal composed of several sinusoidal signals of various frequencies, the summation rule (see Appendix 1) can simply be applied, where each frequency component receives its own weighting factor that is the inverse of its action value.

*Several non-sinusoidal, phase-coherent waveforms*
Frequencies from 1 to 10 MHz can be evaluated in time according to the weighted peak value method. This method is precisely described in generic standard NEN-EN50392:2004, in the product standard for household appliances NEN-EN50366:2003, by Jokela [20] and in the ICNIRP statement [35]. The weighted peak value method takes account of the relative phase and can be carried out by calculations on a time signal, or by measuring directly with a built-in weighting circuit.

It means that there is a weighting function based on the peak values (i.e. the action values that are RMS values, times the square root of 2) in the Directive. Next an equivalent frequency is stated, which is defined as with the pulse. However, now $t_p$ is equal to the smallest rise time (the time in which the signal of the basic field strength builds up to the peak strength) and fall time of the B-field (transient time) instead of the width of the pulse.

For signals with equivalent frequencies up to 820 Hz, this means that the peak value for the time derivative of the magnetic flux density, dB/dt, must remain under 0.22 T/s in order to meet the Directive. For frequencies above 820 Hz, dB/dt must be multiplied by a weighting factor, as stated in the relevant standards.

## 4.4 Specific calculation rules

### 4.4.1 Detection of articles and people

There are two standards within the framework of the EU recommendations:
- EN 50357:2001 Evaluation of human exposure to electromagnetic fields from devices used in Electronic Article Surveillance (EAS), Radio Frequency Identification (RFID) and similar applications.
- EN 50364:2001 Limitation of human exposure to electromagnetic fields from devices operating in the frequency range 0 Hz to 10 GHz, used in Electronic Article Surveillance (EAS), Radio Frequency Identification (RFID) and similar applications.

Four bands of the frequency spectrum are used for RFID:
1. 1 Hz - 500 kHz
2. 2 – 30 MHz
3. 850 – 950 MHz
4. 2.45 GHz and 5.8 GHz

Four bands of the frequency spectrum are used for EAS:
1. magnetic 0.01 – 20 kHz
2. resonant inductive 20 - 135 kHz
3. resonant radio frequency inductive 1 – 20 MHz
4. non-linear microwaves 0.8 – 2.5 GHz

Various magnetic fields are generated by metal detectors.

EN 50357:2001 provides some information about calculations and measurements in Section 4, but these do not provide any rules of thumb.

For fields up to 30 MHz the exposure during the use of RFID, EAS and metal detectors is usually in the near field, which extends a few metres from the equipment. Thus the exposure is not to a plane electromagnetic wave in this instance, and the E-field and H-field components are also weakly coupled. In the calculations the H-field component is usually used. This also applies to the range between 100 kHz and 30 MHz where the SAR is the dominating exposure limit value. Then the SAR is calculated based on the current density $J$ induced by the H-field.

$$SAR = \frac{\sigma E_{RMS}^2}{\rho} = \frac{J^2}{\sigma\rho},$$

For the area where exposure to magnetic fields dominates, the approximation of the H-field is made by the approach of using a single loop. In addition, the summation rule must be used for the various components from which a pulse is composed. The following calculation rule should be used to meet the whole body SAR of 0.4 W/kg [EN 50357:2001]:

$$H \leq \frac{23\sqrt{5}}{f},$$

where $f$ is the frequency in MHz, and $H$ the magnetic field strength in A/m. In addition, for fields up to 10 MHz the exposure limit value for induced current must not be exceeded, which means that $H$ must be < 24.4 A/m.

For EAS and metal detector systems field strengths above the action values have been measured within the gates, but according to calculations this does not lead to the exposure limit values being exceeded. According to Jokela [20] permanent exposure to field strengths around the action values is possible for cashiers. Few calculations are known for RFID systems, but these usually operate at low power and exceeding of the action values is not to be expected.

The rule of thumb for EAS equipment and metal detector gates is: the distance of the operator (e.g. cashier or security official) to the gates must be more than 1 m.

### 4.4.2 Dielectric heating

In September 2005, there was no CENELEC standard for dielectric equipment. Various authoritative institutes have drawn up documents for calculations, measurements and protective measures: guidance note 51 from the HSE [34], *Occupational Safety and Health Series 71* from ILO [27] and an HSE document by Gabriel and Lau [11, formulas C.1 and C.2].

There are three action values between 10 MHz and 110 MHz that must be met: contact current (40 mA), induced current in limbs (100 mA) and electric field (61 V/m). The action values are drawn up for the uniform far field, while the operating location for dielectric equipment is generally in the non-uniform near field. Thus measurements must be carried out in accordance with a protocol, followed by calculation or analysis to establish if the exposure limit values are being exceeded in that situation. It is usually the case that checking the field strengths measured in the near field with the action values established for the far field provides a conservative estimation of the possibility of exceeding the exposure limit values [2, page 510]. There are no rules of thumb for calculating the electric field strengths and thus carrying out measurements is advisable. There are calculation methods, sometimes empirical, for converting the field strengths of induced currents to SAR [11, 27, 29, 30, 32, 33]. This can enable an estimation to be made. For exact results, extensive calculations and modelling are necessary. In any case account should be taken of the duty cycle, averaging of the field over the body, converting from near field to far field and the application of coupling factors.

If the proportion of the electric field strength to the magnetic field strength is above 15 Ohms, then the absorption caused by the magnetic field will be much lower than by the electric field and the magnetic field may be ignored. This is usually the case for dielectric equipment.

Because it involves non-permanent exposure above 100 kHz, the measured field strength may be multiplied by the square root of the duty cycle.

Due to the non-uniformity of the field it is not sufficient just to measure the field strength at one operating position. It is also necessary to carry out measurements at half a metre around this to determine the degree of non-uniformity. A small movement can lead to a different field strength. Also the degree to which energy can be absorbed depends on the currents that run through the body. Thus measuring the induced current through the ankles and wrists is also advisable. Because of the non-uniform exposure the induced current and the electric field strength are also measured at various locations and subsequently averaged over the entire body [11, 28].

There are empirical conversion formulas for measurements in the near field to equivalent measurements in the far field.

In addition coupling factors are applicable for the calculation to SAR for this non-uniform field. Gabriel and Lau provide examples of several factors [11]. These coupling factors usually reduce the calculated SAR values. This means that exposures above the action values will not necessarily lead to exceeding the SAR.

Exposure to a frequency of 10 MHz means that the operator is standing within one wavelength, 30 cm, from the source and thus is in the near field. Thus it can be assumed that he or she will not be exposed to a uniform field. Gabriel and Lau [11, formulas C.1 and C.2] give coupling factors and means of conversion for the measured near field strength to equivalent values in the far field and generated whole body SAR. From an estimation based on these formulas it was found that for continuous exposure to a plastics welding machine at a maximum value of 300 V/m and a frequency of 27 MHz, the maximum whole body SAR of 0.4 W/kg is not necessarily being exceeded, even if the action value of 61 V/m is exceeded.

### 4.4.3 Electricity production and distribution

Power stations consist of broadly three environments:

- Generators
  Here no cases of the action values being exceeded have been shown by measurement.
- Transformers and rectifiers
  Three phase rectifiers that convert 50 Hz high-voltage to DC are often used. Here a significant 300 Hz ripple and higher harmonic components are generated. The spectrum must be measured, and the exposure must be calculated using the summation rule or the weighted peak value method (see Section 4.3). The measured field strengths are many times the action values and the best rule of thumb is to shield the installations and locate them tens of metres away from the workers.
- Bus bars
  These are metal (copper) elements for carrying high currents of several kA. The B-field can be approximated based on the generic formula for a current-carrying wire or for two feed and return conductors running parallel to each other.

Exposure levels above the action values can occur in substations with capacitor banks, near the air cooled coils in the capacitor banks, when they are operating. As a rule of thumb, which is also being used in practice, they must be in a closed room and it must only be possible to enter this room when the capacitor banks are switched off.

### 4.4.4 Electrochemical processes

There are no CENELEC standards specifically for electrolysis installations. There is a high-voltage directive.

Three areas must be considered in electrolysis installations. These are, along with their rules of thumb:

- Bus bars
  These are metal (copper) elements for carrying high currents of several kA. The B-field can be approximated based on the generic formula for a current-carrying wire or for two feed and return conductors running parallel to each other.
- Rectifiers
  Three phase rectifiers are often used for converting 50 Hz high-voltage to DC. This generates a significant 300 Hz ripple and higher harmonic components. The spectrum must be measured, and the exposure must be calculated using the summation rule or the weighted peak value method

(see Section 4.3). The measured field strengths are many times the action values and the best rule of thumb is to shield the installations and locate them tens of metres away from the workers.

- Electrolysis hall
  Depending on the layout, because of simultaneous exposure to various sources and current carrying elements and the level of current used, the distance can be calculated in the same way as for current carrying single wires.

### 4.4.5 Induction heating

In September 2005, there was no CENELEC standard for induction heating. There is one being developed.

The rule of thumb is: consider the worst-case exposure level; assume the coil opening is aimed at the worker, providing maximum exposure of the torso to the B-field. Use the generic formulas both for the B-field of a coil and for the induction current generated in a worker.

### 4.4.6 Welding

There are two standards under development covering exposure to electromagnetic fields during welding:

- prEN 50444:2004 Basic standard for the evaluation of human exposure to electromagnetic fields from equipment for arc welding and related processes.
- prEN 50445:2004 Product group standard to demonstrate the conformity of equipment for resistance welding, arc welding and related processes with the basic requirements for human exposure to electromagnetic magnetic fields (0 Hz – 300 GHz).

In addition there are a few EMC standards, including the standard that provides a few measures for reducing the emission of electromagnetic fields: NEN-EN60974-10 Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements.

The calculation of the exposure levels caused by DC welding equipment must include the exposure to the ripple due to the harmonic components. For pulsed DC, or use of AC, the frequency content of the pulse must be determined in accordance with the generic rules.

The maximum value of the frequencies that must be considered depends on the type of welding current [see Section 5.1.8 in 51]:

- 1 kHz for single phase transformer-rectifier types,
- 3 kHz for three phase transformer-rectifier types,

- 10 times the switching frequency for inverter types,
- 10 times the AC output current frequency for sinusoidal AC power sources,
- the frequency ($f$) defined by the minimum rise or fall time ($t_{p\,min}$ ) of the maximum output current ($I_{max}$) for non-sinusoidal AC or pulsed types,

$$f = \frac{1}{4t_{p\,\min}}$$

Rules of thumb and the calculation rules stated in the two standards under development:
H-field:

$$H = F_G \frac{I}{2d\pi}$$

or the magnetic flux density:

$$\frac{dB}{dt} = F_G \mu_0 \frac{I}{2d\pi}\frac{dI}{dt},$$

where $F_G$ is the geometric factor, as stated in Annex A of prEN50444:2004, $d$ is the distance to the welding cable, $dI/dt$ is the measured change in time for the output current.

Approximate the field by a current density in a disc of radius $r$ perpendicular to the magnetic field:

$$J_{(r)} = \frac{r\sigma}{2}\frac{dB}{dt},$$

or, if the frequency f is determined in accordance with $f = 1/2t_p$ where $t_p$ is the duration of a half cycle for symmetric non-sinusoidal waveforms, then the generic formula for maximum coupling of the B-field with a disc also applies:

$$J_{(r)} = \sigma\pi r f B\,.$$

### 4.4.7 Medical applications

*MRI*

In the MRI field, the NEN-EN-IEC 60601-1-2-33:2002 standard exists for the protection of patients. A new amendment will also cover the protection of medical personnel.

MRI equipment that is being used in troubleshooting situations in the development and production phase or during repair and maintenance falls into category III. Used during intervention activities or intensive patient guidance also causes exposure levels above the action values.

Simple calculation rules for determining the exposure are not possible. Special models must be used for this or measurements must be carried out. A rule of thumb is that during use, medical personnel should stay a few metres away from the equipment.

*Diathermy*

There is an IEC standard for diathermy equipment, IEC 60601-2-3:1993/A1:1998 Electric Medical Apparatus - Part 2-3: Special safety requirements for short wave therapy equipment.

The three main sources of stray fields during the use of diathermy are the electrodes, the supply cables and the connections. They are no simple calculation rules for these stray fields. There are proposals for rules of thumb, but the various groups do not agree about the distances to be maintained - these can extend to 2 m.

Rules of thumb consist of keeping a safe distance and minimising the average exposure by limiting the exposure time per six-minute interval (the 'six-minute' rule). Measurements are necessary to determine the exact time per six-minute interval and distance.

*Deep hyperthermia*

Instances of the action values being exceeded are known, 61 V/m at 70 MHz, at a distance of 1 m. However, due to the position of the antennas, the field cannot couple optimally into the body, making it improbable that exposure limit values will be exceeded.

Rules of thumb consist of keeping a safe distance and reducing the average exposure by limiting the exposure time. By keeping a distance of at least 1 m, the exposure levels drop below the action values. By restricting the time spent in the location combined with the application of the 'six-minute' rule the average field strength will also remain below the action value. Simple measurements are necessary to determine the exact time per six-minute interval and distance.

*Electrosurgery*

The NEN-EN-IEC 60601-2-2:2000 Medical Electrical Equipment - Part 2-2 standard covers electrosurgical equipment: Special requirements for the safety of high frequency surgical equipment.

### 4.4.8 Microwave drying

Open microwave dryers have uses that include the drying of walls and the heating of wood. Usually, the energy is directed in a beam through a type of radiation gun towards the object to be heated. For estimation purposes the generic formula for (beam) transmitters can be applied, see Section 4.4.10.

Further rules of thumb consist of: not standing in the beam and keeping a distance of more than half a metre from the surfaces at which the beam is aimed.

### 4.4.9 Transport and traction systems

According to Chadwick [95] currently all 50 Hz motors fall into category I and thus until further measurements which are above the action values are published, no further measures are needed. It is important that the fields around current carrying wires are calculated.

An Italian investigation [88] of the fields on DC railways indicated that there were no cases of the action values being exceeded and thus these are also classed in category I.

Models are required for the calculation of AC powered rail transport.

### 4.4.10 Transmitters

NEN 50383:2000 is the basic standard for calculating the exposure to fields at base stations for telecommunications [138]. This also includes a few rule of thumb formulas. The American Federal Communication Commission (FCC) has also published various bulletins with rules of thumb for estimating exposure levels [123].

A rule of thumb for exposure to the E-field in the antenna main beam for a person in the far field is:

$$E = \frac{\sqrt{30 \cdot 1{,}64 \cdot ERP}}{r} = \frac{\sqrt{30 \cdot EIRP}}{r} = \frac{\sqrt{30 \cdot P \cdot G}}{r},$$

where EIRP stands for Equivalent Isotropic Radiated Power, which is the same as the input power to the antenna $P$ in watts (W) times the gain $G$ of an antenna relative to an isotropic radiating source and $r$ is the distance in metres from the source to the investigation point. The EIRP is the power that would be necessary if the transmitter was to transmit its radiation isotropically and still produce the same power density at the receiver. ERP stands for Effective Radiated Power and is the power that is required if the transmitter was to transmit as a half-wavelength dipole and still produce the same power density at the receiver. The EIRP can be found by multiplying the ERP by the amplification factor of a half-wavelength dipole compared to an isotropic radiator, that is 1.64. For a gain antenna the EIRP and the ERP are thus larger than the actual power.

In the near field, it is necessary to carry out measurements to be sufficiently accurate, although formulas for an approximation are a possibility. The application of the formula for the far field will lead to an overestimation of the field strength [123].

For beam transmitters, exposure in the working situation can usually be prevented by not standing in the beam in front of the dish. If this is unavoidable, exposure is usually in the near field. The distance from the source to the near field boundary $R_{nf}$, and the exposure can be calculated based on the following rule of thumb from the FCC [123]:

$$R_{nf} = \frac{D^2}{4\lambda},$$

where $D$ is the diameter of the dish in metres and $\lambda$ the wavelength in metres. The maximum power density in the beam in the near field, $\max(S_{nf})$ can then be calculated by:

$$\max(S_{nf}) = \frac{16\eta P}{\pi D^2} \approx \frac{16 \cdot 0{,}75P}{3 \cdot D^2} = \frac{4P}{D^2},$$

where $\eta$ is the aperture efficiency that usually lies between 0.5 and 0.75. $P$ is the power supplied to the antenna in watts. By making a rough estimation, with $\eta$ as 0.75 and $\pi$ as 3, the following rule of thumb can be proposed: the maximum value of the power density in the near field is four times the power supplied divided by the square of the diameter of the dish.

Small dish antennas used in GSM masts have a typical diameter of 30 cm, a supplied power of 130 mW and transmit at a wavelength of 24 to 40 GHz. The near field extends to a maximum of 3 m in front of the dish. Within that the maximum power density is 4 x 0.13 / 0.09 = 5.8 W/m$^2$. That is 12% of the action value of 50 W/m$^2$.

General formulas for calculating the fields originating from one or more antennas are barely available. The shape of the antenna and thus the radiation pattern and the gain are important factors for calculating exposure levels. There is a large variety of commercial software for modelling transmitters and calculating fields. There are also various books with summaries, such as Antenna Theory- Analysis and design by Balanis [139]. Examples of calculations relating to the simultaneous exposure to signals from multiple GSM antennas on roofs are given by an RI&E [101].

There are also several formulas, published up by Puranen and Jokela in 1996, for calculations on various types of radar [140].

Generic formulas are often not adequate and for an accurate assessment, numeric calculation must be carried out and use must be made of the technical antenna data and radiation patterns as distributed by the antenna manufacturer.

## 4.5 Description of 'non-standard circumstances'

*General*

In accordance with Article 4, part 5 of the Directive, the employer must be aware of the following 'non-standard' situations during the risk assessment:

1. the potential consequences for the health and safety of workers who must take special risks; in accordance with Directive 89/391/EEC 'groups particularly at risk must be protected against the hazards that apply specifically to them';
2. interference with medical electronic equipment and aids (including pacemakers and other implants);
3. the risk of ferromagnetic material flying around in a static magnetic field with a magnetic flux density above 3 mT;
4. the activation of electric detonators; and
5. fire and explosions resulting from the ignition of flammable materials by sparks caused by induction fields, contact current or spark discharges.

In practice, there is a need for information about how to handle this. Ideally a matrix of 'working environments' versus 'non-standard circumstances' should be drawn up, enabling the employer to see which extra 'workplace issues' must be examined. It is really impractical to draw up an exhaustive list of all non-standard circumstances.

To be able to assess these non-standard circumstances during the risk inventory, the employer must have access to personal medical data about employees working in categories II and III environments. One way of handling this is to ask the worker to truthfully answer, and if needed to sign, a questionnaire including questions covering whether he or she has an active implant, such as a pacemaker, a defibrillator, a fluid pump (e.g. for insulin) or passive implants such as metallic objects. In addition it is advisable to follow current practice where equipment bears a sign to warn those with these types of implants.

*High-risk groups*

In accordance with the Working Conditions Decree (Article 1.1 part 5b) a pregnant worker is defined as 'an employee who is pregnant and has informed the employer of this'. The moment that employers receive this information, they must take measures to prevent the pregnant employee entering working environments that might be harmful. However, there are no limit values available for testing the maximum allowable exposure for pregnant women.

*Interference with medical electronic equipment and aids*

Active Implantable Medical Devices (AIMD) is the generic name for pacemakers, defibrillators, neurostimulators, analgesic implants and insulin pumps, implants in the inner ear, and all types of equipment for monitoring body functions. Electromagnetic fields can interfere with the operation of AIMDs.

Manufacturers of pacemakers and defibrillators, for example, have made extensive summaries of equipment and situations that can cause interference. It is advised that a distance of at least 15 cm is maintained between objects that contain magnets and a pacemaker or defibrillator to prevent an internal switch being operated. During hospital checks these internal switches are activated by magnets for testing the pacemaker or defilibrillator and for obtaining data from them. Once the magnet has been removed the pacemaker or defibrillator returns to its original state.

Manufacturers usually propose a simple measure if the pacemaker or defibrillator has been interfered with: move away from the equipment and then the effects will disappear.

Manufacturers state various situations where interference could occur, such as near medical applications, in situations at home and at work and during travel. Workers can be present in all these situations. A distinction is made between three types of situations.

Firstly there are situations where interference is likely to be caused and that are best avoided: in the vicinity of arc welding equipment, industrial resistance welding equipment, exclusion zones at broadcasting transmitters, chainsaws, dielectric heating equipment, industrial induction heating equipment, industrial magnets, induction furnaces, exclusion zones in power stations, mattresses and cushions for magnetic pain control, MRI equipment and electrosurgical equipment.

In a few cases additional information is provided. It is advisable to walk as quickly as possible through anti-theft gates. For welding equipment the advice is to restrict the welding current to a maximum of 130 amperes.

According to Pinski, electrosurgery can be safely used on patients with an implanted defibrillator (ICD) as long as the defibrillator has been deactivated in advance and is reactivated after the treatment [141]. An investigation into the interference of fourteen types of equipment used by dentists with two types of pacemaker revealed that the electrosurgical equipment could cause malfunctions at distances up to 10 cm [142]. Irnich provided an extensive overview of the investigations that have been carried out into the interference of surveillance gates (EAS, RFID and metal detection) with AIMDs [143]. He argued that both the manufacturers of AIMDs and the manufacturers of surveillance gates should take measures to prevent interference.

Secondly, there are situations where interference can be caused and where precautionary measures are necessary: during the use of leaf blowers, electric drills and other high-power tools, soldering guns, jigsaws, electric hedge clippers, lawnmowers and other petrol driven tools, during car repair, in the vicinity of anti-theft gates, electronic security systems, metal detector gates, amateur radio antennas, Citizens Band radio antennas and during the use of some mobile telephones (depending on type), hand portables and de-magnetising equipment.

Finally, many situations were stated to be safe. This concerned mainly household appliances, office equipment and the use of all types of tools. These situations are equivalent to the working environments that have been classified as category I in this report.

In an alternating electromagnetic field (or when moving in a strong static field) metallic implants, such as hip prostheses, heart valves, aneurysm clips and sutures (clips in the brain), can move or heat up in high frequency fields. The WHO has proposed that people wearing AIMDs and with ferromagnetic implants should avoid locations where magnetic fields are stronger than 0.5 mT [54].

*Ferromagnetic material flying around in a static magnetic field*

In the vicinity of the following strong permanent magnets or electromagnets, fields with a strength higher than 3 mT can occur: MRI scanners, NMR equipment and large degaussers. There are risks of injury due to flying objects, such as screwdrivers, scalpels, injection needles or scissors, or of persons becoming trapped between the magnet and mobile metal equipment such as gas bottles, metal trolleys (cleaning equipment) and metal chairs. Prevention of such hazardous situations can be accomplished for instance by controlling access, combined with training and instruction by competent employees or a metal detection gate can be installed.

*Activation of electronic detonators and ignition of flammable material*

Due to the induction of electric currents, radio frequency electromagnetic fields can cause explosive and flammable material to ignite. According to a WHO fact sheet this is an exceptional occurrence that usually only happens in the presence of a concentration of radar systems, such as on board a naval vessel, where measures are in force to prevent such effects [144].

NPR-CLC guideline TR 50426:2005 was published in January 2005 for assessing the dangers of the unintentional ignition of hot-wired electric detonators by radio frequency electromagnetic fields of between 9 kHz and 60 GHz. According to this guideline, this is really not applicable to electronic detonators. NPR-CLC guideline TR 50427:2005 was published in January 2005 for assessing the dangers of unintentional ignition of inflammable gas or vapour mixtures by radio frequency electromagnetic fields with frequencies between 9 kHz and 50 GHz. Additionally, all workplaces in the Netherlands must meet the minimum requirements of Directive 1999/92/EC (ATEX 137) by 1 July 2006 [145].

# 5 Inventory of control measures

Section 2.5 provides an overview of the application of rules of thumb and simple control measures per working environment. This chapter gives a more comprehensive overview and the justification for the measures. The first section states the general requirements for measures as stated in the Directive, the second gives a summary of general measures, split into the three working environment categories (zie 2.2) and the third provides specific measures per working environment that can be taken to meet the requirements in the Directive.

As far as possible an attempt has been made to provide information relevant to current practice. In addition to information from published literature, the measures provided have been formulated based on consultation with representatives from industry and employer organisations, and also based on observations made during company visits. The measures required to keep exposure levels below the action values can vary considerably from company to company. Due to the diversity of equipment within the working environment, the difference in the measures already in force and the differences in sizes of companies, there will also be a wide difference in costs incurred by employers.

The measures stated here are intended to be an overview. Extensive literature is available covering various specific situations or there are reports available. The measures stated here are aimed at limiting exposure. After measures have been taken, a check must be carried out by measuring or calculating exposure levels to ensure that these are actually below the action values.

Finally, measures need not be taken for working environments in any category if it can be demonstrated that the exposure limit values are not being exceeded.

## 5.1 Requirements in the Directive and the Working Conditions Act (*Arbowet*)

In accordance with Article 5.2 of the Directive it must be established, based on the assessment, whether it is necessary to take measures to limit exposure. Besides account must be taken of current technological developments and the options available for managing the risk at the source, particularly regarding:

a other working methods that entail less exposure to electromagnetic fields;

b the choice of equipment emitting less 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 maintenance programmes for work equipment, workplaces and workstation systems;
e the design and layout of work places and workstations;
f limitation of the duration and intensity of the exposure;
g the availability of adequate personal protection equipment.

Article 3 of the Working Conditions Act states the steps that must be followed when taking control measures. Taking account of current levels of scientific and technical knowledge, this concerns the following: preventing or limiting the hazard at the source; providing collective protection; offering individual protection; and finally making available suitable personal protection equipment. For each transition to a following phase in this step-by-step approach, protection at a qualitatively lower level is only acceptable if protection at the higher level is not reasonable. The use of the term ‘reasonable’ means that an assessment of interests may take place. Here the technical, operational and economic feasibility of the protection measures must be weighed against the dangers of exposure.

## 5.2 General measures for all working environments

There are general measures that can be taken for all working environments to supplement the rules in the Directive. These measures depend on the category (see Figure 3) into which the working environment is placed. In addition there are measures that must be taken for all categories of non-standard circumstances, e.g. for pregnant women and people with medical implants.

Category I working environments require no specific measures. Category IIa means that it will probably be sufficient to take simple measures in the form of directions for use or providing instruction. An example is maintaining a specified distance. Category IIb means that stronger technical measures must be taken. It may be necessary to carry out measurements for working environments in this category. Category III working environments require stringent measures. Examples vary from making a room inaccessible, placing control panels outside and monitoring the room with cameras, to changing the entire layout of a factory.

Those measures that are applicable to the lower categories also apply to the higher categories. Thus the measures stated for the lowest category, category IIa, are adequate for category IIa, but for a category IIb working environment, the measures for both category IIa and category IIb apply.

It is worth considering as a general measure that the manufacturers of equipment state, depending on frequency and power, the distance within which and the position in which the action values or exposure limit values could be exceeded. Or if exceeding these values is not possible, stating this. This type of information could be included in the user manual. This is already being done for some equipment: For example manufacturers of mobile telephones include the maximum SAR to which the head can be exposed in the manual. Also, there are various types of equipment that, within the framework of the Machine Directive 98/37/EC [146] already provide information about matters such as operating instructions, signalling devices and safety.

### 5.2.1 Compulsory general measures for all working environments

The measures given here are based on Article 4 and 6 of the Directive and Article 8 of the Working Conditions Act:

- inventory of current exposure levels - measurements or calculations may be necessary;
- providing information:
    - making the Directive and the limits known;
    - making known the effects against which the Directive is designed to protect (explicitly stating that it has not been drawn up for protection against long-term effects);
    - informing about the conditions under which workers can claim the right to health check-ups;
    - informing about the risks identified in the inventory and the measures taken;
- training:
    - teaching the operating instructions and safety instructions;
    - teaching safe working methods; for example recognising signalling devices and the use of personal protection;
    - understanding when equipment is defective;
    - reporting situations when exposure levels are above the action values;
- categorising new equipment and applications as well as new working methods with previously assessed equipment. On the introduction of the Directive all equipment must be assessed, followed by appropriate control measures that reduce exposure levels to below the action values. Alternatively, it must be demonstrated that the exposure limit values are not exceeded in the working environment.

### 5.2.2 General measures per category

The following measures are possible per category. More detailed summaries are given in one of the OSH series from ILO for the protection of workers from RF and microwave radiation [66] and for the protection against ELF fields [147]. NEN-EN 12198 states general measures for the elimination and reduction of exposure due to machines [148]. The measures stated in the Directive are each identified by a letter (see Section 5.1) :

**Category IIa**:

- specific training:
    - identifying zones with potential field strengths above the action value;
    - using equipment so that exposure is minimised;
- limiting the intensity (f):
    - using lower power, switching off if necessary;
- alternative working methods (a):
    - keeping a distance from the source; e.g. by choosing routes that do not run next to sources;
- limiting the exposure duration (f):
    - spending limited time per visit to within the zone around the source where the action values are exceeded (the 'six-minute' rule, only above 100 kHz, see Appendix 1); e.g. by leaving the zone immediately after charging and starting up the equipment.

**Category IIb**:

- carrying out measurements to determine the distances where exposure levels are below the action values;
- suitable maintenance programs (d):
    - periodic checking for defects at connections: each wave or current conductor that has poorly fitting components or materials with defects will transmit radio frequency fields;
- technical measures (c):
    - measures at the source:
        - labelling of machines with the maximum field strengths at the operating positions and at the positions where workers might be present for extended periods;
        - fitting warning signals; e.g. (flashing) lights when switching on equipment;
        - fitting shielding:
            - fitting shields of radio frequency absorbing material; this is more effective than reflecting material for reducing exposure;
            - conductive shields for resisting ELF electric fields;
            - shielding of Mu-metal to weaken magnetic fields;
            - metal encasement of cables, electrodes and other components that are not primary causes of product radiation;
        - earthing to prevent secondary radiators and contact shocks:

        - minimising ELF magnetic fields by breaking up large current loops, such as fences of conductive barbed wire on wooden poles;
        - preventing charging by ELF electric fields;
        - preventing RF fields acting as antennas, which can cause conductive materials to be electrically charged;
      - fitting circuit breaker (interlock system) to prevent machines being used, except when all protective measures are in place;
  - preventing secondary sources:
    - removing reflective material in the workplace;
    - removing pieces of metal with dimensions that are multiples of a quarter of the dominating wavelength of the field;
  - separation of people and sources:
    - constructing physical barriers such as fencing;
    - restricting access to the hazardous area (e.g. only following written permission);
    - moving operating panels;
    - hanging up warning signs;
    - applying (painted) markings;
- availability of personal protection equipment (g):
  - wearing RF resistant suits (usually less comfortable than measures taken at the source);
  - wearing conductive clothing for resisting electric fields (at low frequencies < 300 Hz);
  - wearing rubber soles and thick socks to reduce induced current through the body;
  - wearing insulating gloves to prevent contact currents by contact with unearthed, charged objects;
- availability of personal measuring/warning equipment (g):
  - using RF dosimeters to make application of the 'six-minute' rule possible;
  - using measuring equipment with an alarm that is triggered when the field strength exceeds a specific level.

**Category III**:

- Hanging up warning signs (Article 5, part 3 of the Directive); this is compulsory at locations where the action values could be exceeded, unless it can be demonstrated that the exposure limit values will not be exceeded and there are no safety hazards;
- selecting equipment that generates less strong electromagnetic fields (b):

    - replacing a process that generates electromagnetic fields; e.g. by a process that only generates heat (elimination);
    - replacing equipment (often older equipment) by equipment that uses less power and generates less strong fields (replacement);
    - automating the production process so that workers can operate at a safe distance (modification);
- design and layout of the workplace (e):
    - completely shutting off a room to all personnel; this usually means automation of the driving of the equipment, use of remote control and observing the process using cameras;
    - changing the layout of a factory building or machine:
        - creating more space between machines and enclosures;
        - installing reflective walls and objects (removing secondary sources);
        - constructing a Faraday cage to make it possible to pass alongside equipment that generates radio frequency fields.

NEN-EN 12198-3:2003 provides a detailed summary of possible measures for shielding and weakening of fields [148].

#### 5.2.3 Expertise

The employer needs a degree of expertise to carry out the stipulations in the Directive. In the first instance this requires knowledge of the Directive, in the second instance expertise in the fields of electric, magnetic and electromagnetic fields particularly, and in the third instance knowledge of the CENELEC standards to be able to establish exposure levels. This is particularly important for checking the field strengths against the action values. Also taking effective measures requires some expertise.

CENELEC Commission TC106X, WG 4 has drawn up a standard for carrying out the assessment of exposure levels. NEN-EN 12198-2:2002 provides extensive information about measuring around machines [148]. In addition CENELEC will draw up various workplace standards for specific working environments. Regarding the expertise required for carrying out the inventory of the exposures and the checking and application of the control measures, in the OSH series no. 57 and 69 [66, 147]. ILO has also stipulated the requirements that specialists must meet. Here, examples are given such as the radiation protection officer and the health physicist.

The employer has roughly two options for deploying this expertise, either developing it in-house or hiring in external specialists.

The practical research indicated that occupational health specialists or safety specialists from the Health and Safety at Work Executive do not generally have specialist knowledge about electromagnetic fields - some safety specialists had had contact with this field. In particular those safety specialists working in metallurgical companies did often have some knowledge of magnetic fields. When the aim is to produce electromagnetic fields, as with transmitters, the employer usually has sufficient expertise in house to protect workers from exposure to levels above the limit values.

There are roughly 4 types of workers who come into contact with electromagnetic fields:

1. workers who do not work with or in the vicinity of equipment in categories II or III;
2. workers who do not work with equipment in categories II or III, but do work in the vicinity of this type of equipment (e.g. maintenance technicians);
3. workers who work with equipment in categories II or III; and
4. workers who check that the laws relating to health and safety at work are being applied.

Based on this classification of workers, four levels of instruction and training are required. Workers in the higher categories must also meet the requirements for the lower categories. The types of instruction and training listed below include a number of questions that workers must be able to answer after following appropriate training courses.

This summary is a basic list that can be extended with specific questions and requirements per occupation:

1. Company introduction (type of worker 1, 2, 3, 4):
    - Who is the Working Conditions Specialist or Safety Specialist responsible for EM?
    - What are electromagnetic fields (E, H, units)?
    - Where do they occur?
    - What types of equipment generate them?
    - Which areas must be avoided (indicated by: zoning, marking, and enclosure)?
2. Awareness training (type of worker 2, 3, 4):
    - How can I recognise equipment outside the normal workplace (but encountered during work) that is a potential source of electromagnetic fields?
    - Where can I find the standard list including photos of equipment, rules of thumb and tables of safe distances for the equipment encountered during work?

- How do I find and use a list with contact numbers/websites for requesting information (e.g. of spokespersons for mobile telephony).
3. Training about use of equipment (type of worker 3, 4):
   - What are the characteristics of the equipment?
   - At what equipment settings and locations is there a possibility of exposure above the action values?
   - How can you prevent yourself or someone else being exposed?
4. Specialist training – determining EM field strengths (type of worker 4):
   - What are the principles of basic field theory?
   - What are the current laws, action values and exposure limit values?
   - What is the worker allowed to do?
   - Which NEN / CENELEC standards are obligatory for the equipment used?
   - How do you read and use these standards?
   - How do you use the measuring instruments?
   - How can you carry out the calculations yourself?
   - Which calculations/measurements must you carry out yourself?
   - What measures are possible for reducing the exposure?
   - How do you keep up-to-date with the latest developments?

## 5.3 Measures per specific equipment group

There are scientific reports and articles that provide extensive information about protection measures for specific types of equipment. A report from the HSE published in 1999 [11] contains information about such measures relating to transmission and telecommunication equipment, induction heating, dielectric heating and medical equipment.

### 5.3.1 Installation and Maintenance

Three sub-environments require measures for workers in the working environment Installation and Maintenance.

Work in the vicinity of equipment that is being maintained and work on equipment during maintenance and installation fall into category II. The following specific measures, which have been largely adopted from the Canadian Environmental Health Directorate (EHD) [149] apply to both working environments:

Training

- modification of the voltage and power, and replacement of elements that generate radio frequency fields must be carried out by specially trained workers;

Organisational measures

- distances to antennas and equipment at the workplace within which the action values can be exceeded must be known by workers;

- the Antenna Register (www.antenneregister.nl) should be used to check whether the work is being carried out in the vicinity of transmitters and that exposure levels will be below the action values;
- instructions and procedures for repair and maintenance, as drawn up by the manufacturer or by a specialist, should be kept with the equipment and made available via Internet for fast reference;
- replacement materials must be equivalent to the original components, to prevent scattering at connections, e.g. for transmission lines and wave-guides;

Testing and preparing for work

- measuring equipment for current strength, field strength and suchlike before commencing repair work;
- test circuit breakers (interlocks) before starting work and do not switch them off;
- replace protective shields, wave-guides and other components before starting the test;

Carrying out the work

- the beam of radio frequency equipment should not be pointed directly at people when it is switched on for testing for maintenance procedures;
- measuring equipment for testing current strength, power and field strengths must be used during the work to ensure that exposure levels remain below the action values;
- limit intensity and exposure duration when it is essential to work at a location where exposure levels are above the action values;
- components that generate radio frequency energy must be provided with a suitable output load or the electromagnetic energy must be absorbed by an anechoic material, so that the energy cannot scatter freely around the room.

For troubleshooting situations that are classed in category III, there are situations when equipment must be tested without all safety measures being in operation. This situation is undesirable, but cannot always be avoided. Great care must be taken in these situations. It is advisable to always carry a field meter and to be in a position to switch off the equipment at once if exposure levels are too high. This switching facility may be mechanical, but can also be simply arranged by having someone available during the troubleshooting to keep one hand on the on/off switch.

### 5.3.2 Detection of articles and people

Anti-theft and metal detection gates fall into category IIa. The organisational measure of maintaining a distance of at least 1 m is adequate for anti-theft gates. In some cases changes to the layout of the workplace will be required, e.g. moving gates or a cash desk.

For gates used for detecting metal objects, e.g. at airports and in clubs, action values will not be exceeded if employees remain outside the gateways and do not lean against the gate housings. In addition the 'six-minute' rule can be applied to fields with frequencies above 100 kHz (see Appendix 1).

### 5.3.3 Dielectric heating

Capacitive equipment for sealing plastics and for gluing wood has been placed in category IIb. There are many measures available for ensuring that exposure levels remain below the action values. This group has been placed in category IIb and not in III because the field strengths are usually below the action values due to the measures that have already been taken. The principal exposure is to radio frequency and electric fields.

The HSE guidance note published in 1986 [34] and the International Labour Organization (ILO) in 1998 [27] state various organisational and technical measures, as well as tips for monitoring and training. It is advisable to take four types of measure:

- suitable maintenance procedures (not usually normal practice);
- shielding fields (usually carried out to some extent);
- various technical measures (a selection is usually made here);
- organisational (normal practice).

Suitable maintenance procedures are:

- switching off the equipment when it is being cleaned or repaired;
- only allowing trained workers with knowledge of electromagnetic fields to work on the equipment;
- regular checking, preferably twice yearly, (this measure is rarely applied in practice) to ensure:
    - the RF generator is set to the minimum adequate power;
    - the bus bars from generators to electrodes do not exhibit defects that might function as secondary sources;
    - the shielding plates and shields are present and intact;
    - the interlock protection is present and functioning.

Measures at source
There are many ways of shielding RF equipment fields. A few explicit measures that complement each other are:

- shielding electrodes with metal casings (the most effective, but rarely done);
- constructing a casing, with as high a conductivity as possible on the inside, around the RF source;

- allowing as small an opening as possible in the casing (smaller than the transmitted wavelengths);
- using separate conductive parts for the casing to minimise currents;
- connecting conducting components with highly conductive connecting pieces (i.e. unpainted), preferably welded, so that the connections do not function as transmitting antennas;
- meticulous installation, so that supply and return power cables and coolant tubes do not leak RF signals:
    - shielding conductive pipes, or preferably replacing them with plastic pipes;
    - fixing coaxial connections around return cables, so that they cannot emit radiation;
    - placing supply and return power cables as closely as possible to each other;
- carrying out measurements at the start and at regular intervals to check that the shielding is functioning properly;
- preventing secondary sources.

Other measures:

- carrying out simple measurements to determine outside which zone around the source the field strengths remain below the action values (not normal practice);
- separation of people and sources:
    - constructing a non-conductive platform to prevent electrically induced current running through the operator's ankles;
    - erecting physical barriers that increase the distance between the operator and the equipment (e.g. an extra-wide press bench);
    - locating operating panels at a distance from the RF source, for example by the use of:
        - shuttle trays;
        - turntables;
        - conveyor belts and roller conveyors.

    These measures were actually intended to make the use of the equipment as efficient as possible and are thus often used in practice. After all, optimum continuous use of the RF source will be achieved if, for example, the first car can be loaded, while the second is being worked on and the third emptied;
    - indicate the location of the zones where action values could be exceeded using signs (normal practice);
    - indicate when electrodes are live using a light signal (normal practice).

Organisational measures are:

- limiting the average exposure time, so that after application of the 'six-minute' rule the exposure levels are effectively below the action values;
- make user manuals and operating instructions conveniently available next to the equipment.

Personal protection equipment:

- wearing shoes with thick rubber soles and thick socks to prevent electrically induced current running through the operator's ankles.

Secondary sources are highly conductive materials such as metal water piping and air cooling tubes. Objects with lengths that are multiples of a quarter of the transmitted wavelength best absorb energy from fields and retransmit it; close to workplaces new unshielded RF sources can arise. This problem can be tackled by keeping such metallic objects at a distance from RF sources or making sure that their dimensions are not multiples of a quarter of the wavelength.

A conductive floor ensures that the operator is earthed. Absorption of RF energy for an unearthed person is highest between 70 and 80 MHz, but for an earthed person this shifts to 40 - 50 MHz. This changes the current distribution in the body of an earthed person so that more RF energy is absorbed by the lower leg and the ankles. Thus it is better for the operator not to be earthed.

### 5.3.4 Electricity production and distribution

Power stations and air cooled coils in capacitor banks fall into category IIb. The exposure here is to magnetic fields. Action values may be exceeded in power stations near transformers, rectifiers and bus bars. Capacitor banks with air cooled coils are used in some substations. The action values for magnetic fields are exceeded up to 2 to 5 m from these coils.

Measures:

- restricting access within area (e.g. only following written permission);
- placing warning signs;
- carrying out measurements to establish the zones where the action values are being exceeded;
- constructing fencing around these zones.

The same rules apply to rectifiers as given for the rectifiers used for electrochemical processes.

### 5.3.5 Electrochemical processes

On the basis of company visits, KEMA measurements and published literature the rectifier room has been found to fall into category III, because the exposure levels there can be several tens of times above the action values. The bus bars and the electrolysis hall fall into category IIb, because the exposure can be held below the action values by the use of various measures. A number of measures are already used in practice. The exposure for this group is mainly to low frequency 50 Hz magnetic fields. Thus shielding and application of the ‘six-minute’ rule does not apply to this group. The causes of the action values being exceeded are the 50 Hz harmonic components that are not sufficiently filtered out of the DC. After adding the various frequencies using the summation rule, these harmonic components may lead to the action values being exceeded.

It is necessary to carry out measurements for this group to determine the zone around the source outside which the field strengths will remain below the action values (sometimes done in practice).

*Electrolysis hall and bus bars*
For the bus bars and the electrolysis hall the protective measures principally involved controlling access to the area:

- hanging up warning signs at the entrance to the electrolysis hall (usually done in practice);
- carrying out measurements to establish the zones within which the action values are being exceeded;
- using marking paint around the bus bars and the electrolysis tanks to mark areas within which the field strength exceeds the action values (usually done in practice);
- constructing fencing around the electrolysis tanks and bus bars (sometimes done in practice).

*Bus bars*
The following measures are possible for limiting exposure around the bus bars:

- running supply and return bus bars alongside each other for as far as possible (sometimes done in practice);
- running bus bars through the hall several metres above the heads of workers (usually done in practice).

*Electrolysis hall*
A combination of the following measures is required to prevent excessive exposure next to the electrolysis baths:

- calculating whether the exposure limit value is being exceeded;
- sinking electrolysis baths into the floor to increase the distance between the current carrying bath and the worker (done in practice in a few cases);

- marking walkways between the electrolysis tanks so that workers can walk between the tanks without being exposed above the action values.

For existing factory layouts, exposures next to electrolysis tanks cannot always be kept below the action values, although this is often the case. Hence the latter measure. Thus the electrolysis hall falls on the boundary between categories IIb and III.

*Rectifiers*
Exposure levels in rectifier rooms can be multiples of ten times the action value. Thus rectifiers fall into category III.
The following are necessary:

- replacing the equipment with rectifiers that produce fewer harmonic components. In the ideal, not realistic case even none, so that the action values are not exceeded;

or

- hanging up warning signs in the vicinity of the rectifiers;
- closing off the rectifier room making it inaccessible; and
- making the surroundings of the rectifiers inaccessible to personnel.

### 5.3.6 Induction heating

Induction heating equipment falls into category IIb, because of the incidences of the action values being exceeded reported in the literature in EU countries and a few instances of a lack of shielding. Action values for magnetic fields are exceeded in the vicinity of induction heating equipment with open coils and in the vicinity of induction furnaces. In addition to the wide range of frequencies and powers that are used, the working procedure is also very important. Often, workers need not be present at the locations where the action values are exceeded. For determining the distances outside which the action values are not exceeded it is generally necessary to carry out (simple) measurements. This is partly due to be diversity of the equipment. The exposure for large melting furnaces is usually ELF (50 Hz) magnetic fields. Due to the diversity of equipment, exposure to higher frequencies, up to 8 MHz, can also occur for surface heating applications or smaller furnaces.

On the basis of measurements, exposure levels can be kept below the action values using simple to carry out measures such as shielding the source of electric and electromagnetic fields for new or renovated equipment and marking distances or fencing around older equipment. Induction furnaces produce so much heat that it is likely that workers will keep at a safe distance. This reasoning is not always valid, e.g. when heat resistant clothing is being worn. Company visits also indicated that gates and chains in fences are sometimes used improperly as regular access routes.

As with dielectric heating, it is advisable to take four types of measure:

- using suitable maintenance procedures (not normal practice);
- shielding fields (sometimes carried out);
- applying various technical measures (sometimes done in practice);
- organisational (normal practice).

Suitable maintenance procedures consist of:

- switching off the equipment when it is being cleaned or repaired;
- only allowing trained workers with knowledge of electromagnetic fields to work on the equipment;
- a regular, e.g. annual, inspection (not normal practice) to check that:
    - the generator is set at the appropriate power;
    - the conductors from generators to coils do not exhibit defects that might function as secondary sources;
    - the shielding plates and shields are present and intact;
    - the fences are present, locked and intact;
- carrying out measurements at the start and at regular intervals to check that the shielding is functioning properly;
- preventing secondary sources.

Other measures:

- Carrying out simple measurements to determine within which zone around the source the field strengths are exceeding the action values (sometimes done in practice);
- Technical measures at the source side are:
    - automating as much as possible (sometimes done in practice, e.g. tube heating and strip heaters);
    - shielding coils to suppress electric fields (usually done in practice for new and renovated equipment, not for older equipment);
    - placing coils so that the lowest possible component of the magnetic field points towards the locations that are accessible to worker (sometimes done in practice);
    - shielding supply and return conductors;
    - placing supply and return conductors as close together as possible, twisting cables;
    - keeping supply and return conductors out of reach of workers, e.g. suspending several metres above the head.

- Separation of people and sources::
    - erecting physical barriers that increase the distance between the operator and the equipment, e.g. by placing the operating panel at a distance and raising it (usually done in practice);

- constructing fencing around the induction heater, particularly around the coils (sometimes done in practice);
- hanging up warning signs to indicate the areas where the action values may potentially be exceeded (normal practice);
- using warning lights to indicate when the machine is in use, so that workers know to stay at a safe distance (sometimes done in practice).

Organisational measures are:

- limiting time spent in hazardous areas by enforcing the ‘six-minute’ rule (for frequencies above 100 kHz);
- keeping a safe distance from the equipment; workers do not need to approach the induction heaters for most types of work; do not run walkways alongside induction heaters unnecessarily;
- making user manuals and operating instructions conveniently available next to the equipment.

Melting furnaces that must have materials added to them manually during the production process, or where measurements must be carried out through an opening in the furnace can lead to exposure levels several tens of times above the action values and thus fall into category III. These melting furnaces can only be used if it has been demonstrated that the exposure limit values are not being exceeded, or if the production process is automated.

### 5.3.7 Welding

Electric manual welding uses either direct current or alternating current at currents of up to several hundred amperes. With AC, or DC with higher harmonic components, there is the likelihood of action values being exceeded close to the cable. The exposure is mostly to magnetic fields.
During manual arc welding there are two locations where the action values may be exceeded. These are close to the cable and the electrode holder. The electrode holder is classed in category IIa, because the exposure of the central nervous system can easily be prevented. The cable is category IIb, because common working practice is to run the cable over the shoulders via the back and neck to relieve the arm of the weight. By not stressing the arm, the hand can be more easily kept steady and thus a higher quality weld is achieved.

NEN NEN-EN 60974-10 provides instructions for reducing field strength with focus being on the EMC issue [50]. Basic standard NEN-EN 50444:2005 (under development) [51] and product standard NEN-EN 50445:2005 (under development) [52] also provide instructions.

Measures are largely a matter of following specific working procedures, the most important rule to be followed, which is not yet usually followed in practice, is:

- never to run the cable over the neck, shoulders or back!

Technical measures

- using a suspension system or carrier so that the welder does not need to run the cable over the shoulders to take the weight;
- placing an earthed metal shield around the cable, at least for permanently installed equipment;
- shielding the welding installation and the current source using welding shields for example;
- direct earthing of the workpiece or earthing via a capacitor;
- twisting cables, to minimise signals;
- running supply and return power cables (workpiece earthing wire) next to each other for as long a distance as possible;
- keeping cables as short as possible to keep the exposure zone as small as possible.

Organisational measures are:

- keeping a distance between the head and the welding workpiece, i.e. avoid looking very closely at the weld;
- temporarily enclosing the welding zone;
- keeping a distance from the welding cable;
- keeping a distance from welding generators, i.e. keep these at a distance from the workplace.

The minimum distance can be estimated using simple calculation rules and will not usually be more than 40 cm.

For spot and induction welding, usually semi-automated or with fixed equipment, exposure levels of several times the action values are known. Therefore this equipment has been classed in category III. The only way that the use of these welding techniques can continue is by automating them so that no workers are required within the exposure zone.

As a rule of thumb it can be assumed that the action values will not be exceeded if the distances from the cable shown in Table 6 are maintained. If it is not possible to keep this distance then either measurements must be carried out to demonstrate that the action values are not exceeded or a reasoned argument must be given that exposure limit values are not exceeded. In any case the cable must be located well away from the head and spinal column. The cable must not be placed over the shoulder.

### 5.3.8 Medical applications

It is advisable to take three types of measure:

- shielding fields (usually carried out);
- various technical measures (usually carried out in practice);
- organisational measures (normal practice).

*MRI*

Scanning with MRI equipment falls into category IIb. There are both very strong static magnetic fields of several teslas and gradient and radio frequency fields. For an extended summary of possible measures, see Environmental Health Criteria vol. 232 from the WHO and an article by Kanal *et al* [55, 150]. It is advisable to follow all the measures listed below.

Technical measures:

- limiting the external magnetic flux by use of ferromagnetic material for the magnet core;
- shielding the magnetic fields that occur outside the MRI as far as possible, e.g. by the use of a ferromagnetic enclosure that “entraps flux lines”. This is usually an expensive method that does not offer as much protection as installing the MRI equipment in a room sufficiently large to enable staff to keep a distance of several metres (normal practice);
- shielding of the entire room to restrict the spread of magnetic and electromagnetic fields (frequently done in practice);
- locating the operating panel at a distance of a few metres from the coils, so that the operator will be sitting at a sufficient distance from the equipment (normal practice);
- using a warning light to indicate when the MRI is in use;
- fixing a warning sign to access doors that indicates high fields, risks of pacemaker failure and danger of projection of metal objects (normal practice);
- installing a metal-detector gate at access doors to prevent metal objects being projected (normal practice).

Organisational measures:

- keeping a distance of at least a few metres;
- training workers so that they have sufficient information to keep their exposures as low as possible;
- maintaining a medical dossier for each MRI worker and keeping it updated with: traumas, procedures or treatment they have received where a ferromagnetic metallic object might have been placed in their body; and to what degree they may be sensitive to working in magnetic fields.

MRI with intervention activities falls into category III. This means that monitoring must be done to ensure that the exposure limit values are not exceeded, or that a technique must be developed to keep exposure levels below the action values during intervention activities.

*Short wave and microwave diathermy equipment*

Diathermy equipment is set up so that the fields couple optimally with the patient's body. They are intended for warming up and thus the exposure is to radio frequency fields. These applications lie at the border between categories IIa and IIb. Usually, organisational measures such as keeping a distance are sufficient. This distance must be established though by carrying out measurements.

Technical measures:

- shielding electrodes, supply cables and connections, because stray fields occur there, which can couple optimally with the operator;
- removing (large) metal objects from the room where the (microwave) diathermy equipment is set up to prevent reflections of fields.

Organisational measures:

- keeping a distance of at least 2 metres (usually not feasible in practice); a simple measurement can indicate that a distance of a few tens of centimetres, i.e. at arm's length, is sufficient (this is feasible); otherwise the time at the location must be limited;
- restricting time at the location by keeping to the 'six-minute' rule.

A distance of 1 metre is sufficient for microwave diathermy. Then at the operator's location the action values are not exceeded.

*Deep hyperthermia*

Deep hyperthermia is used at two locations in the Netherlands. Measurements have been carried out at both locations.

Organisational measures are sufficient here:

- keeping a distance of at least 1 metre;
- restricting time at the location by keeping to the 'six-minute' rule.

*Electrosurgery*

This treatment has similarities with dielectric equipment and welding. During electrosurgery, frequencies of tens of kilohertz to tens of megahertz are encountered and exposure is largely to radio frequency fields. Nevertheless, potentially high current densities due to a local magnetic field must also be taken into account.

Protection measures are largely organisational. As with welding, there is an important rule that should be followed, although it is frequently not followed in practice:

- Never run the cable over the neck, shoulders or the back!

Technical measures:

- using a cable suspension system or carrier, so that the surgeon does not need to run the cable along his/her body (not current practice);
- using an earthed metal shield around the transmission cable - at least for permanently installed equipment. There is a risk of current leakage at the surgeon's hand if a coax cable is used (sometimes done in practice);
- keeping cables as short as possible to keep the exposure zone as small as possible.

Organisational measures are:

- limiting exposure time by keeping to the 'six-minute' rule, i.e. not keeping the surgical equipment continuously switched on (sometimes done in practice);
- keeping a distance from the transmission cable;
- keeping a distance from radio frequency generators, i.e. keeping these at a distance from the workplace.

#### 5.3.9 Microwave drying

The only practical application in the Netherlands that uses an 'open microwave oven' is for controlling deathwatch beetle (large woodworm) in wood. In addition there are some exotic and still experimental applications, e.g. for disinfecting soil.

Technical measures:

- shielding the magnetron, so that radiation can only be emitted from one side and not from the back;
- using interlock switches (circuit breakers) so that if the protection is removed, or if the source is pointing in the wrong direction, (in the case of soil not downwards), the source cannot be switched on;
- fitting a warning light to indicate when the source is operating;
- hanging up a warning sign.

In addition the most important organisational measure is to inform the workers of the minimum distance they must maintain, and that they must not enter the path of the beam.

### 5.3.10 Research applications

The equipment used in research and educational institutions is very diverse. In general it can be assumed that all equipment listed in the equipment groups may also be encountered in these organisations. That means that in the first instance use can be made of the measures in the relevant groups.

This working environment corresponds closely with Installation and Maintenance, thus it makes sense to use the measures for this group here.

### 5.3.11 Transport and haulage systems

The majority of the rail transport in the Netherlands is powered by direct current. The *hoge-snelheidslijnen* (high-speed passenger lines) currently under construction will be powered by alternating current (50 Hz). The working situations where the highest fields are expected are during the inspection of the overhead conductor (exposure of the head) and when walking over rails (exposure of the feet). It will be sufficient as an organisational measure to keep a distance of more than 10 cm from the cables and rails.

### 5.3.12 Transmitters

*General measures for transmitters*

The following general measures can be taken for the maintenance of transmitters:
- providing specific training;
- measures for transmitter maintenance situations;
- technical measures at the source side;
- technical measures at the workers' side;
- organisational measures;
- personal protection measures.

It is advisable to take all these measures.

Training:
- training to provide personnel with the required technical background knowledge about electromagnetic radiation and protection options (usually done in practice), so that they will easily recognise transmitters and will be capable of carrying out (basic) measurements and calculations to determine field strengths.

Installation and Maintenance
- see the measures for the Installation and Maintenance working environment.

Technical measures at the source side are (often normal practice):

- preventing side lobes as much as possible by choosing suitable antenna types;
- aiming the antenna beam accurately;
- mounting in elevated locations, so that they cannot be approached accidentally and so that the main beam passes above head height;
- minimising power to suit the required range, i.e. not the maximum possible;
- labelling antenna installations (often normal practice) with:
    - name of the responsible person;
    - telephone number of the responsible person;
    - input power and ERP power;
    - transmission frequency;
    - a drawing of the zone within which action values may be/are being exceeded.

Technical measures at the workers' side (separation of people and source):

- constructing fencing (usually done in practice around broadcasting transmitters and radars); if required fit an interlock switch that makes it impossible to approach the transmitters when they are operating;
- applying marking paint to indicate zones where action values are exceeded (often normal practice around radars);
- hanging up warning signs (often normal practice, but certainly not everywhere).

Organisational measures:

- keeping a distance from antennas; check with the Antenna Register (www.antenneregister.nl) which transmitters are in the vicinity of the work, and what the characteristics of the transmitters are, such as the zone within which the action values are exceeded;
- arranging that intensity is reduced; if necessary request that the antenna is operated at a lower power or switched off;
- limiting exposure duration so that after application of the 'six-minute' rule the action values are not exceeded. This can be done by passing quickly through fields with a field strength above the action values, e.g. when climbing a mast containing multiple transmitting elements - this does require accurate calculation;
- written notification and permission to work on a transmitter or to enter an enclosure (normal practice at large broadcasting installations at masts and towers [151].)

Personal protection equipment:

- wearing RF resistant suits (only if other measures are not sufficient);
- carrying RF dosimeter or field strength meter to make application of the 'six-minute' rule possible.

*A few specific measures and rules of thumb*

As a rule of thumb, a distance of 1 m from the antenna can be used for WLL systems. It is important that workers learn to identify the various types of antenna systems, particularly those who do not normally work on the antennas.

For small beam transmitters with an input power of 1 W on antenna masts the action values are not exceeded at a distance of around 1 m. Because there are also beam transmitters with higher powers to which this distance does not apply, it is better to follow the rule of thumb to remain outside the beam by not standing in front of the dish.

TETRA transmitters in masts fall into category IIb. Workers are only exposed above the action values when they climb into the masts. In that case either the transmitters must be switched off, or radio frequency resistant protective suits must be worn, or the exposure must be kept under the limit values by time-averaging.

Large broadcasting transmitters fall into category III. It is certain that the action values will be exceeded. It is not usually possible to take simple measures. One possibility is to construct a Faraday cage to enable workers to pass through hazardous areas. For example in a transmission mast this can be done by constructing a lift cage that cannot be penetrated by radio frequency fields.

Small local and regional FM transmitters are mounted on buildings and due to their unobtrusive appearance may not be recognised by roof workers. Besides these transmitters are not yet recorded on the Antenna Register website. These fall into category IIb. Control measures are required to make them more recognisable.

Other radars fall into category IIb. Because of the high powers of fixed radars it is possible that the action values in the main beam are exceeded at distances of hundreds of metres. However for rotating radars, because of the duty cycle, the average exposure reduces by a few hundred or thousand times. It is necessary to establish an exclusion zone for workers for each radar system by means of measurements or calculations. For example this zone can be cordoned off or marked on the ground. This practice is used by the Royal Netherlands Navy on ships for example.

### 5.3.13 Other working environments

Working environments and equipment that are not explicitly mentioned here must be placed in category II in the first instance. This means that until the classification is definitive, or specific measures have been drawn up for the new working environment, at least the General measures are applicable.

For non-destructive magnetic testing, technical measures can be considered, such as reducing the current and checking using measurements, and also organisational measures can be considered, such as maintaining sufficient distance between the equipment and the head and trunk of the worker.

# 6 Effect on companies

The Ministries of Economic Affairs; Justice; and Housing, Spatial Planning and the Environment have developed guides to assess the effects of intended legislation [152]. One of these guides, the booklet ‘Effects on Commerce and Industry’ (BET) published in April 2003, has been used as a basis for this chapter. The ‘quick scan’ questionnaire (an abridged version of the Effects on Commerce and Industry questionnaire) could be skipped in the case of the implementation of a European directive. According to the booklet, ‘The effect on companies indicates the intended and unintended consequences of the legislation on commerce and industry such as the effect on markets, and socio-economic consequences’.

The consequences of the implementation of the Directive are summarised here. In the first place this chapter covers the assessment of the working environment with relation to the exposure of the worker. Also, employers must advise and instruct their employees. In this report, ‘working environment’ means the combination of the equipment at the workplace that causes electromagnetic fields and its use. In the second place, it is intended that the implementation will lead to control measures being taken to ensure that exposure limit values will no longer be exceeded. In the third-place, measures must be taken to protect workers exposed to special risks and to prevent additional effects.

The Effects on Commerce and Industry questionnaire consists of eight questions. These will be answered in the following sections. The emphasis of the effects on companies is on the costs involved. In addition, other effects on industry and commerce such as benefits, ability to pay, competition with other countries, marketing and socio-economic effects. The costs relate to the difference between the current and future situation.

Distinction is made between two costs, the administrative burdens and the cost of the control measures. The administrative burdens include the cost of the inventory of exposure levels (including measuring and/or calculation) and the cost of advising and instructing workers.

## 6.1 Type and number of companies

*Question 1* *Which categories of company will potentially be affected by the planned legislation?*
*Question 2* *How many companies will actually be confronted with the planned legislation?*

This report summarises working environments where the action values and/or the exposure limit values may potentially be exceeded. These working environments are divided into the categories I, IIa, IIb and III, depending on the potential degree to which the action values or exposure limit values can be exceeded (see Section 2.3).

The majority of companies only have working environments in categories I and IIa. Companies that only have working environments in category I do not have to take any control measures. These companies do have to include the subject 'electromagnetic fields' in their RI&E, but that takes virtually no extra effort. It is expected that the costs for working environments in category IIa will be minimal. It involves simple instructions that can for example be included in the introductory programme for new employees. Thus no attempt has been made to estimate the number of working environments and/or workers for working environments in categories I and IIa.

For those working environments in categories IIb and III, a check was made to establish in which sectors they could occur (see Table 9, 'SBI-codes' column). This was done at the highest aggregation level (see Appendix 3 for the meaning of the SBI codes). Next, CBS data regarding the number of companies per SBI code was used to establish how many companies were involved (see Table 9). In cases where no detailed data was available, an estimate was made of the order of magnitude (10, 30, 100, 300, 1000, etc.). The uncertainty of the estimates amounted generally to a factor of 3, both above and below, but these could also be larger. In the final calculation of the costs of the control measures (see Section 6.2.2) a low and a high estimate of the number of companies or workers was used. Average values are given in Table 9.

There can be several working environments per company that require control measures. In some cases it is also necessary to know the number of workers. If for example the decision is made to inform all arc welders about how to minimise exposure, it is more important to know the number of arc welders than the number of working environments in which arc welders work. Thus either the number of companies with the number of working environments per company or the total number of workers is included in Table 9. A more detailed explanation of the estimated numbers is included in the explanation in Section 6.2.3.

The CBS definition of a company is used in this chapter. According to the CBS, a company (business unit) is the actual transactor of the production process - the production of goods and services for the market - and is characterised by autonomy, being definable and external orientation. Besides, a company must be involved in economic activity. If at least one person works for fifteen hours per week then a company is considered to be economically active. The business unit is the main unit within the system of economic statistics - this is simply called a company [153].

*Table 9 Working environments and industrial and commercial sectors (see Appendix 3 and the explanation in Section 6.2.3 for a complete list of SBI codes)*

| equipment group and working environment | cat | SBI code | no. of companies | no. of working environments per company | total no. of employees |
|---|---|---|---|---|---|
| research applications – difficult to itemise | IIa/b | CA, CB, E, K, M, N | 1,000 | 3 | |
| installation and maintenance - equipment that is being installed or maintained and equipment that employees can come close to | IIb | F, K | | | 60,000 |
| dielectric heating - plastic sealers and wood gluing machines | IIb | DD, DH | 300 | 3 | |
| electricity production and distribution – power stations | IIb | E | 100 | 3 | |
| electricity production and distribution – air cooled coils in capacitor banks | IIb | E | 10 | 1 | |
| electrochemical processes – current supply systems (bus bars) | IIb | DG, DJ, DL | 30 | 10 | |
| electrochemical processes- electrolysis hall | IIb | DG, DJ | 30 | 3 | |
| induction heating - with open coils | IIb | DJ, DK | 1,000 | 1 | |
| induction heating – larger ovens | IIb | DJ | 300 | 10 | |
| welding – arc welding - cable | IIb | DJ, DK, DL, DM, DN, F, G | | | 35,000 |
| medical applications - MRI – scanning | IIb | DL, N | 100 | 1 | |
| medical applications - short wave and micro wave diathermy | IIb | DL, N | | | 5,000 |
| transmitters - small broadcasting transmitters (on roofs) | IIb | DL, I | 30 | 10 | |
| transmitters - radar systems (navigational) | IIb | DL, I | 10 | 20 | |
| other working environments - non-destructive magnetic testing - hand yokes | IIb | DJ, DK | 4 | 250 | |
| other working environments - non-destructive magnetic testing - test benches | IIb | DJ, DK | 40 | 5 | |
| installation and maintenance - troubleshooting work | III | F, K | 1,000 | 1 | |
| electrochemical processes - rectifiers | III | DG, DJ, DL | 30 | 3 | |
| induction heating - smaller melting furnaces (alloying) | III | DJ | 300 | 1 | |
| welding - spot and induction welding, semi-automated | III | DJ, DK, DL, DM, DN, F, G | 1,000 | 3 | |
| medical applications - MRI - intervention avivities | III | DL, N | 100 | 1 | |
| transmitters - large broadcasting transmitters | III | DL (3220), I (6420) | 2 | 50 | |

## 6.2 Benefits and costs

*Question 3 What will the most probable effects of this planned legislation be on the benefits and costs for the companies concerned?*

### 6.2.1 Benefits

At the beginning of this chapter, benefits were described qualitatively as the intended results of the legislation. The benefits cannot be quantified without difficulty. For example a '(maximum) achievable health gain' cannot be calculated because exceeding the limit value does not immediately cause a health effect.

### 6.2.2 Costs

The costs involved with the implementation relate to the difference between the current and future situation. A distinction is made between two costs, the administrative burdens and the cost of the control measures. The administrative burdens include the cost of the inventory or exposure levels (including measuring and/or calculation) and the cost of advising and instructing employees: see also Section 6.6. The remainder of this section covers the cost of the control measures only.

An estimation has been made of the total costs of the control measures to be taken per type of working environment/equipment group. The considerations that played a role in this are included in Section 6.2.3 per type of working environment/equipment group. The costs per control measure are multiplied by the number of working environments (= number of companies times the number of working environments per company) or by the number of employees.

The costs of the control measures consist firstly of investments that are required for protecting workers against electromagnetic fields. Considering the diverse nature of the control measures, the depreciation period of these investments varies from a few years to twenty years in some cases. The calculations assume an average of ten years. Secondly, companies will incur extra costs on an annual basis that are attributed to the year in which the costs are made. An example is keeping workers updated about how to cope with EMF ('training' control measure).

Control measures will be taken in categories IIb and III. These are the groups that are relevant for the calculation of the costs of control measures. Companies without workers scarcely occur in these categories.

It is assumed that, on average, half of the required control measures are already in use. Thus the annual costs are multiplied by 0.5. For example the majority of the required control measures are already in use for transmitters. Low and high estimates have been made because of the wide diversity of possible control measures and uncertainties about the numbers of working environments. The annual costs of control measures for the companies, in as far as can be predicted, work out at €1.9 to €4.5 million. Details of the calculations can be found in Section 6.2.3.

If the assessment of exposure levels for category III working environments indicates that exposure limit values are not being exceeded, no further control measures are needed. The estimates of the costs per control measure for companies with working environments in category III are very uncertain. This is because many types of control measures and combinations of control measures are possible. It may also occasionally be the case that the costs of the control measures are disproportionate or that control measures are not possible. These situations require further study.

### 6.2.3 Cost of control measures per type of working environment/equipment group

***Category IIb***

*Research applications*
This relates to scientific bodies, research departments in industry, and education, the latter being mainly higher education. The number of working environments can vary considerably. The costs of control measures that will be taken in the first instance, such as the adaptation of working methods or modification of equipment, are estimated to be an average of €1000 per working environment.

*Installation and maintenance: equipment that is installed or maintained and equipment that workers approach.*
According to the UNETO-VNI trade association's website (www.uneto-vni.nl) they have 12,300 associate members with a total of 120,000 workers. The workers must be especially aware of the potential risks. This can be achieved by workers being coached by well-informed specialists. The costs of the 'training' control measure are estimated to be an average of €300 per worker. This amount lies somewhere between the costs of simple instructions (€100 per worker) and of following a course (€1000 per worker). It is assumed that a maximum of 50% of the workers will follow a training course.

*Dielectric heating: plastic sealers and wood gluing equipment*
The estimation of the total of approximately 1000 working environments is derived from statements made during the practical research. This research also indicated that shielding control measures were partly used in practice. The costs of shielding control measures are estimated to be approximately €300 per working environment.

*Electricity production and distribution: power stations*
In addition to the large power stations there are various smaller units mostly having more than one generator. The costs incurred will be for carrying out measurements and constructing fencing and are estimated to be €3000 per working environment.

*Electricity production and distribution: air cooled coils in capacitor banks*
The number of capacitor banks is around 10. Because these installations are relatively new, exposure to magnetic fields has generally been taken into account and security fencing is often present. The costs per control measure are estimated to be between €3000 and €10,000.

*Electrochemical processes: current carrying systems and electrolysis halls*
It is anticipated that this involves 10 to 100 companies, each having multiple working environments. In total 300 working environments were assumed. The cost of the ‘construct fencing after carrying out simple measurements’ control measure is estimated to be approximately €3000.

*Induction heating*
Applications using open coils do occur in some workplaces. The number of companies having larger furnaces was derived from CBS data about the size of the base metal industry (300). For the estimated 1000 smaller pieces of equipment with open coils, one-off construction of shielding is the most obvious solution, with costs estimated around €300. For the estimated 3000 larger furnaces, ‘constructing a fence after carrying out simple measurements’ and other obvious control measures, the cost is estimated to be approximately €3000 per furnace.

*Welding*
There are estimated to be 60,000 to 80,000 welders in the Netherlands [154], who presumably do not all use alternating current welding. Thus a low estimate of 10,000 and a high estimate of 60,000 was used. The costs of the ‘training’ control measure are estimated to be an average of €300 per worker. This amount lies somewhere between the costs of a simple instruction (€100 per worker) and of following a course (€1000 per worker).

*Short wave and microwave diathermy*
There are probably approximately 5000 diathermy appliances in use by physiotherapists (see Section 3.9). The control measures involved here are aimed at operators being as short a time as possible within 2 metres of the equipment and these can be achieved by ‘training’. For treatments where the therapist has to be close to the equipment, it may be necessary for measurements to be carried out for a limited number of types of equipment to establish the distance that must be maintained for these specific types of equipment. Costs are estimated to be €100 per therapist.

*Transmitters: smaller broadcasting transmitters*
The number of smaller broadcasting company transmitters located on roofs is approximately 300. Calculations are based on the hang up a warning sign' control measure and €300 per transmitter has been assumed.

*Transmitters: radar systems*
This applies to approximately 200 navigational radars and radars for air-traffic control. It is already normal practice to mark exclusion zones that workers may not enter when the radar is operating. The cost for the application of marking is estimated to be €300 per installation.

*Other working environments: non-destructive magnetic testing*
This involves a total of four large companies that use approximately 1000 hand yokes (service life 2 years and cost approximately €800 each) and tens of companies with a total of no more than 200 test benches (service life 10 years and cost approximately €50,000 each). Approximately 1000 workers use this type of equipment on a daily basis. The costs of changes required to existing training courses are negligible. Two types of control measure have been considered in the calculations: replacement of hand yokes (€300 each) or technical modifications to test benches (an average of €1900 each; composed of 90% at €1000 each and 10% at €10,000 each).

***Category III***

*Installation and maintenance: work in troubleshooting situations (with the equipment switched on)*
This applies to a wide range of possible situations and solutions. Therefore each situation must be examined separately and it will probably be necessary to carry out measurements. The uncertainty of the estimation of the average cost of €10,000 per working environment is probably larger than a factor of 3.

*Electrochemical processes: rectifiers*
Each working environment must be investigated to establish the best solution. The estimate of the costs of €30,000 per working environment used in the calculation is very uncertain.

*Induction heating: smaller melting furnaces (alloying)*
Not all smaller melting furnaces need to be operated from close by when they are in operation. Both the estimate of the number of companies and the costs (€30,000 per working environment) are very uncertain.

*Welding: spot and induction welding; semi-automated*
The question is whether solutions for these working environments are possible. Also full automation by the introduction of welding robots is very expensive. Thus no estimation has been given here.

*Medical applications: MRI - intervention activities*
The estimation of 100 working environments is probably a bit high, because not all MRI scanners are suitable for intervention activities. For these working environments, it is probably best to show that exposure limit values are not being exceeded via measurements and model calculations. If it turns out that exposure limit values are being exceeded, then the question will be whether control measures are possible and whether the activity will be able to continue once the Directive is in force.

*Transmitters: large broadcasting transmitters*
This relates mainly to work in transmission masts where it is preferable that the antennas are not switched off. The estimation of the costs is €30,000 per working environment. This estimation is really very uncertain.

## 6.3 Ability to bear costs

*Question 4 How do the costs and benefits of the Directive relate to the ability of the industrial sectors concerned to bear the costs?*

The highest costs for control measures are expected in the ‘installation and maintenance - equipment that is installed or maintained and equipment that workers approach’ (29%), ‘welding - arc welding - cable’ (17%), ‘induction heating - larger furnaces’ (14%), ‘installation and maintenance - work in troubleshooting situations (with the equipment operating)’ (10%) and ‘induction heating - smaller melting furnaces (alloying)’ (10%) equipment groups. The highest costs per individual company (between €0.075 million and €1.5 million) are expected in the ‘other working environments – non-destructive magnetic testing - hand yokes’, ‘electrochemical processes - rectifiers’ and the ‘transmission installations - large broadcasting transmitters’ equipment groups.

## 6.4 Other countries

*Question 5 What is the situation relating to the legislation in the same policy area in those countries that can be considered to be the most relevant competitors to the industrial sectors concerned in the Netherlands? (Check on other countries)*

There are member states in the European Union where the legislation is already more severe than the level aimed at by the Directive - Poland is an example. They will not be allowed to mitigate their legislation when the Directive is implemented. In the other EU member states, as in the Netherlands, at least the requirements in the Directive must be met. The exposure limit values and action values in the Directive are the same as the values advised by the ICNIRP. Harmony between the measurement and calculation methods applied at the European level will be achieved via the CENELEC harmonised standards. In accordance with the considerations in the Directive, the aim is not just ‘to ensure the health and safety of each worker on an individual basis, but also to create a minimum basis of protection for all Community workers, in order to avoid possible distortions of competition’.

Outside Europe, in countries such as Japan and Australia, the ICNIRP values are followed, but in countries such as the USA, Canada and China this is not the case. It is outside the scope of this report to cover the differences between ICNIRP and the systems in these countries in more detail.

*Question 6 Does the planned legislation contain requirements that bring about the following:*

- *a Access to (or practising of) a profession or activity are subject to more, or to more rigorous, requirements than required by the EU Directive?*
- *b Companies carrying out specific activities are subject to more rigorous requirements than those provided for by EU directives? What are the grounds for this?*

No. The Directive will be implemented without additional national legislation. There are no reasons for the Netherlands to deviate from other member states.

## 6.5 Marketing and socio-economic effects

*Question 7 What are the marketing consequences of the planned legislation?*

Because it relates to the implementation of a European Directive, there are no consequences for marketing.

*Question 8 What are the socio-economic effects of the planned legislation (employment, salaries and suchlike)?*

The socio-economic effects of the Directive relate to the increased safety of workers.

A consequence of the implementation of the Directive could be that discussions arise within companies about possible long-term effects and about possible effects on well-being. Complaints such as sleeplessness, lack of concentration, etc can have many causes and are sometimes related to exposure to electric, magnetic and electromagnetic fields. The Directive states specifically that it was not drawn up for protection against long-term effects. These effects have been investigated, but are considered to have been insufficiently proven for them to be used as a basis for drawing up exposure limits [2, 3]. Good communication may minimise this type of discussion.

In cases where exceeding the exposure limit values cannot be solved by control measures, which for companies with category III working environments is not totally unrealistic, the ceasing of specific activities may lead to job losses.

## 6.6 Administrative burdens

The Directive does not oblige permits or any form of reporting to the government. However, in principle all companies with employees must be familiar with the legislation, and based on the assessment process in this report or, as soon as the applicable CENELEC standards are available, must carry out an inventory of their working environments and inform their employees. These activities will be carried out as part of the RI&E that must be done every four years in any case. The administrative burdens are estimated to be as follows.

*Categories I and IIa*
All companies must check whether employees come (or could come) close to equipment that produces electric, magnetic or electromagnetic fields. Companies that do not have this type of equipment only need to answer 'no' to question 0 in the RI&E module electromagnetic fields (see Appendix 2). They need take no further action. For companies in categories I and IIa, working through the RI&E module means spending such a small amount of extra time that an average time has been used here. The average time required for completion of the part 'making an exposure inventory' in the RI&E is considered to be equivalent to 5% of the time required for the average RI&E. This data has been adopted from the standard calculation model that the Dutch Ministry of Social Affairs and Employment (SZW) usually uses for making assumptions about hourly wages, time spent and frequency. Informing employees is estimated to cost 10% of the extra time needed for making the inventory.

*Categories IIb and III*
Companies in categories IIb and III must follow the information requirements in the Directive. This involves establishing and, if required, measuring or calculating the degree of exposure (assumed to be required in 50% of the cases), keeping a dossier and medical monitoring. The additional time required is estimated to be 25 to 55 hours (average 40 hours) for the two categories. This estimate allows for the costs of outsourcing the measurements or calculations. For the 'induction heating - with open coils', 'medical applications - MRI - scanning', 'welding - spot - and

induction welding, semi-automated' and 'medical applications - MRI – intervention activities' working environments/equipment groups, not all companies will have to carry out measurements. The decision was made to assume that a limited number of all types of equipment would be measured, from which the exposure at the other companies could be derived.

*Results*
The new legislation requires that a module on electromagnetic fields be added to the RI&E. The Netherlands has approximately 326,000 companies with one or more employees (CBS information, 2002). For all these companies, the annual extra cost for the RI&E module is estimated to be €3.9 million. The existing RI&Es must be updated once. Because there is a term of two years between giving notice of and the adoption of new legislation, the costs in this period average €7.8 million per year. From the calculation details it emerged that approximately 50% of the annual administrative burden would fall on companies in categories I and IIa (€1.9 =million per year), 30% in category IIb (€1.1 million per year, 'research applications', 'dielectric heating - plastic sealers and wood gluing machines' and 'induction heating - larger furnaces') and 20% in category III (€0.9 million per year; 'installation and maintenance - troubleshooting (with equipment switched on)' and 'induction heating - smaller melting furnaces (alloying)'. The annual administrative burden per company works out at €6, averaged over all companies. The cost per company can vary from €2 to €112, depending on the size of the company: see Table 10. For companies in category IIb or III there is an additional cost that averages €600 per year, because these companies must measure or calculate exposure levels. The average costs for IIb and III work out at about the same level. It has been assumed that companies in category III will need to carry out more extensive and complex measurements or calculations, but that they will have in-house expertise to handle this. Companies in category IIb will have to carry out less extensive measurements, but may well have to hire in more expensive expertise.

*Table 10 Administrative burdens related to company size.*

| size of companies | number of companies per size | administrative burdens per company (€) |
|---|---|---|
| 1 employee | 96,845 | 2 |
| 2 - < 5 employees | 125,835 | 3 |
| 5 - < 10 employees | 40,815 | 4 |
| 10 - < 20 employees | 26,320 | 7 |
| 20 - < 25 employees | 6,852 | 8 |
| 25 - < 50 employees | 15,988 | 10 |
| 50 - < 100 employees | 7,305 | 12 |
| > 100 employees | 6,385 | 112 |
| total number of companies with employees | 326,345 | 6 |

When purchasing and commissioning new equipment attention must be paid to the potential exposure to electromagnetic fields. It is not expected that this will lead to extra operations and costs for the large majority of equipment. Thus in the course of time the administrative burdens will probably reduce further.

*Records*
In accordance with Article 4, subsection 6 of the Directive, the risk assessment must be suitably recorded, in accordance with national laws and practice. It will be sufficient if a company can produce on paper during a visit from the Labour Inspectorate, the results of the inventory of working environments, the assessment of field strengths and the control measures taken.

*Medical monitoring*
In accordance with Article 8, subsection 2 of the Directive the doctor and/or medical body responsible for medical checkups must have access to the results of the risk assessment recorded in the above-mentioned dossier. In accordance with Article 8, subsection 2 of the Directive, the results of any medical checks must be recorded in the dossier for later reference.

## 6.7 Conclusions

The results of the investigation on the effect on companies are given in this chapter. Approximately 98% of the companies with one or more employees have been found to fall into categories I and IIa. These companies do not need to take control measures, but will bear approximately 50% percent of the annual administrative burdens.

The annual costs of the control measures will amount to between €1.9 million and €4.5 million. The annual administrative burdens will amount to €7.9 million per year in 2006 and 2007 and €3.9 million per year after 2007.

The total costs of the implementation of the Directive amount to €10 to 12 million per year in the first two years and subsequently €6 to 8 million per year. Figure 13 shows the distribution of the costs over the administrative burdens and the costs of control measures in the coming years.

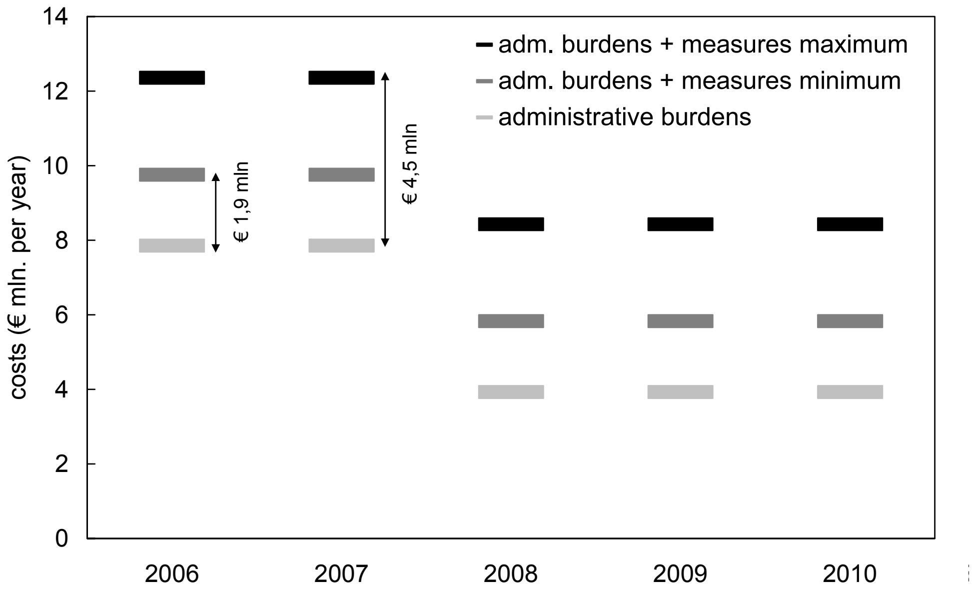


*Figure 13 Annual administrative burdens and costs of control measures.*

# Appendix 1 The Directive

This appendix is intended to be an aid to interpreting the Directive. This means that this appendix must be used together with the Directive. The annex in the Directive contains more information that should be read.

The Directive covers short-term health and safety effects caused by:
- the circulation of induced current in the human body,
- energy absorption, and
- contact current.

According to the system used by the Directive, employees are protected against these health effects if their exposure levels are lower than the exposure limit values. In addition to these exposure limit values, the Directive defines action values for variables that can be directly measured - the electric field strength E, the magnetic field strength H, the magnetic flux density B and the power density S. Compliance with the action values will ensure that the exposure limit values are not exceeded. However, if the action values are exceeded this does not automatically mean that the exposure limit values will be exceeded.

The employer must assess the levels to which employees are exposed and, if necessary, must measure and/or calculate these. Where relevant, emission levels stated by the manufacturer of the equipment may be taken into account, in so far as this equipment falls under European directives [155]. If it turns out that the action values are being exceeded, the employer must assess, and if necessary calculate, whether the exposure limit values are being exceeded.

The assessment, measurement and/or calculation need not take place for working environments that are also accessible to members of the public and for which an assessment of exposure levels is already available in accordance with the EU recommendation for limiting the exposure of the general public [5]. In that case it must be demonstrated that the constraints imposed by this EU recommendation also apply to employees and that no safety risks could arise.

*Exposure limit values*

The exposure limit values are expressed as the following physical variables: the current density J (in $mA/m^2$) in the central nervous system, the Specific Absorption Rate SAR (in W/kg) and the power density S (in $W/m^2$). Depending on the frequency of the electric or magnetic fields or the electromagnetic radiation, these exposure limit values have a specific value: see Table 11. RMS values must be used for current density. Figure 14 shows the exposure limit values for current density J as a function of the frequency.

*Table 11 Exposure limit values (all conditions must be met).*

| frequency-range | current density in the central nervous system $J$ ($f$ in Hz) | body SAR | local SAR (head and trunk) | local SAR (extremities) | power density $S$ |
|---|---|---|---|---|---|
| | $mA/m^2$ | W/kg | W/kg | W/kg | $W/m^2$ |
| up to 1 Hz | 40 | - | - | - | - |
| 1 - 4 Hz | 40/$f$ | - | - | - | - |
| 4 Hz - 1 kHz | 10 | - | - | - | - |
| 1 kHz - 100 kHz | $f$/100 | - | - | - | - |
| 100 kHz - 10 MHz | $f$/100 | 0.4 | 10 | 20 | - |
| 10 MHz - 10 GHz | - | 0.4 | 10 | 20 | - |
| 10 GHz - 300 GHz | - | - | - | - | 50 |

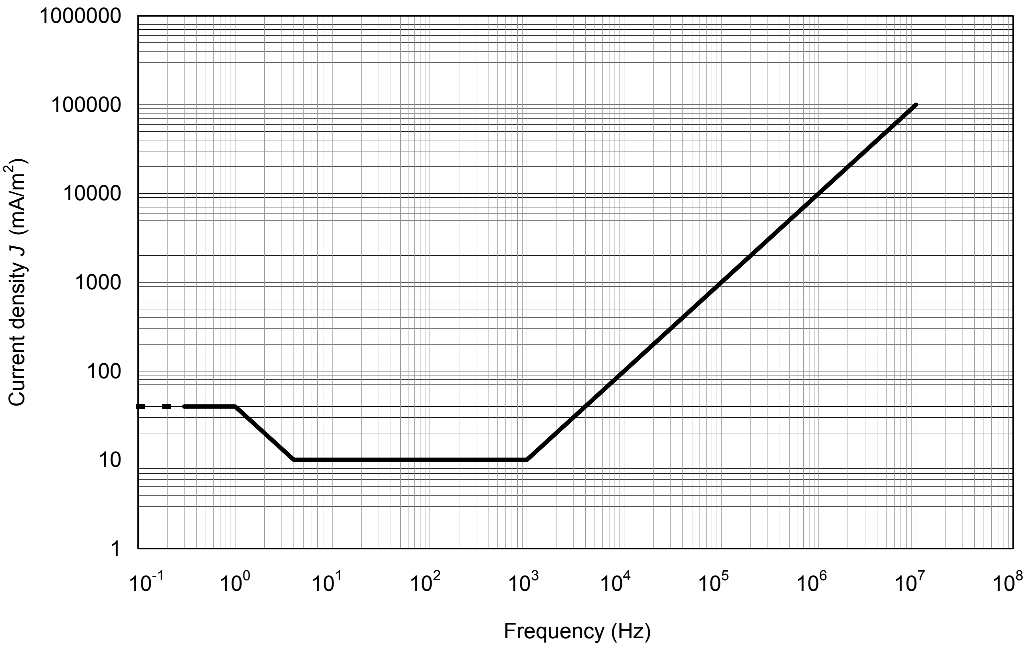


*Figure 14 Exposure limit values for current density.*

*Action values*

The action values laid down in the Directive are given in Table 12 and Table 13.

*Table 12 Action values (RMS values).*

| frequency range | electric field strength, *E* | magnetic field strength, *H* | magnetic flux density, *B* | equivalent power density for plane waves, $S_{eq}$ |
|---|---|---|---|---|
| | V/m | A/m | μT | W/m$^2$ |
| 0 - 1 Hz | - | $1.63\times10^5$ | $2\times10^5$ | - |
| 1 - 8 Hz | 20 000 | $1.63\times10^5/f^2$ | $2\times10^5 / f^2$ | - |
| 8 - 25 Hz | 20 000 | $2\times10^4/f$ | $2.5\times10^4 / f$ | - |
| 0.025 – 0.82 kHz | $500/f$ | $20/f$ | $25/f$ | - |
| 0.82 - 65 kHz | 610 | 24.4 | 30.7 | - |
| 65 -100 kHz | 610 | $1\,600/f$ | $2\,000 / f$ | - |
| 0.1 - 1 MHz | 610 | $1.6/f$ | $2 / f$ | - |
| 1 - 10 MHz | $610/f$ | $1.6/f$ | $2 / f$ | - |
| 10 - 400 MHz | 61 | 0.16 | 0.2 | 10 |
| 400 – 2 000 MHz | $3\sqrt{f}$ | $0.008\sqrt{f}$ | $0.01\sqrt{f}$ | $f/40$ |
| 2 - 300 GHz | 137 | 0.36 | 0.45 | 50 |

Comments:

- *f* in the units stated in the frequency range column.
- Frequencies < 1 Hz, which are in effect static fields, are not given E-field values. Most people do not experience electric surface charges at an electric field strength of less than 25 kV/m as being objectionable. Spark discharges that cause stress or nuisance must be avoided.

*Table 13 Action values for the contact current of conductive objects.*

| frequency range | contact current (*f* in kHz) |
|---|---|
| | mA |
| 300 Hz – 2.5 kHz | 1.0 |
| 2.5 kHz - 100 kHz | $0.4\,f$ |
| 100 kHz - 110 MHz | 40 |

Figure 15, Figure 16 and Figure 17 give the action values for *E*, *H*, and *B* as a function of the frequency. Although the action values for *B* can also be calculated from the action values for *H* using the following formula, a graph for all variables has been included:

$$\mu_0 = \frac{B}{H} = 4\pi \cdot 10^{-7} \approx 1.26 \text{ (μT/(A/m))},$$

where $\mu_0$ is the permeability of vacuum. In vacuum, and in a good approximation in air, $\mu_0$ is a fixed ratio between *B* and *H*.

Figure 18 shows the action values for the power density $S$ and the contact current $I_C$ respectively as a function of the frequency for the conductive object. According to the directive, in the frequency range 10 MHz to 110 MHz, the electric current through the limbs (arms and legs) $I_L$ must be restricted to a maximum of 100 mA.

The action values for $E$, $H$, $B$, $I_C$ and $I_L$ apply to the Root-Mean-Square value (RMS). This is the square root of the (time-)averaged square of the variable. For periodic signals for which the power is proportional to the square, of for example current strength or electric or magnetic field strength, the RMS value is the value that has the same average power, if the signal is constant rather than periodic. The RMS value of an electric field *E(t)* with period *T* is:

$$RMS = \left[ \frac{1}{T} \int_0^T E(t)^2 \, dt \right]^{\frac{1}{2}}$$

For sinusoidal fields the RMS value is approximately 71% of the maximum value.

*Averaging rules for frequencies above 100 kHz*

If the intensity of the fields is not constant, average values over time may be calculated under the following conditions:

1. The average value of $E$, $H$, and $B$ is calculated as the root of the average of the square of the field strength. The normal arithmetic mean is used for $S$.
2. For frequencies $f$ between 100 kHz and 10 GHz the **six-minute rule** applies: the average value (see 1) of each random six-minute period must be checked against the action value. For $f$ > 10 GHz the averaging period is calculated as $68 / (f\ /\ \mathrm{GHz})^{1.05}$ minutes. Averaging may not be carried out for frequencies up to 100 kHz.

*Example of the 'six-minute' rule*

Suppose someone was exposed to a field with a frequency of 2400 MHz and a field strength of 200 V/m for a 30 second period every 7 minutes. For frequencies above 100 kHz, averaging must be done over $E^2$. This can be done by multiplying $E^2$ by the duty cycle, the ratio of the time used per least favourable period of six minutes. Or, the value of the E-field must be multiplied by the root of the duty cycle. Then application of the six-minute rule produces: $\sqrt{(30/360)} = \sqrt{(1/12)} = 0.28$. The resulting E-field is thus 0.28 * 200 = 56 V/m. That is below the action value of 137 V/m.

*Peak action values*

Peak values (high values over a period that is significantly shorter than the averaging period) are limited as follows. First a frequency $f$ is calculated from the duration of the peak $t_p$, according to $f = 1 / (2t_p)$. Next the action value relating to this frequency is looked up in Figure 15, Figure 16 or Figure 17. Finally this value is multiplied by a factor r, read from Figure 19 or calculated as follows:

| | |
|---|---|
| for $f < 100$ kHz: | $r = \sqrt{2} \approx 1.41$; |
| for $f > 10$ MHz: | $r = \sqrt{1000} \approx 32$; |
| between (100 kHz–10 MHz) | $r = 6.8 \times (f / \text{MHz})^{0.68}$. |

The peak value must remain lower than the peak action value as calculated above.

*Summation rules for various signal forms and several sources*

Some sources simultaneously transmit radiation of more than one frequency, either due the use of several carrier waves or because the signal is pulsed or not sinusoidal. According to the Directive, if there is simultaneous exposure to fields of different frequencies '... appropriate methods of assessment, measurement and/or calculation capable of analysing the characteristics of the waveforms and nature of biological interactions have to be applied, taking account of European harmonised standards developed by CENELEC ...'.

Section 4.3 gives an overview of the various calculation methods mainly based on the ICNIRP statement of 2003 [35] and the standard NEN-EN50392:2004.

*The summation rule*

The summation rule used here is based on the EU recommendation for exposure of members of the public [5]. The summation rule is so-called as it is a conservative way of adding up the various frequency components. In such cases the determination of whether the accumulation of field strengths and current strengths meets the set requirements can be carried out as follows. For each relevant frequency $f_i$ the values $a_i$, $b_i$, $c_i$, $d_i$ are read from Table 14 or Figure 20 and $e_i$ from Table 13 or Figure 18 (right; if $f_i$ falls outside the stated frequency range, the value $\infty$ (infinite) must be used).

*Table 14 Values for the coefficients a, b, c and d in the summation rule.*

| frequency range | a<br>V/m | b<br>A/m | c<br>V/m | d<br>A/m |
|---|---|---|---|---|
| 1 - 8 Hz | 20 000 | $1.63 \times 10^5/f^2$ | | |
| 8 - 25 Hz | 20 000 | $2 \times 10^4/f$ | | |
| 0.025 – 0.82 kHz | 500/*f* | 20/*f* | | |
| 0.82 - 65 kHz | 610 | 24.4 | | |
| 65 -100 kHz | 610 | 24.4 | | |
| 0.1 - 10 MHz | 610 | 24.4 | 610/*f* | 1.6/*f* |
| 10 - 400 MHz | | | 61 | 0.16 |
| 400 - 2 000 MHz | | | $3\sqrt{f}$ | $0.008\sqrt{f}$ |
| 2 - 300 GHz | | | 137 | 0.36 |

Note:
- *f* in the units stated in the frequency range column

Next, the following summations must be carried out:

1 the sum of the values $E_i / a_i$ for the relevant frequencies $f_i$ between 1 Hz and 10 MHz;
2 the sum of the values $H_i / b_i$ for the relevant frequencies $f_i$ between 1 Hz and 10 MHz;
3 the sum of the values $(E_i / c_i)^2$ for the relevant frequencies $f_i$ between 100 Hz and 300 GHz;
4 the sum of the values $(H_i / d_i)^2$ for the relevant frequencies $f_i$ between 100 Hz and 300 GHz;
5 the sum of the values $(I_{L,i} / 100 \text{ mA})^2$ for the relevant frequencies $f_i$ between 10 MHz and 110 MHz; and
6 the sum of the values $(I_{C,i} / e_i)^2$ for the relevant frequencies $f_i$ between 1 Hz and 110 MHz.

where $E_i$ respectively $H_i$ is the component of $E$ respectively $H$ at frequency $f_i$, $I_{L,i}$ that of the electric current in the extremities (arms and legs) $I_L$, and $I_{c,i}$ of the electric contact current $I_C$.

A requirement of all these summations is that they must be less than 1.

Note that for the weighting of the field strengths in the frequency range 100 kHz to 10 MHz, two different summations must be done in parallel (different denominators). The reason for this is that at frequencies of 1 Hz to 10 MHz the protection is based on current induced by an electric field (E-field) or a magnetic flux density field (B-field). For frequencies from 100 kHz to 300 GHz the protection is based on heating up.

*Example of the summation rule*

A worker is in the vicinity of equipment transmitting on three frequencies: 100 kHz, 4 MHz, and 20 MHz. Measurements indicate that the RMS values of the E-field at locations where the worker could be present for long periods are 600, 150 and 50 V/m for these three frequencies respectively. The following table can now be completed with the help of these figures:

| $f$ (Hz) | $E$ (V/m) | $E_{act}$ (V/m) | $a$ (V/m) | $c$ (V/m) | $E/a$ | $(E/c)^2$ |
|---|---|---|---|---|---|---|
| $1.10^5$ | 600 | 610 | 610 | 6100 | 0.98 | 0.01 |
| $4.10^6$ | 150 | 153 | 610 | 153 | 0.16 | 0.43 |
| $2.10^7$ | 50 | 61 | ∞ | 61 | 0 | 0.67 |
| sum | | | | | 1.14 | 1.11 |

None of the action values for single frequencies has been exceeded. The summation of the *E/a* values comes to a value above 1 as does the summations of the $(E/c)^2$ values. Thus the action values are exceeded.

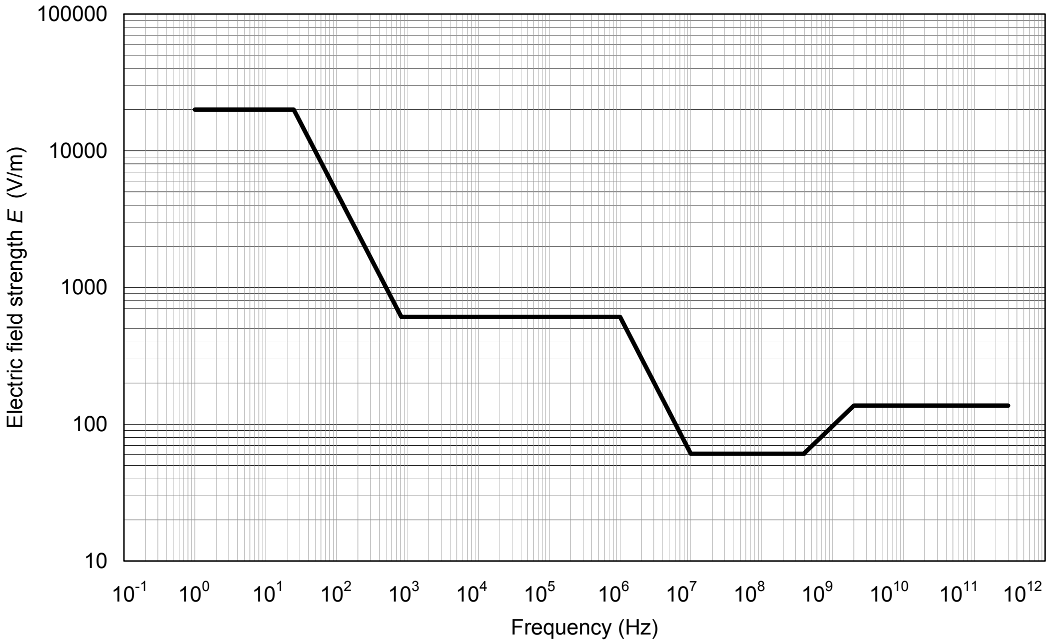


*Figure 15 Electric field strength action values.*

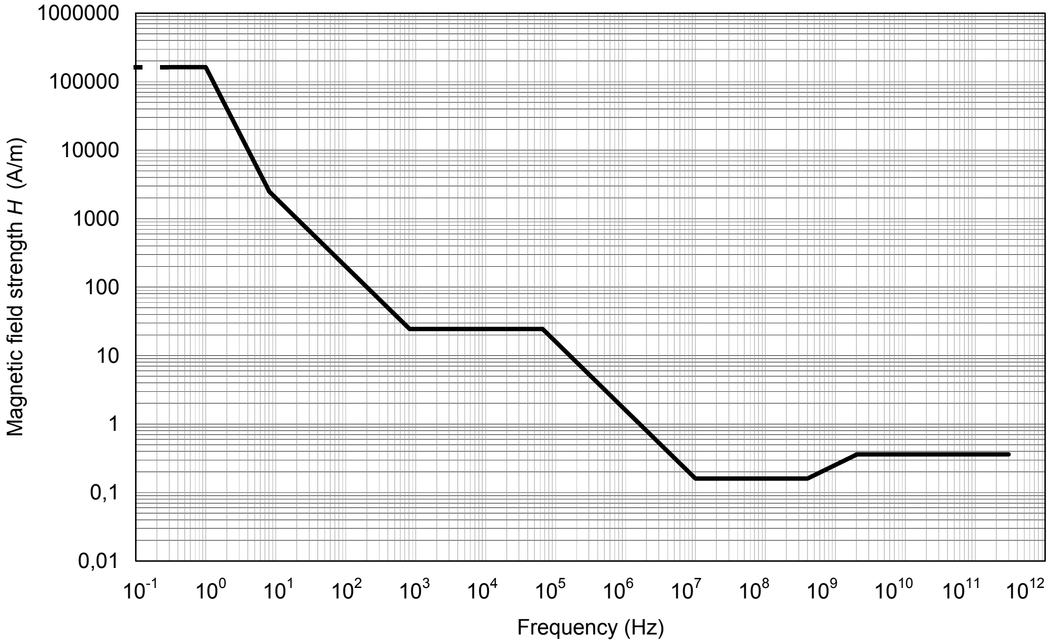


*Figure 16 Magnetic field strength action values.*

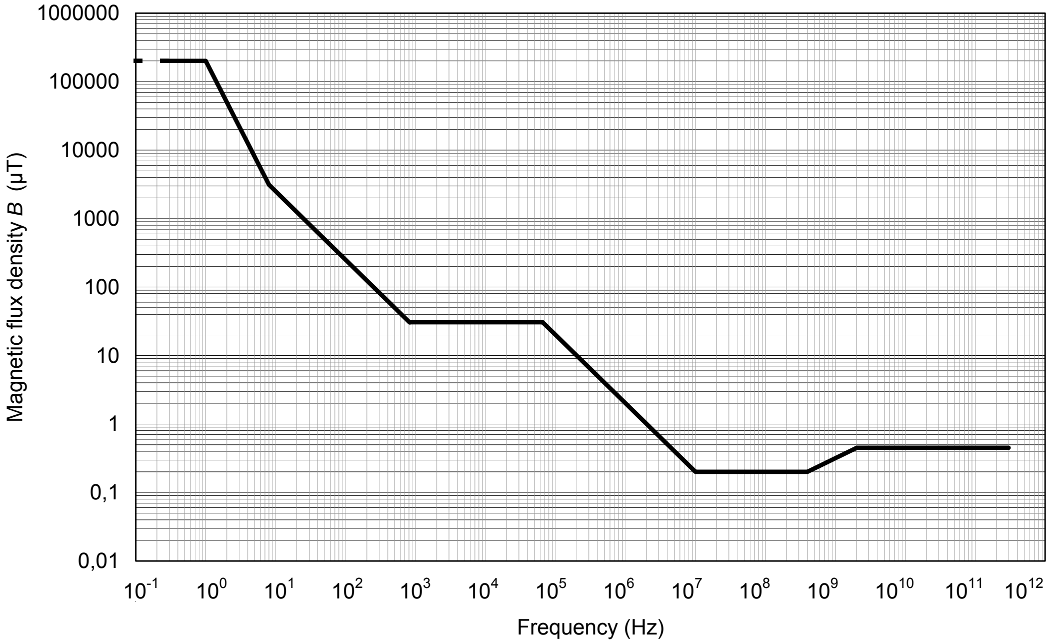


*Figure 17 Magnetic flux density action values.*

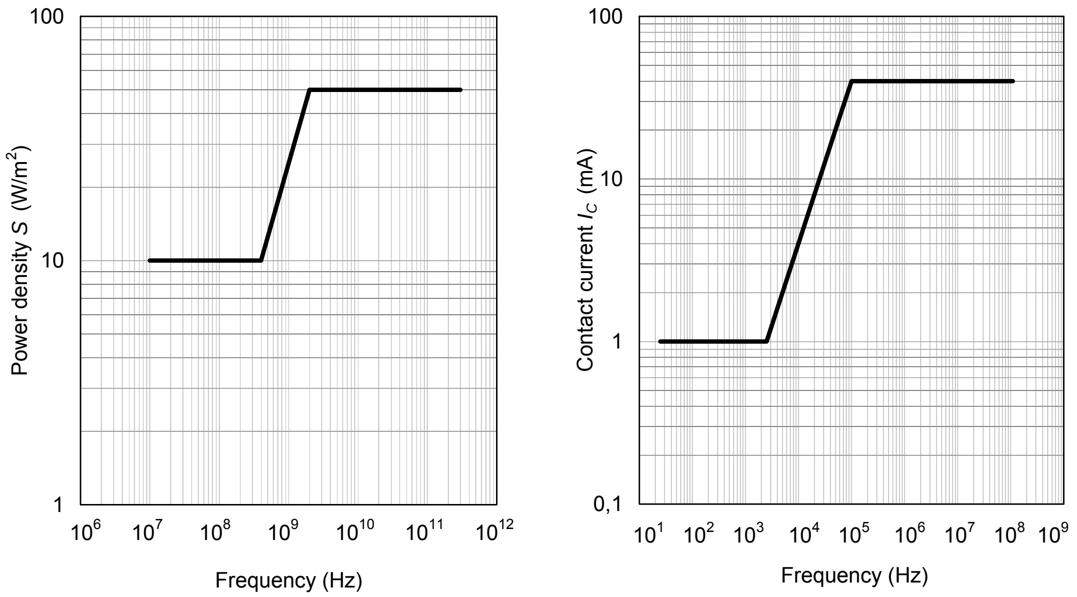


*Figure 18 Action values for power density (left) and contact current (right).*

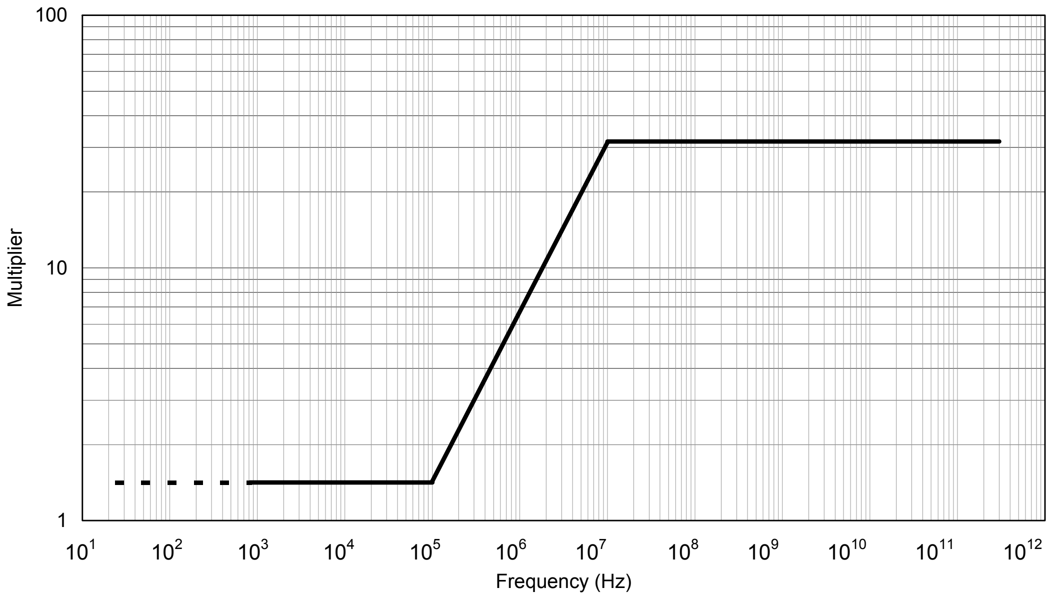


*Figure 19 Multiplier for calculating action values for peak values.*

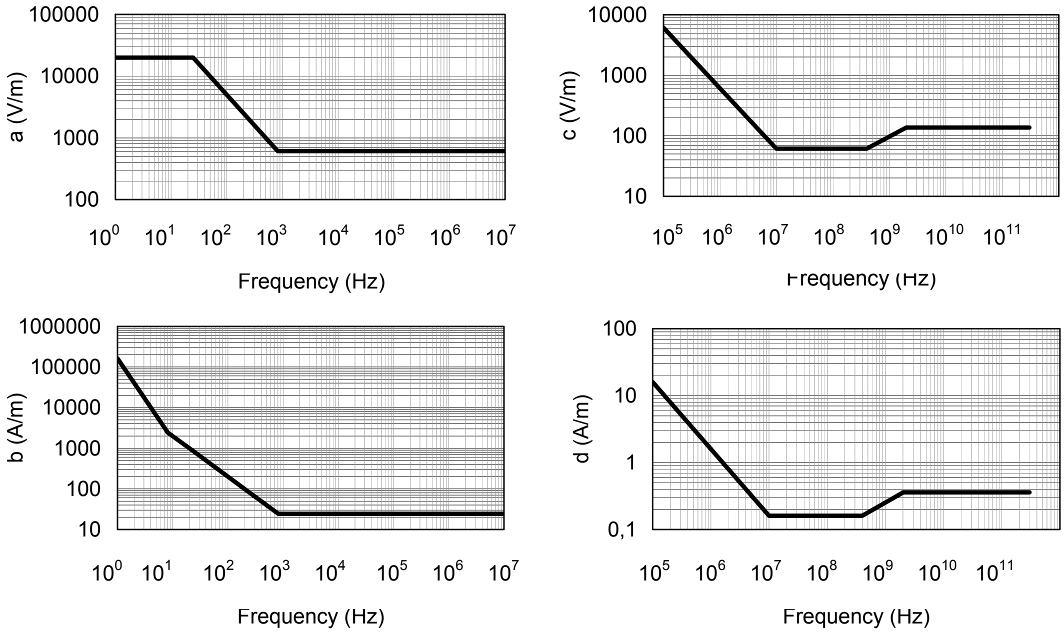


*Figure 20 Values a, b, c, and d for the summation at a number of frequencies.*

# Appendix 2 RI&E module for electromagnetic fields - preliminary version

The RI&E module for electromagnetic fields consists of two parts - the inventory and the action plan. It is a generic module that can be simplified for certain sectors. Also additions can be made or extra items can be specified.

## 1 Inventory

| | *Questions* | yes | no |
|---|---|---|---|
| 0 | During their work, employees may come into contact (intentionally or unintentionally) with equipment that produces electric, magnetic or electromagnetic fields. | | |
| 1 | There is a summary of electric and electronic equipment. | | |
| 2 | All equipment falls under category I (use Table 1 and Table 2 in this report). | | |
| 3 | Only normal situations are involved (use Section 4.5 of this report). | | |
| 4 | Where necessary, control measures have been taken and working instructions given for protecting employees. These control measures are still in force. | | |
| 5 | Everyone knows the control measures and working instructions, and complies with them. Everyone understands the local exposure situations. | | |
| 6 | Instruction has been given about the Directive/legislation and electromagnetic fields. | | |
| 7 | There is a system for checking existing and for estimating new exposure situations. | | |

*Overall explanation*

If question 0 is answered ‘no’, the other answers need not be completed. If at least one of questions 1 to 7 has been answered with a ‘no’ then the action plan must also be completed.

*Explanation per question*

0 Examples of the equipment referred to are: anti-theft gates; metal detection gates; plastic sealers; generators in a power station; air coils in capacitor banks; bus bars; rectifiers; melting furnaces; induction heaters with open coils; arc welding systems; semi-automated spot and induction welding systems; MRI scanners; equipment for short wave diathermy; microwave diathermy; deep hyperthermia; open magnetrons; broadcasting transmitters; base stations for mobile telephony; and radar systems.

Note that in principle all electrical equipment can generate fields. In particular, high-powered electrical equipment uses strong electric currents that are capable of producing significant magnetic fields.

1 The list includes numbers, types of equipment, locations, powers, and the conditions under which the equipment is operated.

2 Equipment that is not mentioned in the tables, or about which there is some doubt, is classified in category II. As far as is known or is possible, the frequencies of the potential fields have been established for each piece of equipment in categories II and III.

3 Non-standard circumstances are for example the presence of employees with electronic implants (pacemakers, heart pumps etc.), medical equipment, flammable or explosive materials, or ferromagnetic objects in a static magnetic field higher than 3 mT.

4 Firstly, the actions under points 2 and 3 must be carried out. If points 2 or 3 have indicated that the action values have been exceeded (or this is considered possible), a check must be made to see if the technical or organisational control measures have actually been taken and are (still) present and adequate, and that working instructions for the application of these have been given, or it has been demonstrated that the exposure limit values are not being exceeded.

5 Has each employee received instruction about electromagnetic fields in the working situation and the actions to be taken? Are all employees (still) fully aware of the working instructions and the control measures, and also the working situations where these are applicable? Do they understand this and can they cope with it?

6 Do employees know that there is legislation designed to protect them against excessive exposure to electromagnetic fields? Do they know what action values and exposure limit values are? Do they know how they can assess potentially hazardous situations?

7 Are there procedures for following the situation and changes to the working environment?

## 2 Action plan

| | subject | action | lapsed | super-visor | prior-ity |
|---|---|---|---|---|---|
| 1 | There is no summary of electric and electronic equipment. | Make a list of the electrical equipment (location and power). | | | |
| 2 | There is equipment in categories II or III. | Select control measures to ensure that the action values are not exceeded or assess exposure levels. Use the assessment flow chart (Figure 3) for this. | | | |
| 3 | There are non-standard circumstances. | Instruct employees with implants to remain at a distance, remove flammable or explosive materials etc. | | | |
| 4 | There are no instructions, and control measures are not or no longer being taken. | Issue instructions for working with or near equipment in categories II or III and carry out the control measures or reintroduce them. | | | |
| 5 | Employees are not familiar with the control measures and working instructions. | Instruct the employees. | | | |
| 6 | Employees are not familiar with the law. | Provide a general explanation about the law and how potential situations of excessive exposure can be recognised. | | | |
| 7 | There is no system for following changes in the working situation. | Keep a systematic record of equipment that is replaced or modified, which old equipment has been removed and what the consequences are for exposure levels (possibly for more than one piece of equipment). Also, the consequences of changed operating procedures must be recorded. | | | |

# Appendix 3 SBI-codes

(adopted from CBS document [12])

A Agriculture, hunting and forestry
- 01 Agriculture, hunting and service industries for agriculture and hunting
- 02 Forestry and service industries for forestry

B Fishing
- 05 Fishing, fish farms and crustaceans

C Extraction of minerals
- CA Extraction of energy containing minerals
  - 10 Peat digging
  - 11 Crude oil and natural gas extraction and services for these industries
- CB Extraction of non-energy containing minerals
  - 14 Extraction of sand, gravel, clay, salt etc.

D Industry
- DA Manufacture of foodstuffs and confectionery
  - 15 Manufacture of foodstuffs and drinks
  - 16 Processing of tobacco
- DB Manufacture of textiles and textile based products
  - 17 Manufacturing of textiles
  - 18 Manufacture of clothing; preparing and dyeing of fur
- DC Manufacture of leather and leather goods (not clothing)
  - 19 Manufacture of leather and leather goods (not clothing)
- DD Timber industry and manufacture of articles made of wood, cork, basketwork (not furniture)
  - 20 Timber industry and manufacture of articles made of wood, cork, basketwork (not furniture)
- DE Manufacture of paper, cardboard and paper and cardboard goods; publishers and printers etc
  - 21 Manufacture of paper, cardboard and paper and cardboard goods
  - 22 Publishers, printers and reproduction of recorded media
- DF Crude oil and coal processing industry; nuclear industry
  - 23 Crude oil and coal processing industry; nuclear industry
- DG Manufacture of chemical products
  - 24 Manufacture of chemical products
- DH Manufacture of rubber and synthetic products
  - 25 Manufacture of rubber and synthetic products
- DI Manufacture of glass, pottery, cement, lime and gypsum products
  - 26 Manufacture of glass, pottery, cement, lime and gypsum products
- DJ Manufacture of primary metals and metallic products

27 Manufacture of metals in their primary state
28 Manufacture of metallurgical products (not machinery and vehicles)

DK Manufacture of machines and equipment
29 Manufacture of machines and equipment

DL Manufacture of electrical and optical equipment and instruments
30 Manufacture of office machines and computers
31 Manufacture of other electrical machines, equipment and ancillaries
32 Manufacture of audio, video and telecommunication equipment and ancillaries
33 Manufacture of medical equipment and instruments, orthopaedic appliances and the like, precision and optical instruments and clocks

DM Manufacture of vehicles
34 Manufacture of cars, trailers and semi-trailers
35 Manufacture of vehicles (not cars, trailers and semi-trailers)

DN Manufacture of furniture; manufacture of other goods
36 Manufacture of furniture; manufacture of other goods
37 Preparation for recycling

E Production and distribution of and trading in electricity, natural gas, steam and water
40 Production and distribution of, and trading in, electricity, natural gas, steam and hot water
41 Extraction and distribution of water

F Construction industry
45 Construction industry

G Repair of consumer articles and trade
50 Trade in and repair of cars and motorcycles; petrol service stations
51 Wholesale and trading (not in cars and motorcycles)
52 Retail trade in, and repair of, consumer goods (not cars, motorcycles and vehicle fuels)

H Hotel and restaurant trade
55 Provision of accommodation, meals and drinks

I Transport, storage and communication
60 Transport over land
61 Transport over water
62 Air transport
63 Provision of services to the transport industry
64 Post and telecommunications

J Financial institutions
65 Financial institutions (excluding insurance and pension funds)
66 Insurance and pension funds (not compulsory social security)

67 Stock markets, stockbrokers, administration bureaus for shares, guarantee funds etc

K Renting of and trade in property, renting of movable goods and business services

70 Renting of and trading in property

71 Renting of vehicles, machines and tools without operating personnel and of other movable goods

72 Computer services and information technology

73 Research and development

74 Other business services

L Public Administration, government services and compulsory social services

75 Public Administration, government services and compulsory social security

M Education

80 Education

N Health and welfare services

85 Health and welfare services

O Environmental services, culture, recreation and other services

90 Environmental services

91 Employers, employees and professional organisations; ideological and political organisations; other idealistic organisations etc.

92 Culture, sport and recreation

93 Other services

P Private households with service staff

95 Private households with service staff

Q Extra-territorial bodies and organisations

99 Extra-territorial bodies and organisations

## Appendix 4 Abbreviations

| | |
|---|---|
| A | ampere (unit of electric current) |
| AC | Alternating Current |
| AIMD | Active Implanted Medical Devices |
| A/m | amperes per metre (unit of magnetic field strength) |
| AT-EZ | *Agentschap Telecom* - agency that is part of the Ministry of Economic Affairs (responsible for wireless telecommunication policy) |
| AZU | Utrecht University Teaching Hospital (*Universitair Medisch Centrum Utrecht, UMCU*) |
| BET | Effects on Commerce and Industry questionnaire, a check on the effect of legislation on companies (*Bedrijfseffectentoets*) |
| BIK | Company Information Code |
| CBS | Statistics Netherlands |
| CE | *Conformitée Européenne* (quality mark that indicates that the product meets the fundamental health, safety and environmental requirements of the Directive concerned) |
| CENELEC | European Committee for Electrotechnical Standardization |
| DC | Direct Current |
| DMO | Direct Mode Operation (TETRA transmission mode) |
| EAS | Electronic Article Surveillance (system for tracking articles electronically; mainly used for anti-theft gates) |
| EDGE | Enhanced Data Rates for Global Evolution |
| EIRP | Equivalent Isotropic Radiated Power |
| EMC | Electromagnetic Compatibility |
| EMC-ESD | Association for electromagnetic compatibility and electrostatic discharge |
| ERP | Effective Radiated Power |
| EU | European Union |
| FIOH | Finnish Institute of Occupational Health |
| FM | frequency modulation |
| FME-CWM | *Federatie Metaal-Elektrobranche - Contact Werkgevers in de Metaal* (Dutch organisation for employers in the electro-technological industrial sector) |
| GPRS | General Packet Radio Service |
| GR | Dutch Health Council |
| GSM | Global System for Mobile Communication |
| HSCD | High Speed Circuit Switched Data |
| HSE | Health and Safety Executive |
| HSL | *Hogesnelheidslijn* (high-speed train) |
| Hz | hertz (unit of frequency) |
| ICD | Implantable Cardioverter-Defibrillator |
| ICNIRP | International Committee on Non-Ionizing Radiation Protection |

| | |
|---|---|
| IEC | International Electrotechnical Committee |
| ILO | International Labour Organisation |
| KEMA | Dutch testing institute for electrotechnical materials (*Keuring van Elektrotechnische Materialen*) |
| kA | kiloampere (one thousand A) |
| kHz | kilohertz (one thousand Hz) |
| KNGF | Royal Dutch Physiotherapy Association |
| kV | kilovolt (one thousand V) |
| kW | kilowatt (one thousand W) |
| MHz | megahertz (one million Hz) |
| MAG | Metal Active Gas |
| MIG | Metal Inert Gas |
| MKB | Small and Medium-sized Enterprises, SME (*Midden- en Kleinbedrijf*) |
| MMA | Manual metal arc welding |
| MoNet | Cooperative of the five mobile network operators in the Netherlands: KPN, Orange, Telfort, T-Mobile and Vodafone |
| MW | megawatt (one million W) |
| MRI | Magnetic Resonance Imaging |
| mT | millitesla (one thousandth of a T) |
| μT | microtesla (one millionth of a T) |
| NEN | Netherlands Standardisation Institute |
| NIL | Netherlands Welding Institute |
| NRPB | National Radiological Protection Board (now part of the British Health Protection Agency (HPA)) |
| PEMF | Pulsed electromagnetic fields |
| R&D | Research and Development |
| RF | Radio frequency |
| RFID | Radio Frequency Identification (system for tracking articles electronically) |
| RIVM | National Institute for Public Health and the Environment *(Rijksinstituut voor Volksgezondheid en Milieu)* |
| RI&E | Risk analysis and evaluation |
| RMS | Root-Mean-Square |
| SAR | Specific Absorption Rate |
| SBI | Standard Company Classification |
| SZW | Ministry of Social Affairs and Employment |
| T | tesla (unit of magnetic flux density) |
| TDMA | Time Division Multiple Access |
| TETRA | Terrestrial Trunked Radio |
| TIG | Tungsten Inert Gas |
| TMS | transcranial magnetic stimulation |
| TMO | Trunked Mode Operation |
| TNO | Netherlands Organisation for Applied Scientific Research |

| | |
|---|---|
| UMTS | Universal Mobile Telecommunications System |
| UNETO-VNI | Employers organisation for the installation sector and the technical retail trade |
| V | volt (unit of electric potential) |
| V/m | volt per metre (unit of electric field strength) |
| VNO-NCW | Employers organisation in the Netherlands |
| W | watt (unit of power) |
| WHO | World Health Organization |

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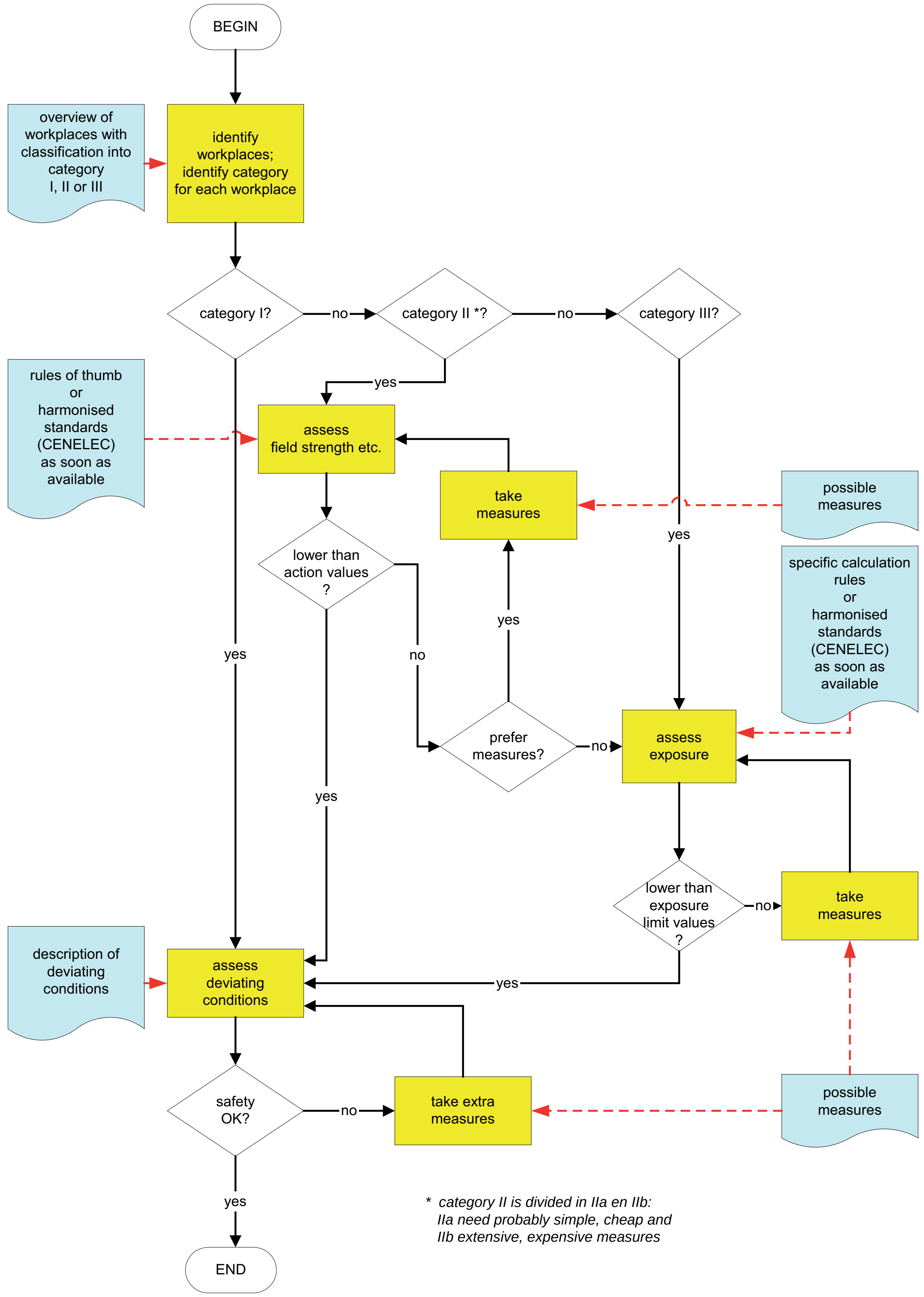


*Figure 1 Flow diagram of the process for establishing whether measures are required in practice.*

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