

# Occupational exposure to electromagnetic fields from medical sources

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**Abstract:** High exposures to electromagnetic fields (EMF) can occur near certain medical devices in the hospital environment. A systematic assessment of medical occupational EMF exposure could help to clarify where more attention to occupational safety may be needed. This paper seeks to identify sources of high exposure for hospital workers and compare the published exposure data to occupational limits in the European Union. A systematic search for peer-reviewed publications was conducted via PubMed and Scopus databases. Relevant grey literature was collected via a web search. For each publication, the highest measured magnetic flux density or internal electric field strength per device and main frequency component was extracted. For low frequency fields, high action levels may be exceeded for magnetic stimulation, MRI gradient fields and movement in MRI static fields. For radiofrequency fields, the action levels may be exceeded near devices for diathermy, electrosurgery and hyperthermia and in the radiofrequency field inside MRI scanners. The exposure limit values for internal electric field may be exceeded for MRI and magnetic stimulation. For MRI and magnetic stimulation, practical measures can limit worker exposure. For diathermy, electrosurgery and hyperthermia, additional calculations are necessary to determine if SAR limits may be exceeded in some scenarios.

**Key words:** Electromagnetic fields, Exposure, Occupational, Hospital, Magnetic resonance imaging

## Introduction

Electric, magnetic and electromagnetic fields (EMF) are widely used in medical diagnostic and therapeutic applications. EMF of sufficient strength can have biological effects and some medical devices use these for a diagnostic or therapeutic aim. Recent technological advances have increased the diversity and potential strength of EMF from medical sources and therefore raise questions about occupational safety. EMF generated by medical sources in the hospital environment can be roughly divided in two categories: sources of static and low frequency fields (defined

here as frequencies from 0 Hz to 100 kHz) and sources of high frequency fields (defined here as frequencies from 100 kHz to 300 GHz). Low frequency EMF that are sufficiently strong can stimulate sensory organs and nervous or muscle tissue via magnetic induction of internal electric fields in electrically conductive body tissues. Depending on the strength of the fields, this may lead to retinal stimulation (magnetophosphenes), vestibular disturbances, tingling sensations, pain or muscle contractions. High frequency EMF that are sufficiently strong can lead to excessive heating and tissue damage (Table 1). For the safe use of EMF, the International Commission for Non-Ionizing Radiation Protection (ICNIRP) has defined basic restrictions in terms of the induced electric field strength and specific absorption rate (SAR) in the body, below which these sensory and health effects will not occur. Reference levels in terms of

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**Table 1. Classification of medical devices according to frequency range and the biological effects that form the basis for restriction of worker exposure to electromagnetic fields**

Frequency range (Hz)	Potential biological effect	Medical device
$f=0$	disturbed equilibrium, reduced blood flow, cardiac arrhythmia	• MRI (static field)
$0 < f < 10^5$	vertigo, nausea, metallic taste, magnetophosphenes, nerve stimulation	• MRI (movement) • MRI (gradients) • magnetic stimulation • magnetotherapy • power frequency equipment
$10^5 < f < 10^{11}$	heating	• MRI (radiofrequency field) • diathermy • electrosurgery • hyperthermia • microwave imaging • radar monitoring • therapeutic ultrasound

the strength of the external EMF have been derived from these basic restrictions. When workers are exposed to EMF weaker than the reference levels, the basic restrictions will not be exceeded<sup>1, 2)</sup>. The European Union uses the ICNIRP basic restrictions and reference levels in its occupational health and safety legislation, in which the reference levels are called ‘action levels’ and the basic restrictions ‘exposure limit values’ (Table 2 and Table 3). For low frequency EMF it distinguishes low action levels, related to sensory effects exposure limit values, and high action levels and limb action levels, related to health effects exposure limit values (nerve stimulation)<sup>3)</sup>.

Focusing on the operating frequencies of medical equipment, the strongest sources of low frequency EMF are devices for magnetic stimulation of brain, nerves or muscles as a diagnostic or therapeutic tool<sup>4)</sup>. With the exception of magnetic resonance imaging (MRI, see below), most of the other sources of exposure to low frequency fields in the health care environment are devices connected to electric mains which generate EMF at power frequency (50 or 60 Hz), such as cardiac monitors or dentistry tools. Strong high frequency EMF are used deliberately to heat patient tissues in therapeutic diathermy and hyperthermia<sup>5, 6)</sup>. Electrosurgery and ablation are common techniques for procedures such as endometrial excision or arrest of bleeding in the hospital operating room by applying high frequency electrical currents or EMF. Unintended stray field exposure of surgeons or helpers can occur near these devices<sup>7)</sup>. Novel diagnostic techniques using high frequency EMF have been developed more recently. Radar applications are used to monitor vital functions such as heart rate and respiration and for imaging of tumours by exploiting varying surface reflections and differences in dielectric properties of

**Table 2. Action levels for magnetic fields in Directive 2013/35/EU**

Frequency	Low AL B ( $\mu$ T)	High AL B ( $\mu$ T)	Limbs AL B ( $\mu$ T)	Thermal AL B ( $\mu$ T)
$1 \leq f < 8$ Hz	$2.0 \times 10^5 / f^2$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$	—
$8 \leq f < 25$ Hz	$2.5 \times 10^4 / f$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$	—
$25 \leq f < 300$ Hz	$1.0 \times 10^3$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$	—
$300 \text{ Hz} \leq f < 3$ kHz	$3.0 \times 10^5 / f$	$3.0 \times 10^5 / f$	$9.0 \times 10^5 / f$	—
$3 \leq f \leq 100$ kHz	$1.0 \times 10^2$	$1.0 \times 10^2$	$3.0 \times 10^2$	—
$100 \text{ kHz} \leq f < 10$ MHz	$1.0 \times 10^2$	$1.0 \times 10^2$	$3.0 \times 10^2$	$2.0 \times 10^6 / f$
$10 \leq f < 400$ MHz	—	—	—	0.2
$400 \text{ MHz} \leq f < 2$ GHz	—	—	—	$1.0 \times 10^{-5} \sqrt{f}$
$2 \leq f < 300$ GHz	—	—	—	$4.5 \times 10^{-1}$

**Table 3. Exposure limit values in Directive 2013/35/EU**

*A. Low frequency fields*

Frequency	Sensory effects ELV		Health effects ELV	
	B (T)	$E_{int}$ (V/m)	B (T)	$E_{int}$ (V/m)
$0 \leq f < 1$ Hz	2	—	8	—
$1 \leq f < 10$ Hz	—	$0.7/f$	—	1.1
$10 \leq f < 25$ Hz	—	0.07	—	1.1
$25 \leq f \leq 400$ Hz	—	$0.0028 f$	—	1.1
$400 \text{ Hz} \leq f \leq 3$ kHz	—	—	—	1.1
$3 \text{ kHz} \leq f \leq 10$ MHz	—	—	—	$3.8 \times 10^{-4} f$

*B. High frequency fields*

Frequency	Health effects ELV SAR (W/kg)	Health effects ELV power density (W/m <sup>2</sup> )
$100 \text{ kHz} \leq f \leq 6$ GHz		
whole body average	0.4	—
localised 10 g, head and trunk	10	—
localised 10 g, limbs	20	—
$6 \text{ GHz} \leq f \leq 300$ GHz	—	50

Abbreviations and symbols: AL, action level; B, magnetic flux density;  $E_{int}$ , peak internal electric field strength; ELV, exposure limit value; SAR, specific absorption rate.

healthy and diseased tissues. Microwave-induced thermoacoustic echography uses modifications of the reflection of acoustic waves by thermal expansion. Volumetric EMF phase-shift spectroscopy uses the modification of magnetic induction in a conductive receiver coil by the properties of the intermediate brain tissue<sup>8,9</sup>.

MRI is unique in exposing workers to four different types of EMF exposure. Firstly, the static field can generate a Lorentz force via interaction with ion currents in the vestibular organ and in large blood vessels, potentially leading to cupula movement and loss of balance or to reduction of blood flow<sup>10</sup>. Secondly, the induced electric fields and currents caused by movement in strong static magnetic field spatial gradients (frequencies 0 to 25 Hz) can interact with the sensory organs in the head to cause vertigo, nausea and metallic taste and potentially cause nerve or muscle stimulation<sup>11</sup>. Thirdly, the switching gradient fields (frequencies 500 to 5,000 Hz) may cause nerve or muscle stimulation. Fourthly, the radiofrequency fields generated by the imaging coils (8.5 to 500 MHz) may cause localised or systemic tissue heating<sup>12</sup>.

A systematic assessment of medical occupational EMF exposure across the full EMF spectrum could help to clarify where more attention to occupational safety may be needed. Previous research has indicated that ICNIRP-based occupational exposure limits can be exceeded near some medical sources of occupational exposure to low frequency EMF, including MRI scanners<sup>13</sup>. The present review updates this literature database, expands it to high frequency medical sources of EMF and discusses the health risks and possible mitigation measures. The review focuses on EMF sources that are exclusively used in medical, physiotherapy or dental practice. Sources that are also used in other working environments, such as mobile phones, radiofrequency identification or wireless data or power transfer, fall outside its scope.

## Methods

### *Data collection*

Relevant medical devices were identified in previous health technology assessments by the National Institute for Public Health and the Environment<sup>8,14</sup> and in the ICNIRP project group on non-ionising radiation from medical diagnostic devices<sup>9</sup>. For data on occupational exposure, the online databases PubMed (<http://www.ncbi.nlm.nih.gov/pubmed/>) and Scopus (<http://www.scopus.com/>) were then searched for peer-reviewed articles published up to 31 December 2016 and pagination of advance publications

was added if available before submission of the manuscript. Different combinations of blocks of search terms were used, relating to electromagnetic fields [(magnetic OR electric OR electromagnetic OR emf OR radiofrequ\* OR rf OR low frequ\* OR elf OR microwave\*) AND (field\* OR radiat\*)], occupational setting [(worker\* OR working OR workplace OR occupation\* OR employ\*)], [exposure], and EMF in either general medical setting [(medical OR hospital OR clinical OR “health care”)] or specific medical devices [(magnetic OR electric OR electromagnetic OR emf OR radiofrequ\* OR rf OR low frequ\* OR elf OR microwave\*) AND (field\* OR radiat\*) AND (worker\* OR working OR workplace OR occupation\* OR employ\*) AND exposure AND (mri OR “magnetic resonance imaging” OR nmr OR “nuclear magnetic resonance” OR mrs OR “magnetic resonance spectroscopy”) OR (tms OR “transcranial magnetic stimulation”) OR (electrosurg\* OR ablation OR diathermy OR hyperthermia OR magnetotherapy) OR (“induction tomography” OR “phase-shift spectroscopy” OR thermoacoustics OR thermoplasty OR tomography OR “movement tracking” OR (radar AND (imaging OR monitoring)))]]. Relevant grey literature (measurement reports) in English and German was identified on the websites of the following organisations: Allgemeine Unfallsversicherungsanstalt (Austria); Center for Devices and Radiological Health (USA); European Commission; Health and Safety Executive (UK); National Institute for Occupational Safety and Health (USA); Portale Agenti Fysici (Italy); Public Health England (UK). Only publicly available measurement reports were used.

### *Data extraction for external field*

Only those publications listing individual maximum exposure values at specific frequencies were used, since time-averaged (for low frequency fields), frequency-averaged, or group averaged data make it impossible to compare maximum individual exposures to the action levels (reference levels) or exposure limit values (basic restrictions). When multiple publications were produced by the same authors based on same subjects and study protocol, the maximum exposure values were extracted from only one of these. Apart from distance to the source, worker exposure from radiofrequency medical devices also depends on the output power of the device in question (for example diathermy equipment). We assumed that the maximum exposures we extracted are associated with the highest output power and/or closest proximity to the device under normal working conditions. All magnetic field measurements are presented as magnetic flux density.

Where only the magnetic field strength was available, the magnetic flux density was calculated by multiplying with the magnetic permeability ( $4\pi \cdot 10^{-7}$  H/m). Exposure at the main frequency component with highest exposure was used, even though higher harmonics may also contribute to exposure. Where action levels are exceeded, this should be seen as an indication that there are potential issues with exposure levels for higher harmonics and that the frequency-summed exposure may be higher. For non-sinusoidal fields, the maximum value for magnetic flux density is listed at a frequency of  $f=1/(2t)$  where  $t$  is the phase duration<sup>15)</sup>. For comparison with the action levels, all dB/dt values in the original publication were converted to equivalent B using the relationship  $B_{eq}=dB/dt/2\pi f^{16)}$ .

Where peak values were measured or calculated, they have been converted to root-mean-square (rms) values by dividing by  $\sqrt{2}$ , for easier comparison with the action levels. Where no mention of peak or rms values was made in the publication, rms values were assumed. The highest value of magnetic flux density measured at the actual workplace was used as an indicator of maximum exposure to the source. When this was not available, the highest value measured at a distance of 20 cm from the source was used. When measurements were made at multiple heights from the floor, 1.75 m (approximate head height) was chosen or, if unavailable, the lower height closest to 1.75 m. Most of the publications did not contain sufficient information to determine whether the maximum flux densities listed were restricted to the limbs. It was therefore presumed that all measured flux densities could involve head or trunk exposure.

#### *Data extraction for internal field*

In studies where induced electric fields were calculated using tissue voxel models, 1%-thresholded maximum values were used to avoid numerical staircase errors related to edge singularities in the induced fields<sup>17)</sup>. Where only current densities were listed, these were converted to induced electric field strength through dividing by the appropriate tissue conductivity from the Italian National Research Council online database of dielectric properties of body tissues (<http://niremf.ifac.cnr.it/tissprop/>). For movement-induced electric fields, the conductivities at 10 Hz (the lowest frequency listed in the database) were used. The actual simulated frequency used for movement-induced electric field was usually 1 Hz and this was also assumed where no information on movement time or frequency was given. Where available, the duration of the movement associated with the maximum induced electric field was used to cal-

culate the dB/dt frequency. For electric fields induced by the switched magnetic fields of the gradient coils, the conductivities at 1,000 Hz, the simulated gradient frequency, were used. For other medical sources, the actual source frequency was used. For the central nervous system, the average conductivity of grey matter and white matter was used. For peripheral tissue voxels, where tissue type was not specified, the conductivity of muscle tissue (which is close to the average body conductivity) was used.

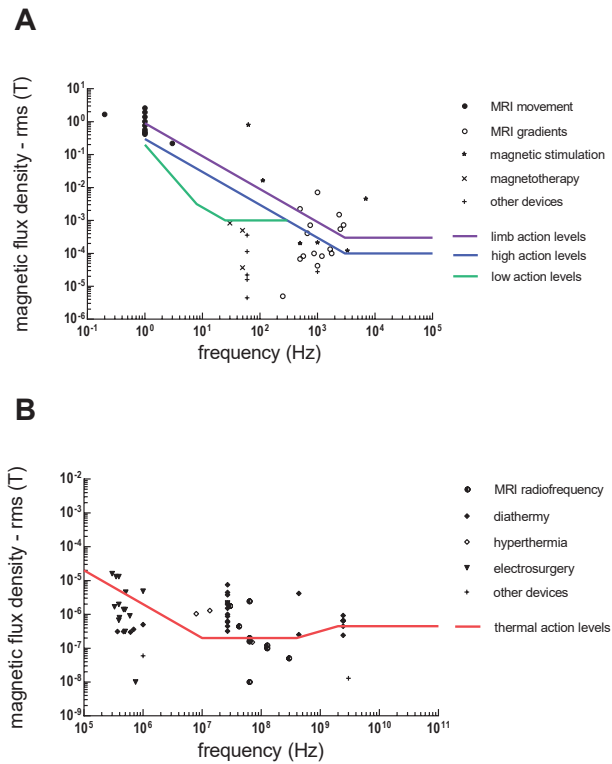
## **Results**

### *Exposure limits*

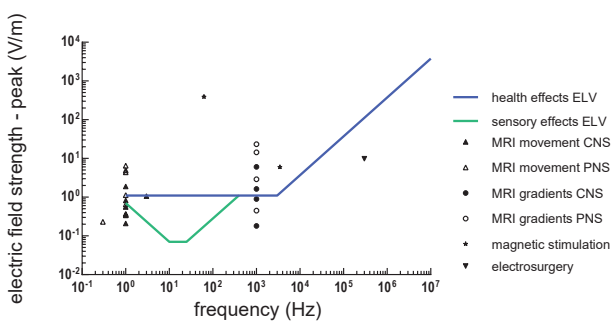
The maximum magnetic flux densities at the workplace are shown in Fig. 1 and the maximum calculated internal electric field strengths are shown in Fig. 2. The lines in Fig. 1 represent the different categories of action levels in Directive 2013/35/EU. For low frequency fields, these are based on the ICNIRP2010 guidelines<sup>2)</sup>. The low action levels for frequencies between 1 and 400 Hz are equivalent to ICNIRP reference levels derived from basic restrictions based on the prevention of sensory effects such as magnetophosphenes, which may generate safety risks. The high action levels are derived from ICNIRP basic restrictions based on the prevention of peripheral nerve stimulation, applying the ICNIRP conversion factors for frequencies between 400 Hz and 10 MHz to the entire frequency range from 1 Hz to 10 MHz. In addition, limb action levels are set at three times the high action levels based on the approximate ratio in diameter between limbs and head or trunk (Table 2 and Fig. 1A). For high frequency fields (100 kHz to 300 GHz), the action levels for thermal effects are based on the ICNIRP 1998 guidelines<sup>1)</sup> (Table 2 and Fig. 1B). The lines in Fig. 2 represent the sensory effects exposure limit values and health effects exposure limit values in the EU Directive (Table 3), which are based on the ICNIRP 2010 basic restrictions<sup>2)</sup>.

### *Exposure from MRI-related fields*

The measured range of maximal static field exposure of workers in MRI activities varies since the methodology differs among references<sup>19, 21–23, 25, 28, 29, 31, 32, 34, 77–79)</sup>. In those studies which use spot measurements at observed or likely worker locations, maximum values can reach the maximum flux density of the MRI scanner in question<sup>19, 22)</sup>. When focusing on studies using wearable field measurement devices, the highest exposure level for 1.5 T scanners is 1,430 mT at the head position<sup>29)</sup> and 1,479 mT at the hand position<sup>79)</sup>. In the 3 T MRI environment,



**Fig. 1.** Maximum measured magnetic flux density at the worker's position per publication, per main frequency component for medical sources of EMF. **A:** sources of low frequency EMF. **B:** sources of high frequency EMF. Abbreviation: MRI, magnetic resonance imaging. Literature references used: MRI<sup>18–34</sup>); Magnetic stimulation<sup>35–40</sup>); Magnetotherapy<sup>39, 41</sup>); Diathermy<sup>6, 39, 41–54</sup>); Hyperthermia<sup>5, 55, 56</sup>); Electrosurgery<sup>6, 7, 37, 39, 52, 57–61</sup>); Other (intensive care, emergency, pharmacy, physiotherapy, dentistry, ultrasound, defibrillator)<sup>39, 41, 54, 62–66</sup>).



**Fig. 2.** Maximum calculated induced electric field strength in the worker's body per publication for medical sources of EMF. Abbreviations: CNS, central nervous system; ELV, exposure limit value; MRI, magnetic resonance imaging; PNS, peripheral nervous system. Literature references used: MRI<sup>17, 22, 67–76</sup>); Magnetic stimulation<sup>37, 38</sup>); Electrosurgery<sup>60</sup>).

the highest exposure is 2,057 mT at head position, 1,464 mT at chest position<sup>34</sup>) and 2,891 mT at hip position<sup>32</sup>). In the 7 T environment, the highest exposure level is 2,890

mT at head position and 1,439 mT at chest position when subjects were asked to simulate MRI procedure in scanner room<sup>34</sup>). Generally, the maximal exposure level would be expected to increase in accordance with the static field flux density of the MRI system and with proximity to the scanner, for example to look into the bore or administer an anaesthetic or contrast agent. However, measurements with wearable exposimeters seem to indicate that in normal working practice, maximum exposure may not be substantially higher for 7 T than for 3 T systems<sup>28, 34</sup>). Where the exposure exceeds the 2 T ICNIRP basic restriction (equivalent to EU sensory effects exposure limit value), mitigation measures against nausea or vertigo can be considered. No data on occupational exposure near 9.4 T scanners were available, but if these become more widely used, exceeding the ICNIRP 8 T basic restriction for limbs and controlled environment (equivalent to EU health effects exposure limit value) may become an issue.

The maximum magnetic flux density related to workers' movement near MRI scanners (derived from the maximum movement dB/dt) and the maximum magnetic flux density for gradient fields (derived from gradient dB/dt) can exceed both the high action levels and the limbs action levels in Directive 2013/35/EU (Fig. 1). The maximal calculated induced electric field at a movement-related frequency of 1 Hz can exceed both the sensory effects and the health effects exposure limit values in the EU Directive in some scenarios, at the anatomical locations of both the central and peripheral nervous system. For the MRI gradient fields, the maximal calculated induced electric field at a standardised equivalent frequency of 1,000 Hz can also exceed the health effects exposure limit values in both central and peripheral nervous system (Fig. 2). In some cases were workers such as surgeons or anaesthetists have to bend into the bore of the MRI scanner, the action levels for thermal effects may also be exceeded (Fig. 1). This assumes that the exposure lasts long enough to remain above the action level after the 6-min averaging that is allowed for high frequency fields<sup>1, 3</sup>). Nevertheless, calculations indicate that the exposure limit values for whole body or local special absorption rate (SAR) in the EU Directive (equivalent to ICNIRP 1998 basic restrictions) will not be exceeded even if a worker bends into the magnet bore during scanning<sup>22</sup>).

#### Other low frequency sources

The strongest sources of medical occupational exposure to EMF other than MRI are the coils used for transcranial magnetic stimulation or peripheral nerve stimulation, which the worker may hold in the hand above the region

of interest in the patient. The magnetic flux density at the worker position can exceed both the high action levels and limbs action levels in the EU Directive (Fig. 1). The maximal calculated internal electric field in the worker's body can exceed the health effects exposure limit values in the EU Directive (Fig. 2). Other sources of low frequency magnetic fields in the medical environment operate mostly at power frequency (50 or 60 Hz) and generate magnetic flux densities that do not exceed the low action level in the EU Directive. These include equipment for low level magnetotherapy (physiotherapy), dentistry tools, laboratory equipment, and intensive care units (Fig. 1).

#### *Other high frequency sources*

The exposure of medical workers to high frequency EMF near equipment for diathermy, hyperthermia and electro-surgery can exceed the action levels for thermal effects in the EU Directive (Fig. 1). This presumes the exposure lasts long enough to remain above the action level after 6-min averaging. The action levels for contact currents and limb currents can also be exceeded in diathermy<sup>54</sup>). Those publications that reported magnetic flux densities higher than the thermal action levels for diathermy, hyperthermia and electro-surgery did not give any information on the calculated SAR in a worker's body. Where the thermal action level was not exceeded, the SAR also remained below the exposure limit value<sup>37</sup>). Regarding the newer diagnostic imaging techniques, worker exposure is compliant with both the action levels and exposure limit values in the EU Directive near devices for ultrawide-band radar imaging to monitor vital functions<sup>80, 81</sup>). Microwave radar imaging of the breast normally leads to energy depositions in the patient below the ICNIRP basic restrictions for the general public<sup>82</sup>) and should therefore also be safe for nearby health care workers.

## **Discussion**

For EMF exposure of MRI workers, the present review confirms and extends the finding in earlier reviews that the high action levels and limb action levels and the low frequency health effects exposure limit values can be exceeded near the MRI scanner<sup>13, 83</sup>). The possibilities for static field-related and radiofrequency field-related overexposure will increase with the wider availability of ultrahigh field scanners with static field flux densities greater than 7 T<sup>84</sup>). The EU Directive allows the exposure limit values to be exceeded if the exposure is related to MRI equipment for patients in the health sector, provided that certain preconditions are met, including the demonstra-

tion that workers are still protected against adverse health effects and safety risks. Various strategies are possible to reduce the extent or frequency of overexposure near MRI devices. For movement in static fields stronger than 2 T, self-motivated motion control, such as reducing walking speed in the vicinity of the scanner, is recommended to MRI workers in order to prevent sensory effects<sup>11, 85</sup>). It is as yet unclear how effective such instructions are from a health and safety management viewpoint. Avoiding close approach of the scanner when this is not absolutely necessary is the simplest way to reduce exposure. Setting a restricted access area with visual aids (floor markings) at a distance of 30 cm from the end of a 3 T MRI scanner results in reduced static field exposure levels (26% reduction in the average maximum value) without noticeable changes in worker performance such as velocity<sup>86</sup>). In the design stage of the MRI room, an engineering-based mitigation approach is to lower the level of the MRI scanner by 1 m relative to the floor of the MRI room. This can result in a reduction of calculated electric field strength in the central and peripheral nervous system of the operator<sup>70</sup>). Using a detachable patient bed is another way to minimise time spent in the scanner room, although this system is not available in all MRI scanners. With regard to the gradient fields, optimisation of pulse sequences has been suggested to reduce occupational exposure without affecting image quality<sup>27</sup>). The exposure limits in the EU Directive are related to direct sensory effects, nerve stimulation and heating which are scientifically well-established. However, there is some recent evidence that high MRI-related EMF exposures may have effects on the nervous system that outlast the immediate exposure period and may contribute to an increased risk of accidents<sup>87</sup>). With an eye on future exposure guidance it would be useful to have more insight into the exposure-effect relationships for such delayed risks and how they are affected by mitigation measures.

For the other medical sources of occupational exposure to EMF, the EU Directive requires that measures are taken to prevent exceeding the health effects exposure limit values. For those scenarios where the worker's EMF exposure in diathermy, hyperthermia or electro-surgery exceeds the action levels, calculations on SAR are needed to establish whether exposure limit values may also be exceeded. However, instead of undertaking SAR assessment an employer may always opt to take risk reducing measures when the indicative action levels are exceeded. For low frequency magnetic stimulation, worker exposure can be reduced by mounting the coil on a flexible mechanical arm close to the patient and keeping distance<sup>35</sup>). Another possibility is

the application of metallic shielding to the side of the coil facing the operator (and away from the patient). For diathermy, possible technical exposure reduction measures are the shielding of electrodes, supply cables and connectors and the removal of metallic objects in the vicinity that can cause field reflections. For electrosurgery and ablation, examples of technical exposure reduction measures are shielding the supply cable, keeping it as short as possible and suspending it instead of letting it rest on the body. For all the high frequency sources mentioned, keeping distance and reducing exposure time are general organisational measures to reduce the level of exposure<sup>88)</sup>.

As in the previous analysis<sup>13)</sup> our approach to reviewing peak exposures with regard to exposure limits has several limitations. Only the maximum magnetic flux densities at the workplace per frequency per publication are listed as an indication of a worst-case scenario. These flux densities are not necessarily representative of the majority of exposures and may not represent good working practice. For high frequency devices in particular, the literature database is relatively old and it may be that more recent devices in combination with mitigation measures have reduced worker exposure. On the other hand, it cannot be excluded that even higher exposures are possible in specific workplaces, locations or scenarios that are not covered by the publications reviewed here. A comparison with the limits in the EU Directive was only made for the main frequency of the source in question. Other frequency components may add to the total exposure particularly when ICNIRP's frequency summation method is used<sup>2)</sup>. Another limitation is the source publications did not provide sufficient information to assess the impact of measurement uncertainty when comparing the measured values with the action levels. The European Commission's non-binding practical guide for the EU Directive provides some suggestions on how this could be achieved in practice<sup>89)</sup>. Finally, detailed worker exposure data are not yet available for some of the newer diagnostic and therapeutic techniques such as bronchial thermoplasty<sup>90)</sup>, volumetric EMF phase-shift spectroscopy<sup>91)</sup> and microwave-induced thermoacoustic echography. For the latter technique, there are indications that it should be possible to achieve sufficient image quality and depth with non-thermal EMF strengths<sup>92)</sup>. Preliminary field measurements in the vicinity of the patient would be helpful to determine if more extensive dosimetry is necessary.

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