EMFCOMP-10-A-2020

EMF Report for:
NDT Equipment Commonly Used

8 October 2020

Report

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Submitted to -

British Institute of Non-Destructive Testing
8 October 2020

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1 Introduction

1.1 EMFs and NDT

EMFcomp Limited was asked by the British Institute of Non-Destructive Testing (BINDT) to review the situation relating to the practice of non-destructive testing (NDT) and related quality testing practices, and the current electromagnetic field (EMF) safety regulations and guidance.

The aim of the review is to provide recommendations that will allow BINDT members to ensure the health, safety and welfare of employees and customers using NDT equipment in relation to EMF exposure. The intention is to act positively to minimise the incidence and severity of electromagnetic field workplace risks related to the practice of non-destructive testing. Employers have a legal responsibility to comply with the UK Statutory Instrument No. 588, The Control of Electromagnetic Fields at Work (CEMFAW) Regulations 2016 (HSE 2016a). The primary route to achieve compliance with the CEMFAW regulations is the measure/model the electromagnetic fields produced by NDT equipment and compare with the Action Levels/Exposure Limit Values stated in the regulations.

Electromagnetic fields are all around us, as they are generated wherever there is electrical power. They can be described as low frequency (LF) fields, produced by electrical currents and voltages, and radiofrequency (RF) fields, produced by antennas and communication devices.

In most occupational situations, the field strengths are not at a level that would cause adverse health effects. However, in some workplaces and for some devices, the field strengths may present a risk. The CEMFAW regulations exist to ensure the safety and health of workers in these situations.

The CEMFAW regulations lay down the minimum safety requirements regarding the exposure of workers to risks arising from electromagnetic fields. Employers in the UK have a duty to evaluate the risks arising from the work they undertake and to put into place protective or preventative measures to reduce the risks they identify. The CEMFAW regulations were introduced to help employers to comply with their duties for the specific case of EMF exposure in the workplace.

The CEMFAW regulations address direct and indirect effects caused by electromagnetic fields; it does not cover suggested long-term health effects. The direct effects can be separated into: non-thermal effects, such as the stimulation of nerves, muscles and sensory organs and thermal effects, such as tissue heating. Non-thermal effects are associated with low frequency fields, hence that is the focus for this report related to NDT. Indirect effects occur where the presence of an object within an electromagnetic field may become the cause of a safety or health hazard.

1.2 Low Frequency Adverse Health Effects

The nature of the particular electromagnetic field (primarily frequency and magnitude) determines the type of health effect the field will have on a worker. Some fields cause stimulation of sensory organs, whilst others cause heating. The effects caused by heating are defined as thermal effects in the CEMFAW Regulations, and all other effects are defined as non-thermal effects. There is a field threshold, below which there is no risk, and exposure below that threshold is not cumulative in any way. The effects from exposure to electromagnetic fields are transient – they are limited to the duration of the exposure, and they will stop or decrease once exposure ends. This means that, in the majority of cases, there can be no further risk to health once exposure has ended.

Electromagnetic field exposure can cause either direct or indirect effects. Direct effects are changes that occur in a person as a result of being exposed to a field. The CEMFAW Regulations only consider well established effects that are based on known biological mechanisms. The CEMFAW document distinguishes between sensory effects and health effects, which are considered more serious.

The direct effects at low frequency are:

- vertigo and nausea
- effects on sensory organs, such as nerves and muscles

The direct effects from high frequency field exposure are:

- heating of the whole body or parts of it; above a few GHz heating is increasingly limited to the surface of the body.

Indirect effects are defined as those that may occur due to the presence of objects in the field, resulting in a safety or health hazard. The indirect effects are classified as:

- interference with medical electronic equipment and other devices
- interference with active implanted medical devices or equipment, such as cardiac pacemakers or defibrillators
- interference with medical devices worn on the body, such as insulin pumps
- interference with passive implants (artificial joints, pins, wires or plates made of metal)
- effects on shrapnel, body piercings, tattoos and body art
- projectile risk from loose ferromagnetic objects in a static magnetic field
- fires or explosions from ignition of flammable or explosive material
- electric shocks or burns from contact currents when a person touches a conductive object in an electromagnetic field

The CEMFAW Regulations do not address suggested long-term effects of exposure to electromagnetic fields, since there is currently no compelling scientific evidence of a causal relationship. However, if such compelling evidence emerges, the Health & Safety Executive (HSE) have stated that they will consider the most appropriate way of addressing such concerns.

1.3 Workers at Particular Risk (Pacemaker Wearers etc.)

The CEMFAW Regulations are based on the EU's EMF Directive 2013/35/EU (EU 2013). The Action Levels within CEMFAW are designed to protect 'standard' workers, or workers not at particular risk, from EMF health hazards.

The practical EMF guide (EC 2015) and published HSE guidance (HSE 2016b) recommend that the EC Council Recommendation (EC 1999) Reference Levels, based on the ICNIRP public Reference Levels in their 1998 guidance (ICNIRP 1998), are used for ‘workers at particular risk’. Factors categorising a worker at particular risk are shown in Table 2 and described in more detail in the following sections.

Table 1 Recognised Adverse Health Effects of Electromagnetic Fields.

Field & Frequency Range	Effects	Examples of Activities
Low Frequency Fields (50-300 Hz)	**Health effects**: Nerve stimulation, effects on the central & peripheral nervous system of the body. Tingling, muscle contraction, heart arrhythmia. **Sensory effects:** Nausea, vertigo, metallic taste in the mouth. **Indirect effects**: Interference with active or passive implanted or body worn medical devices, electric shocks.	High voltage power lines; production and distribution of electricity, induction heating, electric welding and melting, industrial electrolysis, industrial magnetisers/demagnetisers, any high sources of current/voltage.

The Council Recommendation Reference Levels are, amongst other things, intended to prevent electromagnetic interference with a pacemaker, hence avoiding undesired behaviour of the implanted device, such as resetting and pacing inhibition. At 50 Hz, the Council Recommendation Reference Levels are 100 µT and 5 kV m^{-1} for magnetic and electric fields respectively.

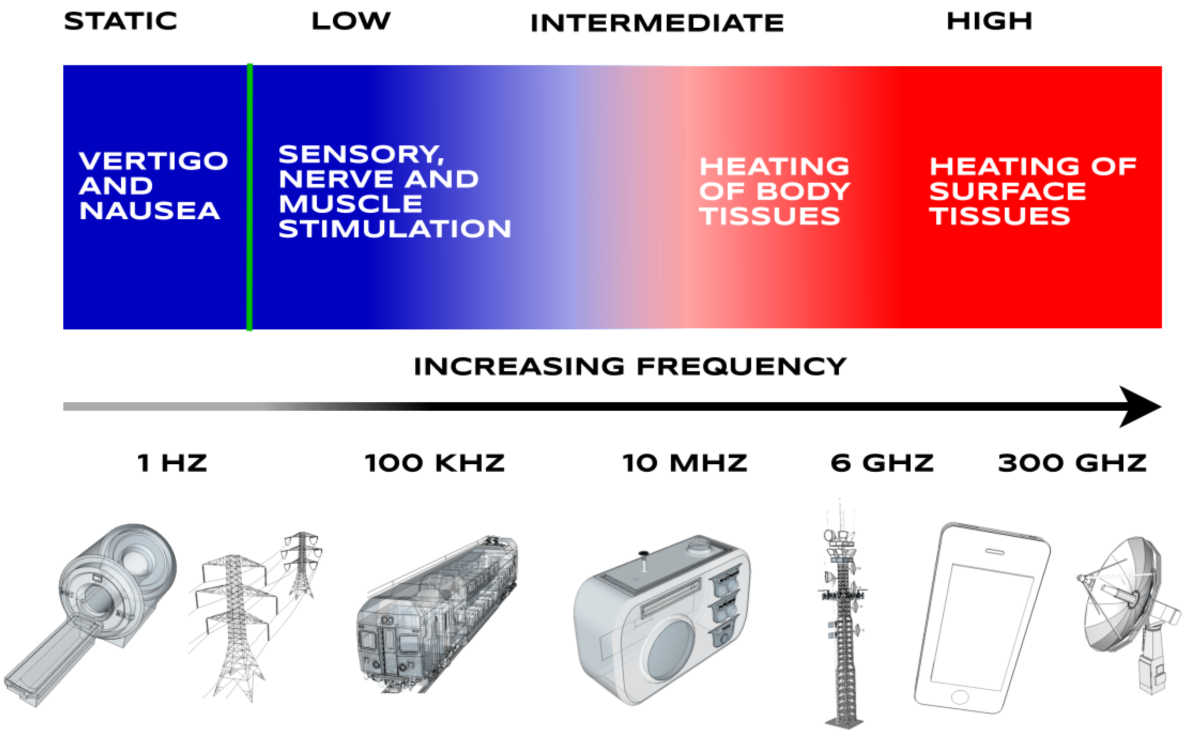

Figure 1 Adverse health effects of electromagnetic fields at various frequencies and related applications. The green line shows the frequency range with which this report is concerned (50/60 Hz etc).

Table 2 Examples of 'workers at particular risk', also applicable to the public, contractors etc.

Workers at particular risk	**Examples**
Workers wearing active implanted medical devices (AIMD)	Cardiac pacemakers, cardiac defibrillators, cochlear implants, brainstem implants, inner ear prostheses, neurostimulators, retinal encoders, implanted drug infusion pumps
Workers wearing passive implanted medical devices (PIMDs)	Artificial joints, pins, plates, screws, surgical clips, aneurism clips, stents, heart valve prostheses, annuloplasty rings, metallic contraceptive implants, penile implants
Workers wearing body-worn medical devices	Insulin pumps, hormone infusion pumps, continuous glucose monitoring systems, metallised drug-delivery patches
Pregnant workers	-

(i) Active Implanted Medical Devices (AIMDs)

Active Implanted Medical Devices or AIMDs, such as those detailed in Table 2, are considered to be immune to interference at field levels below the general public/Council Recommendation Reference Levels. Manufacturing standards for electronic devices state they should be unaffected at these field levels.

For electromagnetic fields above these levels, it should be assumed that interference is possible – although the susceptibility of particular devices can be sometimes higher and can be assessed on a case-by-case basis.

(ii) Passive Implanted Medical Devices (PIMDs)

Passive Implanted Medical Devices (PIMDs), such as those listed in Table 2, are considered not to be a risk for LF fields at levels below the general public Reference Levels. They have been identified as potentially presenting problems above Reference Levels, mainly because they can experience heating from exposure to high frequency fields.

However, there are no known biological mechanisms or compelling reports of any health and safety issues arising in practice from passive devices at power frequency fields. Therefore, EMFcomp advise that there is no significant risk to passive devices from power frequency fields and any general control measure would be disproportionate to the risk presented. That said, the option to investigate particular employee specific exposure situations on a case-by-case basis should be retained.

(iii) Expectant Mothers

Workers who inform their employer that they are pregnant should be given the option of complying with the public exposure limits (equivalent to the Council Recommendation Reference Levels) for the duration of their pregnancy. The EMF Directive 2013/35/EU, on which the UK legislation is based, encourages employers to take account of expectant mothers in risk assessments, however it does not give specific requirements.

The 2011 draft of the EMF Directive stated that ‘The employer shall enable the worker to avoid having to enter areas where exposures exceeding the exposure limits for the general public given in the Council Recommendation 1999/519/EC, or its subsequent revisions’. However, this was removed from the final 2013 document.

The HSE Guidance to the Regulations (HSE 2016b) states ‘As working with certain levels of EMFs could result in a greater risk to an expectant mother, you should encourage your workers to advise you in writing if they become pregnant. You may wish to take a practical approach and limit the exposure to the public exposure limits. These are stated in Council Recommendation 1999/519/EC.’

EMFcomp Limited would recommend that, as a matter of precaution and reassurance, expectant mothers should be allowed to be restricted to the Council Recommendation Reference Levels. However, it is important to note that this is a precautionary measure and there is no clear evidence of any actual risk up to the standard worker CEMFAW Action Levels. Additionally, note that EMF exposure could occur before the female worker knows that she is pregnant or chooses to notify her employer.

1.4 Report Objectives

This report aims to clarify the adverse health effects related to exposure to the low frequency fields produced by NDT equipment. It also outlines the relevant legislation and guidance relevant to EMF exposure in the UK. It sets out to briefly explain the assessment methods available, summarise the field levels produced by NDT equipment routinely used and attempts to provide recommendations for ways forward for the NDT community in terms of clarifying NDT hazards related to EMF exposure.

Note that the NDT equipment listed in the NDT exposure assessment section is not intended to be an exhaustive list of the NDT techniques currently used in the UK. It is simply a summary of equipment we as a company have routinely come across in the two hundred or so EMF compliance assessments, since the publication of the EMF Directive 2013/35/EU (the forerunner to the UK’s Control of EMF at Work Regulations 2016). We welcome further suggestions from the BINDT and its members for other potential high sources of magnetic fields used in industry.

2 EMF Regulations & Guidance

2.1 The CEMFAW Regulations 2016 and Council Recommendation 1999/519/EC

The CEMFAW 2016 Regulations describe a two-tier system to assess human electromagnetic field exposure, involving a first set of easily measurable external field levels (the Action Levels or ALs) and a second set of calculated, internal to the body, limits (the Exposure Limit Values or ELVs). The ELVs are complex to calculate as they require modelling of the interaction of electromagnetic fields with human tissues, however – these are less restrictive that the ALs, hence do provide a route to compliance in situations where the Action Levels are exceeded and the worker needs to be close to the field source. These ALs and ELVs are applicable to workers who are 'not at particular risk' to EMF exposure.

For workers at particular risk (workers with active medical devices such as pacemakers, pregnant workers etc.), the more restrictive Council Recommendations 1999/519/EC (EC 1999) reference levels (RLs) are applicable instead of CEMFAW Action Levels.

Table 3 – CEMFAW Action Levels and EC Reference Levels at 50 Hz for Magnetic Fields.

Body Region	**Magnetic Flux Density (microtesla (µT))**	
	CEMFAW Occupational Action Levels (ALs)	**Council Recommendation Public Reference Levels (RLs)**
Low Action Level (Head)	1000	100
High Action Level (Trunk)	6000	100
Limb Action Level (Limbs)	18000	100

The CEMFAW Action Levels and EC Council Recommendation Reference Levels for measured magnetic fields at 50 Hz (power frequency common to NDT applications) are shown in Table 3. Action Levels and Reference Levels for electric fields at 50 Hz are shown in Table 4. If field values are below these values, known adverse health effects will be avoided. If the field levels are above these values, further work is required to ensure safety.

Table 4 – CEMFAW Action Levels and EC Reference Levels at 50 Hz for Electric Fields.

	Electric Field (kV m^{-1})	
	CEMFAW Occupational Action Level (AL)	**Council Recommendation Public Reference Level (RL)**
Low Action Level (Head)	10	5
High Action Level (Rest of body)	20	5

For magnetic field ALs across the low frequency range, please see Figure 2. This demonstrates the difference in levels for the head, trunk and limbs, as there are different adverse health effects for these body regions. Note that the region of interest for this work, approximately 50 Hz to 300 Hz, is shaded in yellow.

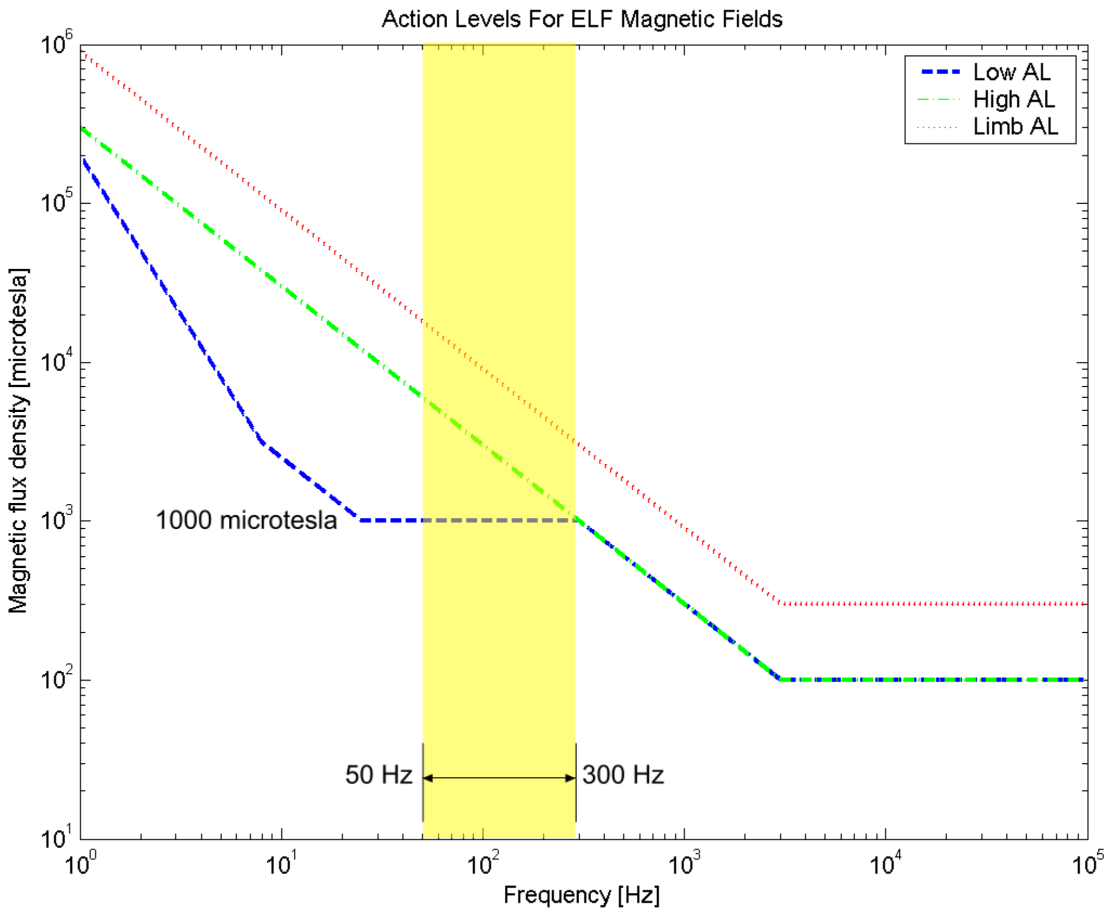

Figure 2 The Control of EMF at Work Regulations 2016 Action Levels for low frequency magnetic fields. Highlighted in yellow is the frequency range of interest for the assessments carried out in this assessment. Note that *x* and *y* axes are log scales.

2.2 HSE Exemptions

When the EMF Directive 2013/35/EU was transposed into UK legislation (The CEMFAW regulations) in 2016, it also issued statements on 'exemptions' to the regulations. The HSE's exemptions tend to be a source of confusion to some UK industry sectors and EMF assessment specialists. HSE exemption certificates are available to download from the HSE website. It is a common misconception that if a company partakes in a work activity that is exempted according to the HSE list, simply downloading this certificate is sufficient to continue to carry out a work activity where high levels of electromagnetic fields exist without any other action. It is important to stress that this is not the HSE's intention of the exemptions.

Note that the employer is required to meet the conditions attached to the exemption. If they do not, or cannot, meet these conditions, then the exemption does not apply. The conditions include that an employer still has to carry out an EMF exposure assessment, ensure that exposure is low as practically possible, and ensure that employees are protected against the health effects and safety effects from that exposure.

From the HSE website:

"Exemptions from certain exposure limits in the CEMFAW Regulations include those issued by HSE the MRI exemption for medical purposes and the military exemption.

Exemptions issued by HSE

Regulation 13(1) of CEMFAW Regulations grants the Health and Safety Executive (HSE) power to exempt employers from the exposure limits contained in the Regulations. Any exemption will be subject to safety conditions. It should be remembered that exposure limits are not a line between safe and dangerous exposures.

If HSE exempts an activity from the exposure limits, you as the employer must ensure that:

- exposure is as low as is reasonably practicable; and
- employees are protected against the health effects and safety risks arising from that exposure.

Exempting activities not on the current HSE Exemption certificate

If you carry out a work activity that is not included in HSE's certificate of exemption but think it should be, an application for the activity to be included can be submitted to HSE. Remember you will not be applying for an exemption for your business/organisation but for the activity itself. If the activity applied for is then included on HSE's exemption certificate it will be available to all employers subject to meeting the necessary safety conditions.

The request should include the following:

- Nature of the work activity - An explanation of what process is carried out and why it is not possible to meet the exposure limits.
- Description of equipment - outlining frequencies, emissions, power levels etc. and what measures are taken regarding equipment and operator positioning and any operator screening.
- Description of operating cycles - providing information on duty-cycles, shifts, or the temporary nature of the exposure can support a case for exemption
- An account of preventative actions taken - demonstrating how measures to ensure 'lowest levels reasonably practicable' have been devised and implemented.
- Why continuing the work activity is essential to business - whether commercial or otherwise.

(This list is not exhaustive - any additional information considered relevant to the case but not specifically mentioned here should also be submitted). HSE may review and revoke exemptions at any time."

EMFcomp Limited would recommend that the best way to ensure that these conditions are met is by carrying out a measurement or calculation-based EMF assessment, and comparing the field values obtained with the relevant Action Levels or Exposure Limit Values stated in the CEMFAW regulations. It is important to reiterate the statement that the CEMFAW regulations were introduced to help employers comply with their safety duties for the specific case of EMF exposure in the workplace.

Additionally, this exemption list issued by the HSE only applies to the UK exposure situations. If a manufacturer intends to market its NDT equipment in another European country, an exemption certificate is not applicable to that country and there will be a requirement to comply with field limits relevant to that particular location, i.e. the Action Levels and Exposure Limit Values in the EMF Directive 2013/35/EU.

Finally, it is our understanding that the exemption certificates and process expire in 5 years from the publication date of the CEMFAW regulations, 1 July 2016. Hence, this translates to an expiry date of 1 July 2021. It is currently unclear as to whether the exemption certificates or procedures will extend beyond this date.

In summary, we would strongly advise the NDT community that the best way to ensure the health, safety and welfare of employees and customers using NDT equipment, along with carrying out their legal responsibility to comply with the Control of Electromagnetic Fields at Work Regulations 2016, is by carrying out a measurement or calculation-based EMF assessment. This includes comparing the field values obtained from such an assessment with the relevant Action Levels or Exposure Limit Values stated in the CEMFAW regulations. Following such a procedure will allow employers in the UK to evaluate the EMF risks arising from the work they undertake and to put into place protective or preventative measures to reduce the risks they identify.

3 EMF Assessment Methods

3.1 Measurement for Comparison with CEMFAW ALs and Council Recommendation RLs

Specialist measurement probes are used to measure the electromagnetic fields from NDT equipment. Examples of this equipment are shown in Figure 3. Included in this figure is the Narda ELT-400 for CEMFAW Action Levels, Narda ELT-400 for Council Recommendation 1999/519/EC Reference Levels, the Narda EHP-50H for spectrum measurements and the MetroLab THM-1176 for static magnetic field measurements.

Figure 3 Measuring time-varying, low frequency magnetic fields using the Narda EHP-50 device, Narda ELT-400 probes and associated equipment.

Measurements performed tend to be either spot measurements of static fields, broadband spot measurements of low frequency magnetic and electric fields or measurements of fields at specific frequencies. The handheld magnetic field measurement probes used assess the multiple frequency components waveforms commonly produced by power applications by the 'weighted peak method', as mentioned in the Control of EMF at Work Regulations 2016 and associated documents.

The collected magnetic field waveform is processed through a filter that has an instantaneous amplifying response, equivalent to the frequency dependent limits. When a waveform passes through this filter, it is scaled to an output value, corresponding to a percentage of the relevant Action Level (or Reference Level).

Therefore, field values tend to be reported as percentages of the Action Levels (or Reference Levels for 'at risk' workers) rather than field values in Tesla. Any value under 100% is in compliance with the Action Level (or Reference Level). Any number above 100% is not in compliance with the Action Level (or Reference Level).

3.2 Modelling for Comparisons with the CEMFAW ELVs

The CEMFAW low frequency Exposure Limit Values (ELVs) are expressed as induced electric fields, internal to the human body, produced by exposure to low frequency magnetic fields. Effectively, because the human body is made up of conductive tissue types (water makes up approximately 60% of the human body), fields are induced in a similar way to an electric motor on exposure to a power frequency magnetic field. The applied field induces electric currents in the body, which then circulate around the body depending on the size, shape and posture of the individual. As signals within the brain or from the brain through the nerves take place via small electrical impulses, these impulses can be disrupted by other electrical currents - induced from exposure to externally applied fields.

The effects on the body from these externally applied fields can be seen from a process used in clinical environments called 'Transcranial Magnetic Stimulation'. We would invite the reader to view the effects of field exposure from this process, documented via many sources, e.g. YouTube etc.

Electromagnetic field absorption in people cannot be accurately assessed by measurement, as field strengths cannot be easily measured in a living body. Computer modelling using numerical methods and fine resolution, anatomically realistic heterogeneous human body phantoms provide a way in which human absorption can be directly investigated.

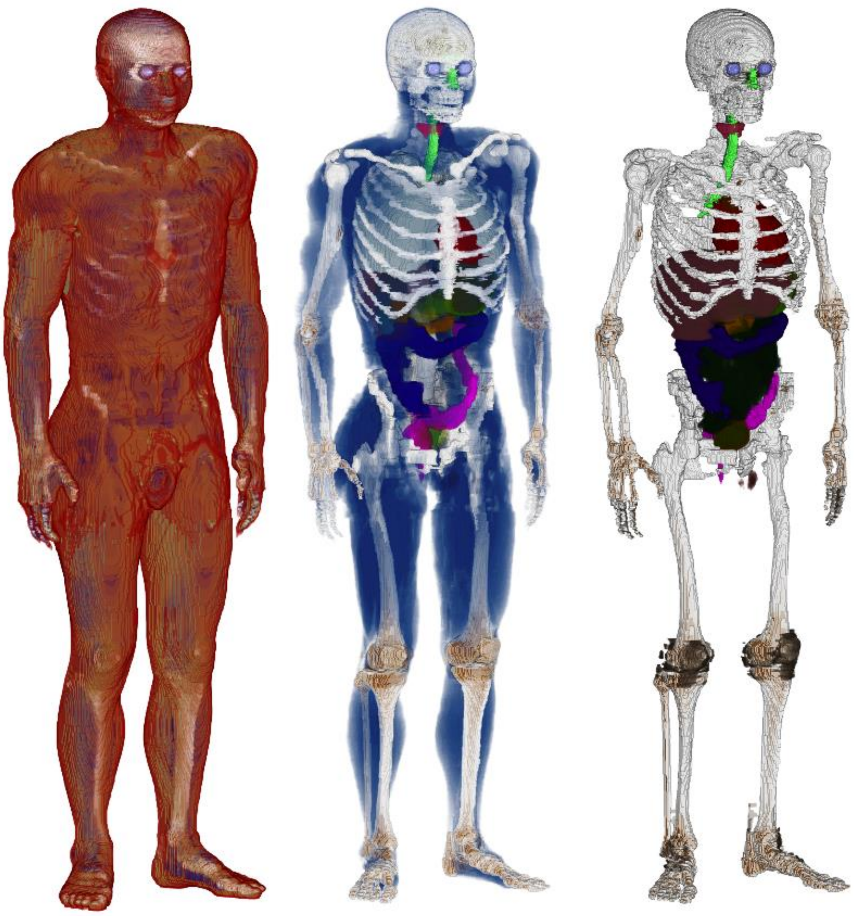

Figure 4 Volume rendered images of MAXWEL at a resolution of 2 mm. The opacity of certain regions has been varied to enable the internal skeleton and some internal organs to be seen.

The human models are derived from medical imaging data and the latest versions are referred to as surface-based phantoms. In these models, the boundary of each tissue type can be mathematically described by a form of parameterised surface that might be as simple as a planar quadrilateral or as sophisticated as a two-dimensional spline.

Complex numerical methods such as the scalar potential finite difference (SPFD) method are required to calculate induced electric fields in the body, to directly compare with the ELV limits expressed in the CEMFAW regulations. For those that are interested, the continuous elliptical equation relating the scalar potential to the magnetic vector potential can be mapped onto a three-dimensional computational domain containing the human model, which is discretised into a uniform set of cells or voxels. The electrical properties within each voxel of this domain are assumed to be constant. The electric fields are defined as a set of discrete vectors on a staggered array defined by the voxel edges, with the field values defined at the edge centres. Magnetic fields are defined on a conjugate mesh defined by the voxel face normal.

The magnetic vector potential is solved iteratively using successive over relaxation to hasten convergence. Having reached convergence, the electric fields along the edges of the cuboid cell are obtained. Therefore, the primary output of the scalar potential finite difference code is a set of discrete electric vector components.

The results can then be expressed in a 'heat map' of electric field values induced in the body. Figure 5 shows such a field distribution image calculated for a person's exposure in close proximity to a demagnetiser.

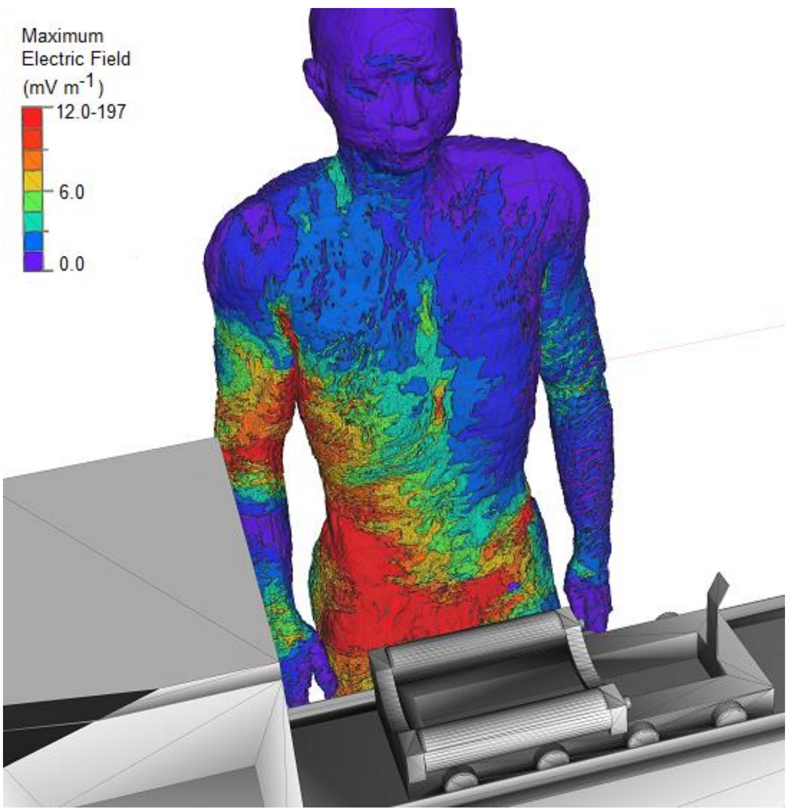

Figure 5 Distribution of the induced electric field in the human model from exposure to a demagnetiser when standing 1.25 cm from the bore of the magnet.

4 EMF Exposure Assessments

This section is intended not as a comprehensive review of strong field sources in the NDT sector, but as an indication of fields produced by different types of equipment that we have encountered in our day-to-day EMF assessments of various industrial sectors.

4.1 Demagnetisers

4.1.1 Description

Demagnetisers are used to demagnetise metal components after a magnetic field has been applied to the component, typically after the magnetic particle inspection (MPI) process. The demagnetisers appear in various shapes and sizes, depending on the application for which they were designed. Generally, a power frequency current is passed through a coil would around a ferrous metal core. When a component is pushed through this coil (which can be done utilising a variety of methods, from the use of a trolley to the operator using their hands), the component is demagnetised after appearing on the other side.

Figure 6 – A demagnetiser.

4.1.2 Exposure Summary

Employers are aware that these devices produce magnetic fields and there are potential EMF hazards associated with demagnetisers, as routinely the manufacturers' information states that the equipment can affect pacemakers. However, often there is no further information provided on this hazard.

Due to this lack of information, employers are usually keen to understand the specific hazard presented to both 'standard' workers and 'workers at particular risk', and the extent of this hazard. The approach to the exposure assessment is to measure the low frequency, time-varying magnetic fields around the demagnetiser using an appropriate meter that can carry out a weighted peak average calculation, expressing the results as a percentage of the relevant Action Level or Reference Level.

4.1.3 Exposure Assessment Details

Low frequency magnetic field measurements of the magnetic field were carried out around the demagnetiser shown in Figure 6. The field values measured are shown in Table 5.

Table 5 Demagnetiser Measurement Positions & Values for Magnetic Fields

Equipment	Distance from Demagnetiser Coil	% of Council Recommendation Level	% of Occupational Action Level
Inspection Booth Demagnetiser	0 cm, inside coil		1830% of low AL
Inspection Booth Demagnetiser	0 cm, flush to casing		1050% of low AL
Inspection Booth Demagnetiser	0 cm, side		555% of low AL
Inspection Booth Demagnetiser	0 cm, top		300% of low AL
Inspection Booth Demagnetiser	50 cm, side		90% of low AL
Inspection Booth Demagnetiser	20 cm, top		90% of low AL
Inspection Booth Demagnetiser	0 cm, inside coil		310% of high AL
Inspection Booth Demagnetiser	20 cm, side		90% of high AL
Inspection Booth Demagnetiser	0 cm, inside coil		190% of limb AL
Inspection Booth Demagnetiser	5 cm, flush to casing		88% of limb AL
Inspection Booth Demagnetiser	120 cm	90% of RL	

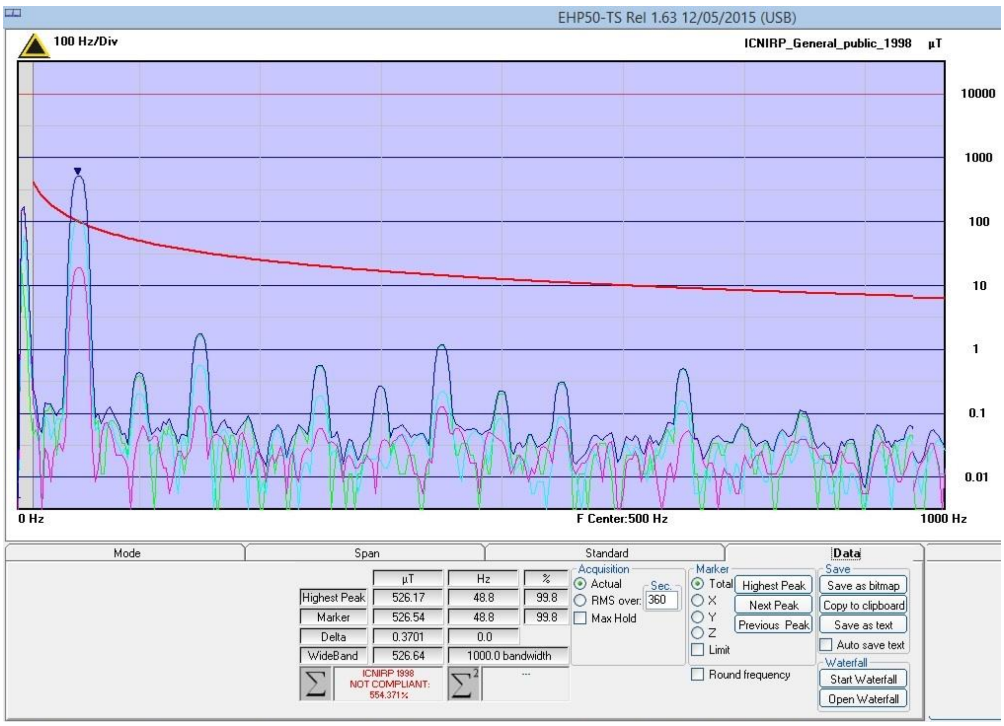

Figure 7 – Magnetic field spectrum for the demagnetiser, showing the dominant frequency at 50 Hz with smaller harmonics.

Figure 7 shows the magnetic field spectrum for the demagnetiser. It produces 50 Hz fields, with no other significant components. The peaks for the 150 Hz, 250 Hz, 350 Hz etc peaks are all below 1% of the 50 Hz peak.

When switched on, the magnetic field significantly exceeded the low, high and limb Action levels inside the coil. On the side of the casing, the field again exceeded the low, high and limb Action Levels, applicable to the head, torso and arms/legs respectively.

The compliance zone for the head was measured as 50 cm and 20 cm for the torso. The limb Action Levels were complied with at separation distances of above 5 cm. The Council Recommendation Reference Levels were exceeded with 1.2 metres of the bore of the demagnetiser coil.

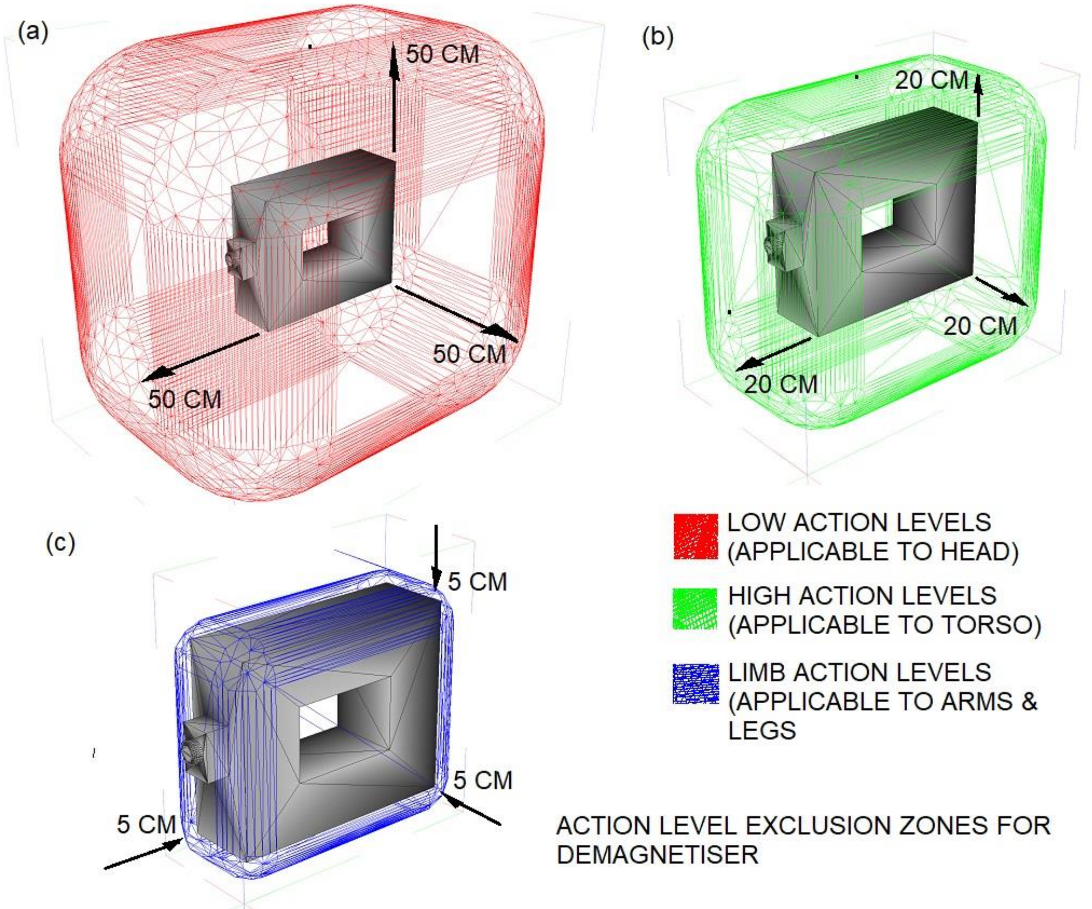

Figure 8 – Isometric views of the demagnetiser showing regions within which the (a) low Action Levels – red mesh (b) high Action Levels – green mesh and (c) limb Action Levels – blue mesh could be exceeded.

4.2 MPI Benches

4.2.1 Description

Magnetic particle inspection (MPI) benches are used in the non-destructive testing of metal components. Defects are detected in the workpiece by magnetising it using an electrical current and looking for perturbations in the applied magnetic field. Ferromagnetic dyes are applied to the surface of the component, and defects are identified using a suitable light source. Operators carrying out the inspection tend to work in close proximity to the equipment, as obviously they have to visually inspect for any defects.

4.2.2 Exposure Summary

Again, employers are aware that these devices produce magnetic fields and there are potential EMF hazards associated with the MPI process, as the manufacturers' information tend to state the hazard to implanted medical devices. However, similar to the demagnetisers, often there is no further information provided on this hazard.

Due to this lack of information, employers are usually keen to understand the specific hazard presented to both 'standard' workers and workers at particular risk, and the extent of this hazard.

The approach to the exposure assessment is to measure the low frequency, time-varying magnetic fields around the MPI bench using an appropriate meter that can carry out a weighted peak average calculation, expressing the results as a percentage of the relevant Action Level or Reference Level.

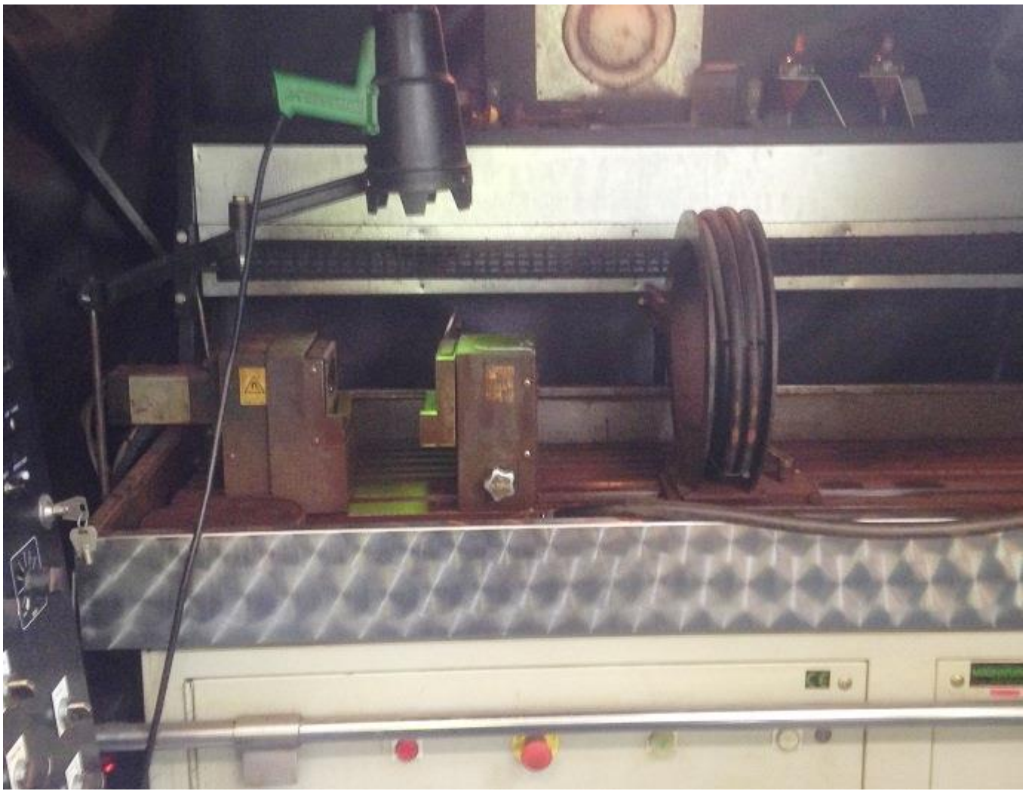

Figure 9 – Magnetic Particle Inspection (MPI) Unit.

4.2.3 Exposure Assessment Details

The MPI unit operated at an electrical current up to 2600 Amps. For the measurements, it was understood that a typical field level of approximately 80% of this maximum was used. It could be used in two ways, either by securing a workpiece within the electrode jaws, or by passing the workpiece through a coil. Both operations were measured for the magnetic fields, with the results shown in Table 6.

Table 6 MPI Unit Measurement Positions & Values for Magnetic Fields

Equipment	Distance from Electrodes or Coil	% of Council Recommendation Level	% of Occupational Action Level
MPI, electrodes	40 cm, electrodes		90% of low AL
MPI, electrodes	20 cm, electrodes		60% of high AL
MPI, electrodes	8 cm, electrodes		40% of limb AL
MPI, electrodes	120 cm	106% of RL	
MPI, coil	0 cm, inside coil		2085% of low AL
MPI, coil	40 cm, surface of coil		90% of low AL
MPI, coil	0 cm, surface of coil		576% of high AL
MPI, coil	20 cm, surface of coil		90% of high AL
MPI, coil	0 cm, inside coil		206% of limb AL
MPI, coil	8 cm, inside coil		90% of limb AL
MPI, coil	120 cm	90% of RL	

Figure 10 shows the magnetic field spectrum for the MPI unit. It can be seen that the dominant frequency of the magnetic field generated was 50 Hz, with no other harmonics over 10% of this main peak.

Figure 10 - Typical magnetic field spectrum from the MPI unit showing the dominant frequency at 50 Hz with significant harmonics at 150 Hz, 250 Hz, 350 Hz etc.

During operation of the unit, it was observed that the operator stood approximately 30 cm from the electrodes when carrying out procedures. At this distance, the head Action Levels were exceeded.

During the operation of the MPI unit using the coil, the operator was required to put their hands near or through the bore of the coil when operating the unit. At these distances, the low, high and limb Action Levels were exceeded. Exclusion zones can be seen in Figure11 and 12.

The Council Recommendation 1999/519/EC Reference Levels were exceeded within 1.2 metres of the MPI unit into areas adjacent to the MPI booth.

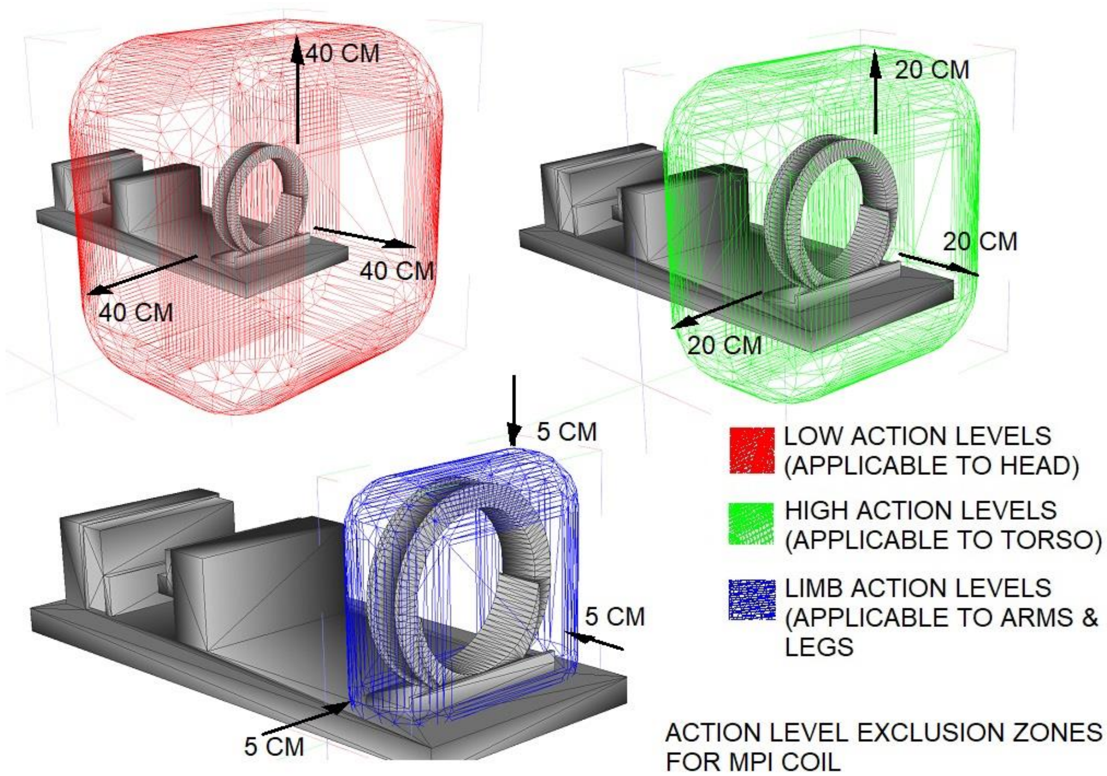

Figure 11 – Isometric views of the MPI bench showing regions within which the (a) low Action Levels - red mesh (b) high Action Levels - green mesh and (c) limb Action Levels - blue mesh could be exceeded for the coil.

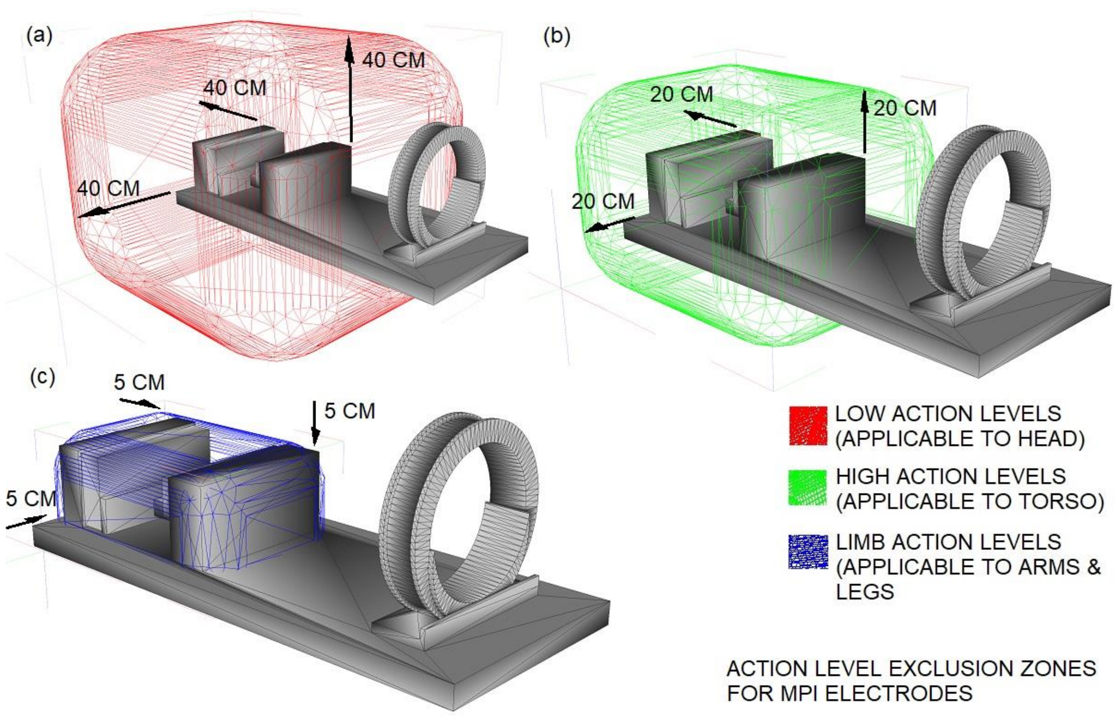

Figure 12 – Isometric views of the MPI bench showing regions within which the (a) low Action Levels - red mesh (b) high Action Levels - green mesh and (c) limb Action Levels - blue mesh could be exceeded for the electrodes.

4.3 Yokes

4.3.1 Description

Yokes tend to be operated using the hand, designed to apply magnetising currents to workpieces for the identification of defects. Being handheld, they can be more versatile than the MPI benches, Hence, they are used for applications where the portable nature of the field source is important. Due to the yokes being handheld, the operator is usually in close proximity to the magnetic field generated.

4.3.2 Exposure Summary

Similar to demagnetisers and MPI benches, the handheld yokes produce low frequency magnetic fields. The measurement procedure is to assess these fields in various positions (e.g. hand, torso, head) and record a result as a percentage of the limb, low or high Action Level (or Reference Level). We have measured many different yokes in the course of our EMF assessments. These have been of different designs, powers and sizes, from various manufacturers. However, in the interests of brevity, just the two yokes, shown in Figure 13, are studied here.

Figure 13 – Yokes (a) CEGB Y801 and (b) Magnaflux.

4.3.3 Exposure Assessment Details

The magnetic field values measured for Yoke 1 were in compliance with the low, high and limb Action Levels at separation distances of 20 cm, 8 cm and 2 cm respectively, For Yoke 2, the magnetic field values measured were in compliance with the low, high and limb Action Levels at separation distances of 18 cm, 5 cm and 2 cm respectively. These are shown graphically in Figures 14 and 15.

There did not seem to be an issue for the head and torso in this application (depending on how close the operator chooses to hold the device to the torso), as the separation distances for compliance were smaller than those distances observed when the operator used a yoke routinely. However, obviously the exclusion zone for the hands produced a problem, as these devices are handheld.

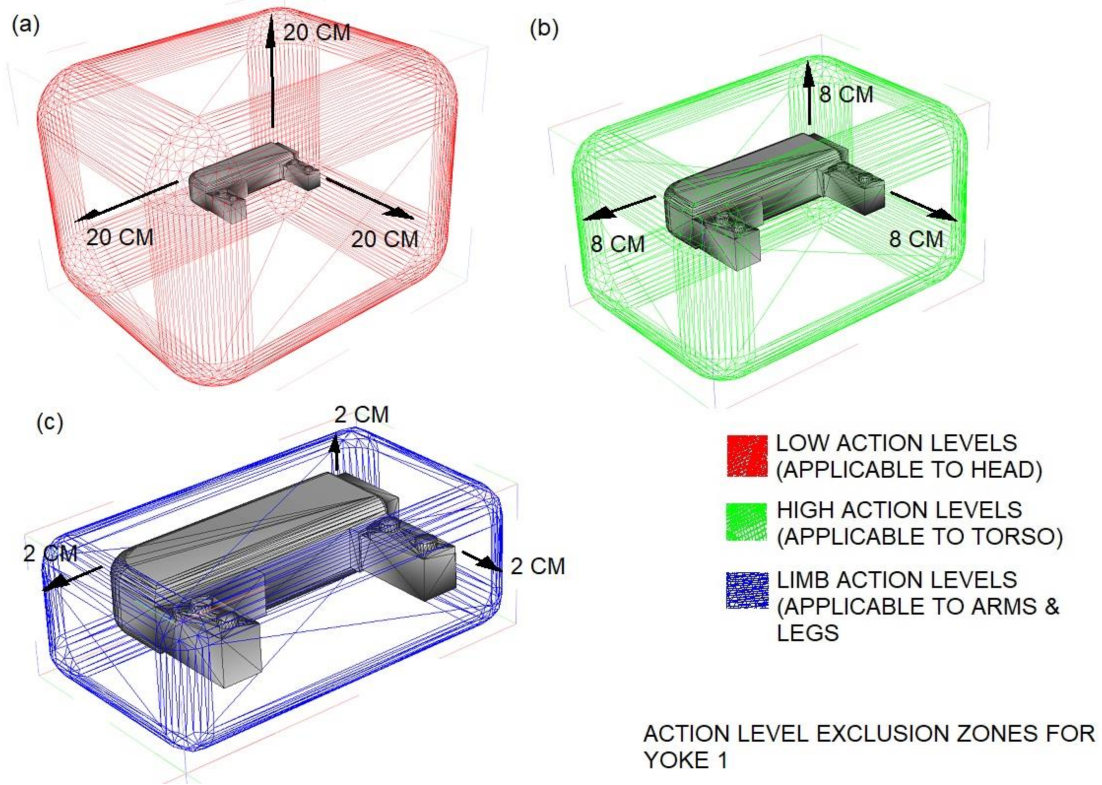

Figure 14 – Isometric views of Yoke 1 showing regions within which the (a) low Action Levels – red mesh (b) high Action Levels – green mesh and (c) limb Action Levels – blue mesh could be exceeded.

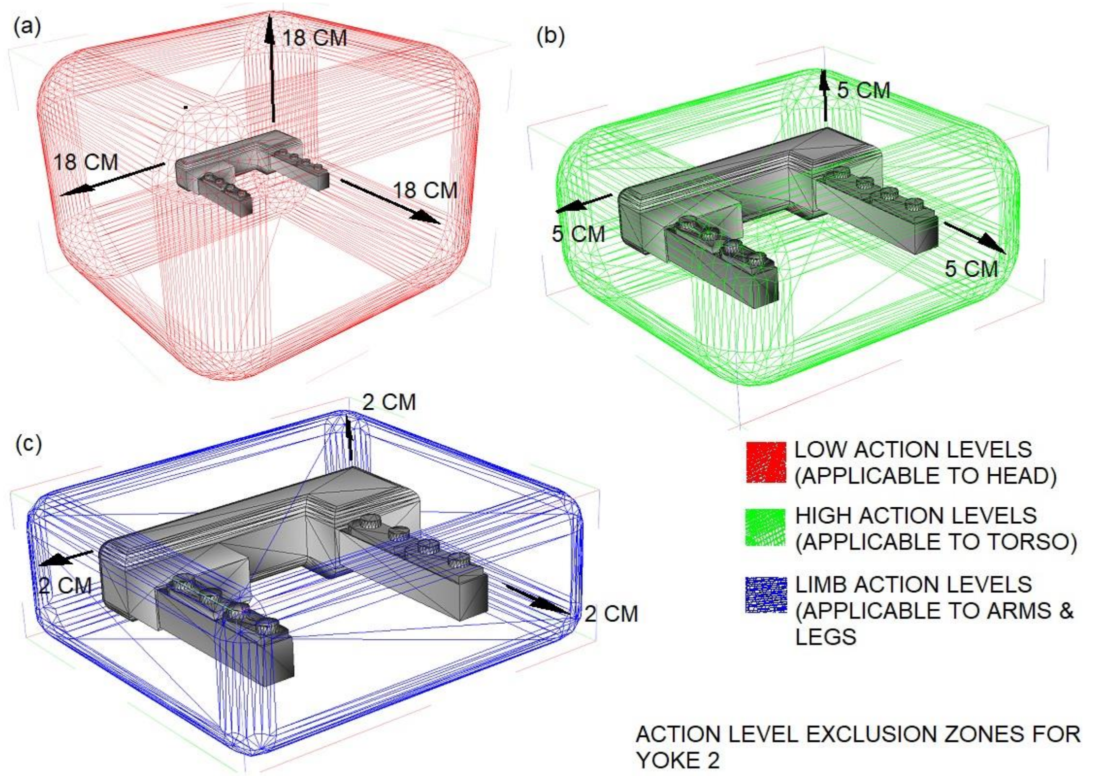

Figure 15 – Isometric views of Yoke 2 showing regions within which the (a) low Action Levels – red mesh (b) high Action Levels – green mesh and (c) limb Action Levels – blue mesh could be exceeded.

4.4 Cable Loops or Coils

4.4.1 Description

Another method of magnetising a metal component is a to coil an electrical current carrying cable around the workpiece. This technique is more applicable where the component to be magnetised is large. The magnitude of electrical currents used during this process tends to be high, therefore, depending on where the operator is located (and the size of the current), high exposures can be generated.

Figure 16 - Current loop and power supply for current loop 1.

Figure 17 - Current loop and power supply for current loop 2.

4.4.2 Exposure Summary

A power frequency electrical current passed through a cable will generate a magnetic field around that cable. The strength of the magnetic field is directly proportional to the current. Hence, the higher the current, the higher the magnetic field. The magnitude of the field drops off very quickly with distance, so separation distance can be used as a way to reduce an employee's exposure to the fields produced.

Similar to the other equipment described in this section, the measurement procedure is to energise the equipment and assess these fields in various positions around the cables, recording results as a percentage of the limb, low or high Action Level (or Reference Level).

4.4.3 Exposure Assessment Details

The magnetic field values measured for Coil 1 were in compliance with the low, high and limb Action Levels at separation distances of 40 cm, 25 cm and 5 cm respectively, For Coil 2, the magnetic field values measured were in compliance with the low, high and limb Action Levels at separation distances of 10 cm, 5 cm and 0 cm respectively. These are shown graphically in Figures 18 and 19.

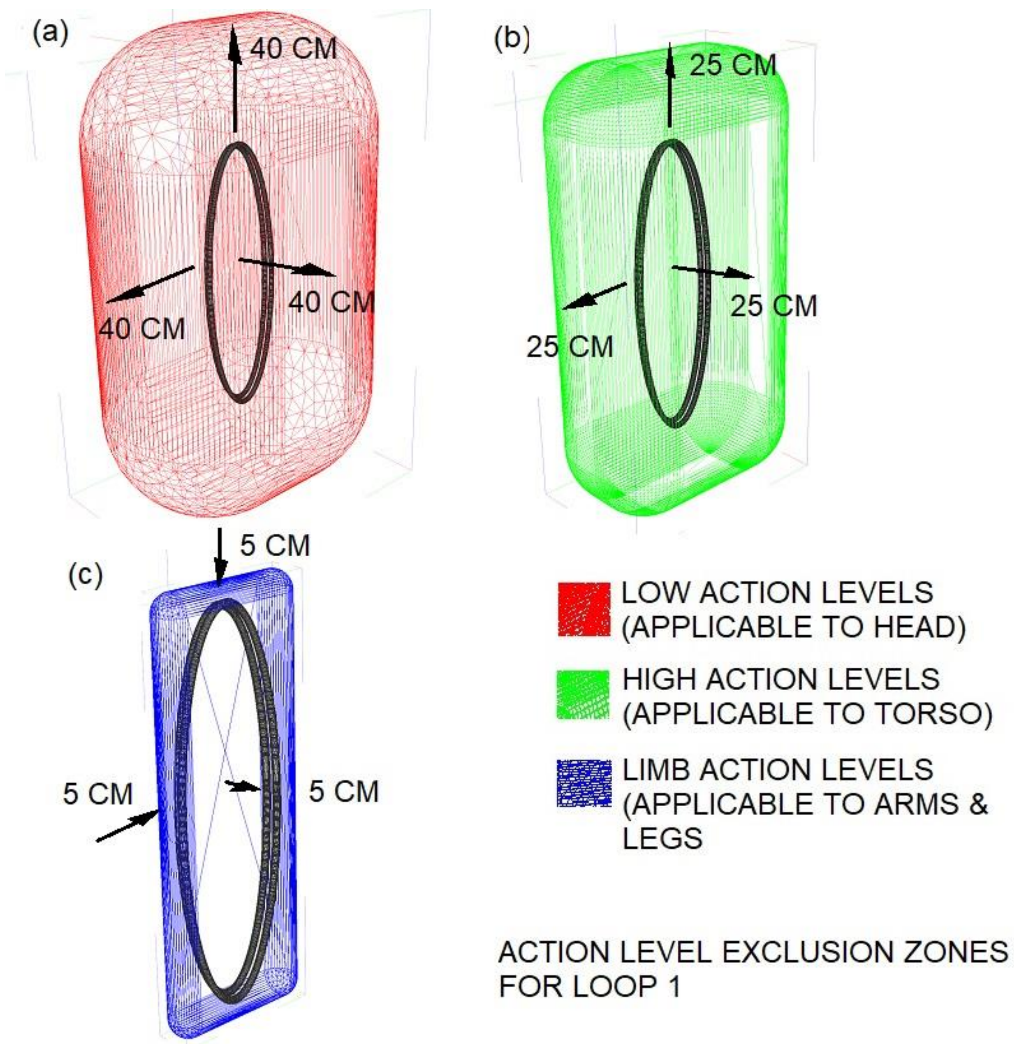

Figure 18 - Isometric views of Coil 1 showing regions within which the (a) low Action Levels - red mesh (b) high Action Levels - green mesh and (c) limb Action Levels - blue mesh could be exceeded.

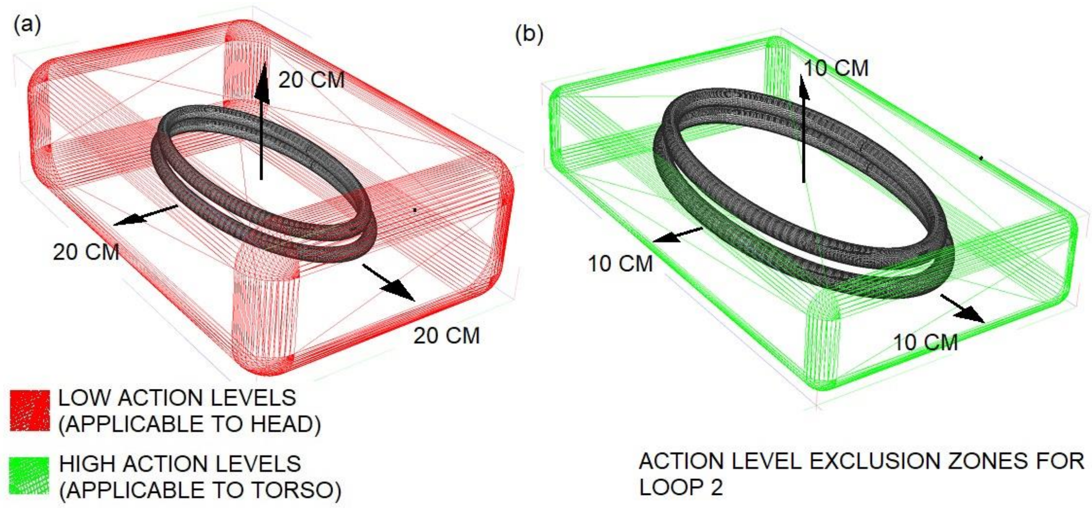

Figure 19 – Isometric views of Coil 2 showing regions within which the (a) low Action Levels – red mesh (b) high Action Levels – green mesh and (c) limb Action Levels – blue mesh could be exceeded.

Similar to the yokes, there did not seem to be an issue for the head and torso in this application, as the separation distances for compliance were smaller than those distances observed when the operator used these routinely (although this was dependent on how a particular user chooses to work). However, obviously the exclusion zone for the hands would produce a problem, should the operator be required to hold the coils whilst the current was applied. Note that the electrical currents in the coil used for these measurements was 800 A for Coil 1 and 400 A for Coil 2. Obviously, if these currents were required to be increased, or the number of turns in the coil were required to be increased etc, this would then present more significant exposure problems.

4.5 Other

There are inevitably other NDT equipment and processes that we are not aware of or have not encountered. We would obviously recommend EMF assessments to be carried out for any equipment where it is anticipated that the Action Levels or Reference Levels could be exceeded.

5 Discussion

5.1 Non-compliances with the Council Recommendation 1999/519/EC Reference Levels

It is important that employees at particular risk (people with pacemakers/defibrillators etc), are considered, as these people may not be adequately protected by the CEMFAW Action Levels. In general, however, they will be adequately protected by the Council Recommendation 1999/519/EC Reference Levels.

The easiest way to manage this hazard is to identify areas where exposure exceeds the Reference Levels, and then either restrict access to these areas or alternatively look at a person-specific worker assessment, which is dependent on the individual exposure situation. Whilst access restrictions are often the default approach, employers may want to keep open the option to permit access to an individual where it can be shown that it will not put them at unnecessary risk.

The Council Recommendation 1999/519/EC Reference Levels are exceeded within a distance of 1 to 2 metres of many demagnetisers, MPI benches, NDT yokes and coils when these are operated. Hence, in the absence of a person-specific worker assessment, it is important that workers at particular risk do not use this equipment or come within 1 to 2 metres of the devices when they are being operated.

It is important to adhere to these exclusion zones for cardiac equipment interference. Those with active implants or body-worn devices are a risk of device malfunction even during transient exposure. Hence these people should not enter an area where exposures in excess of the Reference Levels are possible unless it can be shown that the particular device on which they rely is not susceptible to interference at the field strengths produced by the NDT equipment. Localised fields may also present a risk if it is foreseeable that they could give rise to exposure of the device. Hence, these individuals should be kept away from NDT equipment capable of generating localised strong fields.

5.2 Non-compliances with the CEMFAW Action Levels

For all four types of NDT equipment considered in this report, there were situations where the magnetic fields produced by the devices could give rise to worker exposures in excess of the low Action Levels (applicable to the head), high Action Levels (applicable to the torso) and limb Action Levels (applicable to the arms, hands and legs) as specified in the Control of Electromagnetic Fields at Work Regulations 2016. Taking each in turn:

5.2.1 Demagnetisers

Magnetic field strengths exceeded the CEMFAW low Action Levels (applicable to the head), high Action Levels (applicable to the torso) and limb Action Levels (applicable to the arms, legs and hands) in regions around the demagnetiser when operated.

The specific separation distances, at which compliance with the Action Levels is achieved, for the particular demagnetiser presented in this report were head – 50 cm, torso – 20 cm and limbs - 5 cm.

If this was to be applied to other demagnetisers of a similar design, it is common practice to double these distances to allow for site-to-site variability. Hence, these compliance separation distances for demagnetisers of a similar design become: head – 100 cm, torso – 40 cm and limbs - 10 cm.

Applying access restrictions for the demagnetiser for these separation distances, effectively achieved by installing physical barriers (although suitable floor markings can be considered as an alternative), would usually mean that the equipment could not be operated. The operator observed during the assessment was close to the coil and passed the workpiece through the demagnetiser with their hands.

Hence, the head was within 100 cm, the torso was within 40 cm and the hands within the 10 cm exclusion zone. In the event that the equipment cannot be operated whilst adhering to these measured restricted access areas or exclusion zones, modelling of the induced electric fields in the body and comparisons with CEMFAW Exposure Limit Values should be considered, to allow this practice to be in compliance with EMF regulations and therefore be allowed to continue.

5.2.2 MPI Benches

Magnetic field strengths exceeded the CEMFAW low Action Levels (applicable to the head), high Action Levels (applicable to the torso) and limb Action Levels (applicable to the arms, legs and hands) in regions around the MPI when operated.

The specific separation distances, at which compliance with the Action Levels is achieved, for the particular equipment presented in this report were head – 40 cm, torso – 20 cm and limbs - 5 cm.

If this was to be applied to other MPI benches of a similar design, it is again common practice to double these distances to allow for site-to-site variability. Hence, these compliance separation distances for benches of a similar design become head – 80 cm, torso – 40 cm and limbs - 10 cm.

Applying access restrictions for the MPI benches for these separation distances, effectively achieved by installing physical barriers (although, similar to demagnetisers, suitable floor markings can be considered as an alternative), would make it very difficult to operate the equipment. The operator observed during the assessment was required to be close to components under inspection in order to identify defects in the workpiece.

Hence, the head was within 80 cm, the torso was within 40 cm and the hands often within the 10 cm exclusion zone. In the event that the equipment cannot be operated whilst adhering to these measured restricted access areas or exclusion zones, modelling of the induced electric fields in the body and comparisons with CEMFAW Exposure Limit Values should be considered, to allow this practice to be in compliance with EMF regulations and therefore be allowed to continue.

5.2.3 Yokes

Magnetic field strengths often exceeded the CEMFAW low Action Levels (applicable to the head), high Action Levels (applicable to the torso) and limb Action Levels (applicable to the arms, legs and hands) in regions around the yokes when operated.

The specific worst-case separation distances, at which compliance with the Action Levels is achieved, for the particular yokes presented in this report were head – 20 cm, torso – 8 cm and limbs - 2 cm.

If this was to be applied to other yokes of a similar design, it is common practice to double these distances to allow for site-to-site variability. Hence, these compliance separation distances for yokes of a similar design become head – 40 cm, torso – 16 cm and limbs - 4 cm.

Applying access restrictions for the yokes for these separation distances, possibly achieved by installing physical barriers (such as equipment guards, longer handles etc), would effectively mean that the equipment could not be operated. The operator was required to be close to components under inspection in order to identify defects in the workpiece.

Hence, the head was typically within 40 cm, the torso was within 16 cm and the hands always within the 4 cm exclusion zone.

In the event that the equipment cannot be operated whilst adhering to these measured restricted access areas or exclusion zones, modelling of the induced electric fields in the body and comparisons with CEMFAW Exposure Limit Values should be considered, to allow this practice to be in compliance with EMF regulations and therefore be allowed to continue.

5.2.4 Coils

Magnetic field strengths exceeded the CEMFAW low Action Levels (applicable to the head), high Action Levels (applicable to the torso) and limb Action Levels (applicable to the arms, legs and hands) in regions around the coils when operated.

The specific worst-case separation distances, at which compliance with the Action Levels is achieved, for the particular coils presented in this report were head – 40 cm, torso – 25 cm and limbs 5 cm.

If this was to be applied to other coils of a similar design, it is common practice to double these distances to allow for site-to-site variability. Hence, these compliance separation distances for coils of a similar design become head – 80 cm, torso – 50 cm and limbs 10 cm.

Applying access restrictions for the coil for these separation distances, effectively achieved by installing physical barriers (such as guards etc), would make it difficult to follow the operating procedure. It is understood that again the operator was required to be close to components under inspection in order to identify defects.

Hence, the head was typically within 80 cm, the torso was within 50 cm and the hands within the 10 cm exclusion zone.

In the event that the equipment cannot be operated whilst adhering to these measured restricted access areas or exclusion zones, modelling of the induced electric fields in the body and comparisons with CEMFAW Exposure Limit Values should be considered, to allow this practice to be in compliance with EMF regulations and therefore be allowed to continue.

5.3 Considerations for NDT EMF Exposure

It is important that these exclusion zones are adhered to, when the NDT equipment is being operated. The particular employer should carry out its own risk assessment for any work, similar to other risk assessments the employer has previously implemented.

Options that an employer should consider for such a risk assessment include:

5.3.1 Guarding and Exclusion Zones

Guarding, or the introduction of an exclusion zone is an inexpensive and effective method of restricting access to potentially high field regions – hence it has been recommended as the primary protection measure in this report. As mentioned previously, field strengths fall rapidly with distance from the source of the field, so the use of guarding or exclusion zones to restrict access to the immediate vicinity will often be a practical option. With knowledge of the field distribution, it is relatively straight forward to provide an effective solution. Where there is no need to gain access to the restricted area in normal operation, then fixed guards will often be the simplest and cheapest solution. Where physical barriers are not practical, boundary lines marked on the floor can be effective. However, where operators need to be close to the NDT equipment and exclusion zones prevent this from being practical (e.g. holding a yoke), guarding and exclusion zones are not a viable option.

5.3.2 Shielding

Shielding can provide an effective means to reduce electromagnetic fields produced by a source and can be incorporated into the design of equipment in order to limit exposure. Shields can also be applied to enclosures to produce a weak electromagnetic environment. However, it is recognised in these NDT situations that shielding of low frequency magnetic fields is challenging, and may prevent the equipment from operating correctly.

5.3.3 Sensitive Protection Equipment

The use of sensitive protective equipment (such as light curtains, scanning devices and pressure sensitive mats) is an option where it is not practicable to install fixed or moveable guarding. The equipment can detect entry into or the presence of someone in an area of strong fields and can prevent the operation of equipment generating electromagnetic fields. Sensitive protective equipment makes use of a range of detection technologies, which will vary in their suitability for any particular situation.

5.3.4 Safety Signs and Notices

Safety signs and notices form an important part of any system of organisational measures. They are obviously only effective if they are clear and unambiguous. Signage should be placed at eye level to maximise their visibility and the nature of the hazard should be clearly indicated. Example pictograms relevant to electromagnetic fields are shown in the various figures along with their recognised meanings. In general, it is appropriate to add a supplementary text notice to aid comprehension.

5.3.5 Site Safety Information

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

5.3.6 Supervision and Management

General advice states that electromagnetic field safety should be managed through the same health and safety management structure as other potentially hazardous activities. The detail of the organisational arrangements varies according to the size and structure of the organisation. Where fields are sufficiently strong to require specific management, it is recommended that a knowledgeable member of staff is given the task of supervising the day-to-day aspects of EMF safety in the workplace, should problems occur.

5.3.7 Adoption of Good Working Practices

It is often possible for workers to minimise the generation of strong fields or reduce their exposures through adopting simple changes to their work practices, e.g. the adherence to exclusion zones around equipment.

5.3.8 Coordination Between Employers

It may be necessary within a working environment for workers from more than one employer to work in the same location. Because of this, there should be an exchange of information between the employers so that all workers are adequately protected.

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

5.3.9 Emergency Response

A pragmatic approach by an employer may be to put into place an emergency plan to deal with an individual experiencing adverse health effects from EMF exposure, e.g. interference with the implanted pacemaker or defibrillator of worker at particular risk / contractor / visitor etc near NDT equipment when operated.

It is assumed that employers already have general emergency plans in place and it may be possible to cover potential adverse incidents arising from EMFs through these existing arrangements.

Emergency plans may include arrangements for administering first aid and subsequent medical examination. In any event, the level of detail and the complexity of the plans depends on the risk. In general, it is good practice to rehearse emergency plans to identify deficiencies and keep them fresh in the mind. The response to any adverse incident will inevitably be dynamic and informed by its nature and severity. The list below illustrates a typical sequence of events in the response to an incident. Not all the actions will necessarily be appropriate for every adverse incident.

- Incident starts
- Make Incident Safe: remove person from the hazard, keep other people away from the hazard
- Assess the need for first aid and administer if required
- Inform management: Arrange medical examination/treatment if appropriate, prevent continuation of work pending investigation results. If possible, preserve scene for subsequent investigation, prepare preliminary incident report
- Investigation by H&S Personnel: Estimate magnitude of exposure, identify root causes of incident
- Report incident to Health and Safety Executive if appropriate: Requirement to report dependent on severity of incident, provide written report if required
- Review and revise risk assessment: Identify why risk of adverse incident was not identified and/or preventative/protective measures inadequate
- Implementation of measures to prevent a recurrence

5.4 Recommendations

5.4.1 Identification of Other Potential High Field Sources in NDT

As can be seen, this is not a comprehensive review of NDT devices - the array of NDT equipment giving rise to strong fields presented in this report is limited. We are not specialists in the NDT sector; therefore, we have little experience in both the amount of NDT equipment generating significant fields, how the NDT equipment is used by operators on a day-to-day basis, and the array of field strengths produced. We have reported here some applications where the electrical currents, and hence magnetic fields generated, were at a particular level.

However, we remain unable to confirm that these fields reported are worst-case in the NDT sector (our prediction is these are unlikely to be worst-case). Obviously, for example, a demagnetiser can be of any shape and size, and the strength of the field required to demagnetise an object can be of any strength – depending on the workpiece or component that is required to be demagnetised.

It is hoped that the points raised in this report will give the BINDT and its members a clearer understanding of the issues related to fields generated by NDT equipment. It is recommended that, using this information and discussions at previously held BINDT meetings on the subject, the BINDT and its members can put together a more comprehensive list of NDT devices that may give rise to strong electromagnetic fields. Once these have been identified, they can determine the most appropriate way in which this equipment can be assessed (in terms of EMF exposure) to ensure that hazards related to exposure are minimised.

5.4.2 Computer Modelling of Induced Fields for Comparisons with ELVs

The report presents a number of exposure situations where the CEMFAW Action Levels are exceeded in regions where operators are required or likely to be, to carry out a particular NDT assessment or procedure. Hence, the introduction of an exclusion zone related to EMF measurements is often not a viable solution in these cases.

Recall that non-compliance with a measured CEMFAW Action Level does not necessarily mean that a particular NDT practice is required to stop. The Action Levels are not limits. To reiterate, comparisons with the Action Levels are a 'first check' for compliance, or 'a level at which further action should be taken'. If a field strength at a particular point is in excess of an Action Level, the next step is to compare the exposure with the relevant CEMFAW Exposure Limit Values (which are, by definition, exposure limits).

This involves modelling the induced electric fields in the human body from a particular NDT exposure situation and comparisons with the CEMFAW Exposure Limit Values. Because the ELV are significantly less restrictive that the ALs for the majority of exposure situations, this work is more likely to show compliance with the CEMFAW legislation than measurement assessments alone.

Hence, it is recommended that worst-case and representative exposure situations are modelled for demagnetisers, MPI benches, yokes and coils (and other exposure situations identified that are potentially hazardous). After this, the resultant induced electric fields can be compared with the ELVs to determine exactly what processes are and are not in compliance with the CEMFAW regulations.

5.4.3 Measurement Assessments for Workers at Particular Risk

Note that, for workers at particular risk, the Reference Levels in the Council Recommendation 1999/519/EC are the recommended limits - deemed a level at which interference with a person's cardiac device can occur.

Therefore, computer modelling and comparisons with ELVs do not help in this particular matter. It is recommended that measurement-based assessments are carried out for NDT exposure situations and areas identified where the exposure exceed the Council Recommendation Reference Levels. Then, access to these areas should be restricted to individuals with active implanted or body-worn medical devices, appropriate warning signage and training put in place etc.

If an employee needs to be within a restricted area, the employer has the option to carry out a person-specific assessment, dependent on the individual's situation, to explore the option to permit access to specific workers - where it can be shown that the exposure will not put them at unnecessary risk.

5.4.4 Other control measures

It is recommended that other appropriate control measures, examples of which are listed in Section 5.3, are applied to workplaces involved in NDT practices.

6 Summary

EMFcomp Limited have carried out a brief review of the situation relating to the practice of non-destructive testing (NDT) and other quality testing procedures, alongside the current electromagnetic field (EMF) safety regulations and guidance.

The EMF measurements reported showed that the CEMFAW Action Levels, applicable to occupational exposure, and Council Recommendation 1999/519/EC Reference Levels, applicable to members of the public and workers with active implanted medical devices, can be routinely exceeded near NDT equipment when energised.

Therefore, it is recommended that further work is carried out to ensure the prevention of adverse health effects to people working with or near NDT equipment, from exposure to the magnetic fields generated.

Produced by: Richard Findlay **Date Produced:** 8 October 2020

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6 References

EC 1999 European Council Recommendation: On the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) Health Official Journal of the European Communications 199 59-70

EC 2015 Non-binding guide to good practice in implementing Directive 2013/35/EU Electromagnetic Fields – Volume 1 – Practical guide European Commission Employment, Social Affairs & Inclusion Publication

EU 2013 Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) Official Journal of the European Union L179/1 1-21

HSE 2016a The Control of Electromagnetic Fields at Work Regulations 2016 www.legislation.gov.uk/uksi/2016/588/pdfs/uksi_20160588_en.pdf

HSE 2016b A Guide to The Control of Electromagnetic Fields at Work Regulations 2016 www.hse.gov.uk/pubns/priced/hsg281.pdf

ICNIRP 1998 Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz) Health Phys. 74 494-522

ICNIRP 2009 Guidelines on limits of exposure to static magnetic fields Health Phys. 96 504-514

ICNIRP 2010 Guidelines for limiting exposure to time varying electric, magnetic fields (1 Hz to 100 kHz) Health Phys. 99 818-836

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