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# Magnetic Fields of Induction Heaters in the Framework of Directive 2004/40/EC of the European Parliament and of the Council

Gilbert Decat
Leo Deckx
Guy Meynen

VITO, Mol, Belgium

Emmy De Graef

Umicore, Hoboken, Belgium

Florence Jonlet

CBMT, Liège, Belgium

*The spectrum and the polarization of the magnetic flux density (B-field) of 6 induction heaters and 1 arc oven were measured by means of a PMM (Italy) spectrum analyser. The spectrum analysis showed that no substantial harmonics were observed while the polarization analysis revealed that the operator's exposure was non-homogeneous within a distance of 1.5 m from the heater. When the distance was larger, the body was homogeneously exposed. In general we can state that the B-field strongly varied between heaters and that exposure exceeded the occupational reference levels recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) (1998) and European Directive 2004/40/EC in 5 of the 7 heaters. Within the framework of the Directive some protection actions should be taken. Whereas mitigation of existing/old induction ovens is difficult, the design of new induction heaters and their housing should be based, among others, on electromagnetic reducing engineering concepts.*

electromagnetic field    occupational exposure    high exposure sources    mitigation

## 1. Introduction

Since the publication of European Parliament/Council Directive 2004/40/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from electromagnetic fields [1], the industrial safety staff has been much more concerned about electromagnetic field exposure than before. Induction heating is an industrial technology [2] associated with high magnetic flux densities (B-fields). Induction heaters and furnaces operate at various frequencies (50 Hz–3 MHz) and are used to heat metals in industrial processes, such as melting, surface hardening, tempering, annealing, soldering, glass-to-metal sealing and fatigue testing [3].

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Correspondence and requests for offprints should be sent to Gilbert Decat, Integral Environmental Studies, VITO, Boeretang 200, BE-2400 Mol, Belgium. E-mail: <gilbert.decat@vito.be>.

Since operators of low frequency induction heaters may be exposed to high B-fields, these fields have to be measured according to a well-balanced protocol taking into account all exposure factors (oven parameters, exposure duration, field orientation and frequency analyses) required for compliance testing and possible mitigation. In this respect, the present data deal with a measurement of the B-field from six low frequency induction heaters and one large arc oven, which are used for melting silver, gold, waste and steel.

## 2. PRINCIPLE OF INDUCTION HEATING

Figure 1 is a schematic representation of the induction heating technique.

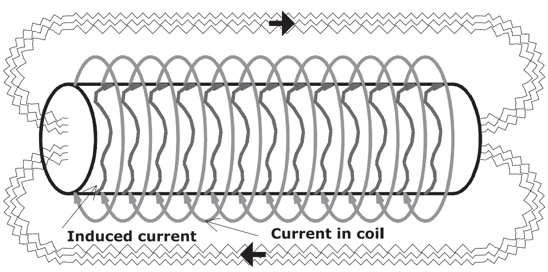


**Figure 1. Principle of induction heating.**

An induction heater consists of an AC power supply, an induction heater, an induction coil and the material to be heated or melted. In the operation mode, the current of the coils which surround the material under treatment produces strong eddy currents into the material (Ag, Au, waste, metal or steel), which in turn generate the amount of heat necessary to fulfil the required process.

## 3. METHODS

### 3.1. Description of the Heater Sample

As shown in Table 1 the heater sample consisted of six different types of induction heaters and one arc oven.

The first four heaters were small and, except for the waste heater (No. 4), were used for melting silver and gold. The steel melting heaters (No. 5–7)—and consequently the magnitude of their power—were substantially higher. The operating frequency of the heaters varied from 300 Hz up to 9 kHz.

### 3.2. Field Polarization

Figure 2 gives a schematic representation of the way an operator is exposed as a function of the **X**-, **Y**-, **Z**-field vector components and how the resultant ($R_{rms}$) is derived from the vector magnitude.

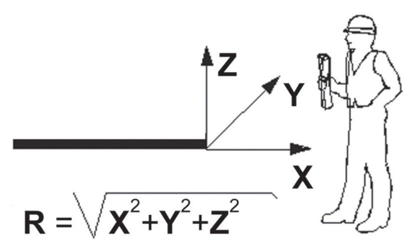


**Figure 2. B-field polarization and resultant (*R*) calculation.**

**TABLE 1. Characteristics and Applications of the Induction Heaters and the Arc Oven**

| | | Power (kW) | | Frequency | | |
|---|---|---|---|---|---|---|
| ID | Heater Type | Nominal | Operating | Nominal | Operating | Application |
| 1 | D-266 | 450 | 60% | 300 Hz | 300 Hz | silver melting |
| 2 | D-330 | 800 | 90% | 3–3.3 kHz | 3 kHz | gold melting |
| 3 | D-340 | 800 | 60% | 3–10 kHz | 9 kHz | gold melting |
| 4 | bullion | 200 | 90% | 1 kHz | 1 kHz | waste melting |
| 5 | 2.5 ton | 2600 | ? | 500 Hz | 500 Hz | steel melting |
| 6 | 2 ton | 1800 | ? | 1 kHz | 1 kHz | steel melting |
| 7 | arc | ? | ? | 500 Hz | 50 Hz | steel melting |

*Notes*. ID—identification number.

For all heaters, field polarization was performed by positioning an EHP 50A probe (PMM, Italy) (Table 2) always in the same direction: the orientation of the Y-sensor was always perpendicular to the front plan of the induction heater. In this way the magnitude of the **X**-, **Y**-, **Z**-vectors was recorded as a percentage of the B-field resultant at operator distance from the induction heater.

### 3.3 Spectrum Analysis

All measurements were performed by means of a PMM 8053 portable field meter (PMM, Italy) (Table 2) connected to an EHP 50A electrical and magnetic field spectrum analyser (Table 3).

By means of this equipment we were able to perform a spectral analysis of the B-field in the frequency range of 5 Hz up to 100 kHz. The PMM equipment offered the possibility to select the span between the following values: 100, 200, 500, 1, 2, 10 and 100 kHz. The selected span indicated the maximum spectrum frequency, whereas the minimum spectrum frequency was about 1.2% of the selected one. The minimum frequency was never below 5 Hz.

## 4. RESULTS AND DISCUSSION

Table 4 summarizes the main oven characteristics, the application, the exposure characteristics and the magnitude of the B-field at the position that an operator most often works or watches from.

**TABLE 2. Specifications of the EHP 50A Magnetic Field Analyser (PMM, Italy)**

| Description | Specification |
|---|---|
| Frequency range | 5 Hz–100 kHz |
| Level range | 10 nT–10 mT |
| Dynamic | >120 dB |
| Resolution | 1 nT |
| Sensibility | 10 nT |
| Absolute error | ±0.8 dB (@ 50 Hz and 0.1 mT) |
| Flatness (40 Hz–10 kHz) | ±0.5 dB |
| Isotropicity | ± 1 dB |
| Electric field rejection | >20 dB |
| Magnetic field rejection | 1 nT |
| Calibration | 10 nT |
| Temperature error | 0.05 dB/°C |

**TABLE 3. Specifications of the PMM 8053 Portable Field Strength Meter (PMM, Italy)**

| Description | Specification |
|---|---|
| Frequency range | 5 Hz–18 GHz |
| Dynamic range | >100 dB |
| Operation range (E-field) | 0.03 V/m–100 kV/m |
| Operation range (H-field) | 10 nT–10 mT |
| Resolution | 0.01–100 V/m |
| | 0.1 nT–0.1 mT |
| Sensitivity | 0.1–1 V/m |
| | 10 nT–0.1 mT |
| Sample rate | 1, 10, 100 s every 6 min |
| Units | V/m, kV/m, μW/cm$^2$, mW/cm$^2$, W/m$^2$, A/m, nT, mT |

**TABLE 4. Exposure Parameters and *B*-Field Strength**

| | | | | | *B*-Field Exposure (μT) | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Heater Type | FO | *OT* (min) | *OD* (m) | $R_{rms}$ | x% | y% | z% |
| 1 | D-266 | irregular | 60 | 0.30 | 20 | 6 | 85 | 9 |
| 2 | D-330 | irregular | 60 | 0.30 | 107 | 7 | 51 | 43 |
| 3 | D-340 | irregular | 60 | 0.20 | 35 | 4 | 47 | 49 |
| 4 | bullion | irregular | 45 | 0.10 | 309 | 44 | 39 | 17 |
| 5 | 2.5 ton | continuous | 45 | 0.15 | 60 | 20 | 70 | 10 |
| 6 | 2 ton | continuous | 60 | 0.60 | 29 | 8 | 87 | 5 |
| 7 | arc | continuous | 90 | 0.40 | 113 | 38 | 35 | 27 |
| | | *M* | 60 | 0.10 | 96 | 29 | 48 | 23 |
| | | *SD* | 15 | 0.14 | 101 | 29 | 26 | 17 |

*Notes*. *B*-field—magnetic flux density, ID—identification number, FO—frequency of operation, *OT*—operating time, *OD*—operator distance.

The standard deviation of the mean shows that there is a substantial variation in the operating time, operator distance and consequently *B*-field strength from which the resultant ($R_{rms}$) varies from 20 μT to 0.31 mT.

Table 4 shows that the use of most heaters was irregular. Though the knowledge of the operation frequency and the duration of the operator's work are very important parameters for exposure assessment, these data are often lacking. Therefore, and in the framework of the new European Directive [1], it is very important that operators fill up an exposure logbook with all data that are needed for reliable exposure assessments in all kind of industries.

### 4.1. Field Polarization

The **X**-, **Y**-, **Z**-vector analysis roughly indicates that when operators work within a distance of about 1.5 m, with their chest in the direction of the heater, the predominant exposure axis is the **Y**-vector.

On average, 48% of the operator's exposure takes place via the *y* axis. This means that the chest and abdomen are most exposed and that the exposure of the hips (**X**-vector: 29% of *R*) and the head (**Z**-vector: 23% of *R*) is weaker. As shown by the vector polarization of the arc oven (No. 7) the magnitudes of the horizontal and vertical vectors come closer to each other when the radial distance between the sources and the operator increases. In this case polarization becomes more spherical so that the exposure of the whole body of the operator becomes more homogeneous, yet weaker, because the *B*-field of coils decreases with the cube of the distance ($1/r^3$).

### 4.2. Spectrum Analysis

Figures 3 to 8 show the oven types and the corresponding spectral analyses of the *B*-field. Since spectral analysis has sometimes been performed at a more convenient place than the operator mentioned in Table 4, the *B*-field value in the table may be different from the wide band *B*-field value indicated on the associated chart of the frequency spectrum.

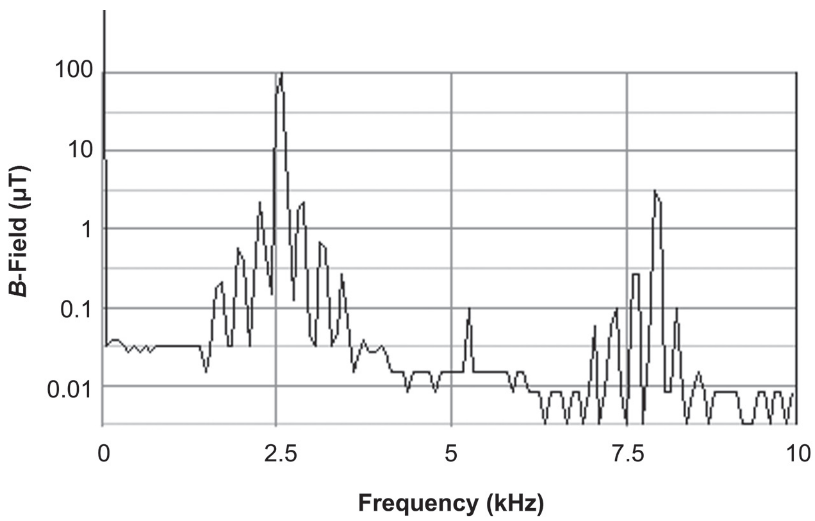


**Figure 3. Spectral analysis of induction heater No. 2.** *Notes*. Wide band: 107 μT, *B*-field—magnetic flux density.

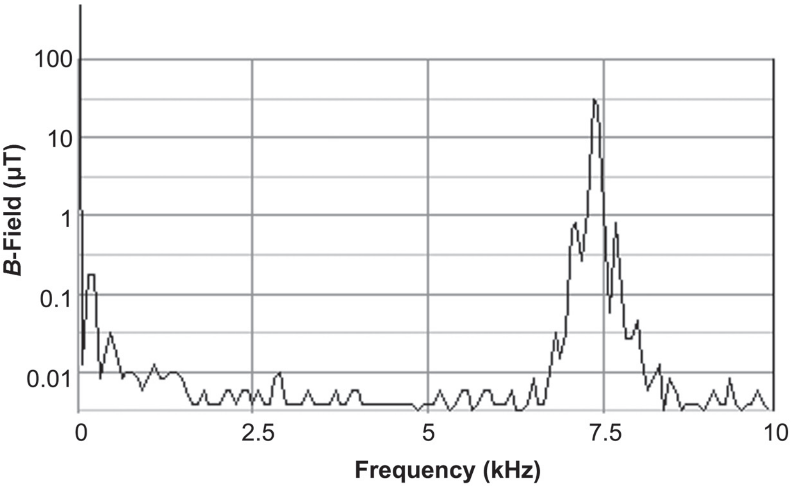


**Figure 4. Spectral analysis of induction heater No. 3.** *Notes*. Wide band: 107 µT, *B*-field—magnetic flux density.

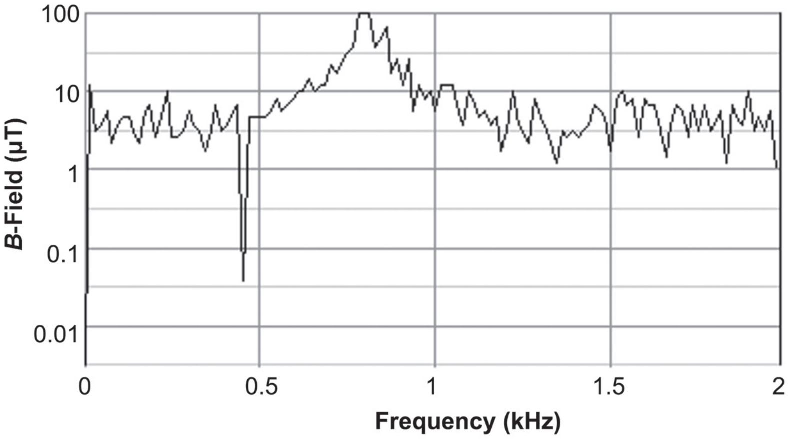


**Figure 5. Spectral analysis of induction heater No. 4.** *Notes*. Wide band at 70 cm from heater: 303 µT, *B*-field—magnetic flux density.

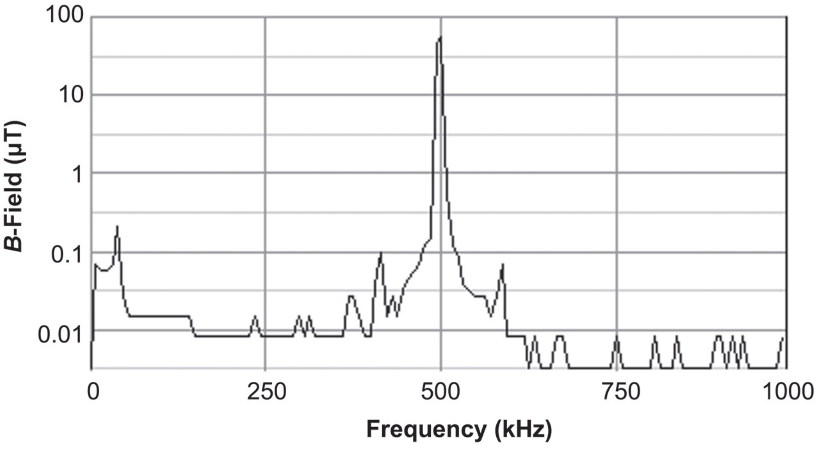


**Figure 6. Spectral analysis of induction heater No. 5.** *Notes*. Wide band at 60 cm from heater: 60 µT, *B*-field—magnetic flux density.

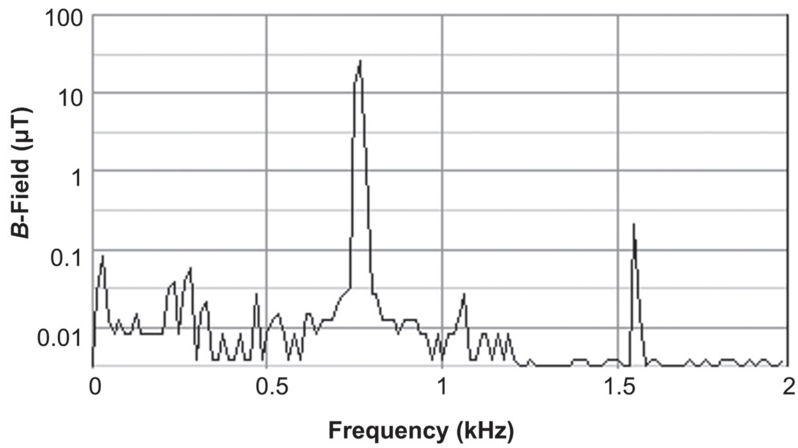


**Figure 7. Spectral analysis of induction heater No. 6.** *Notes*. Wide band at 30 cm from heater: 28 µT, *B*-field—magnetic flux density.

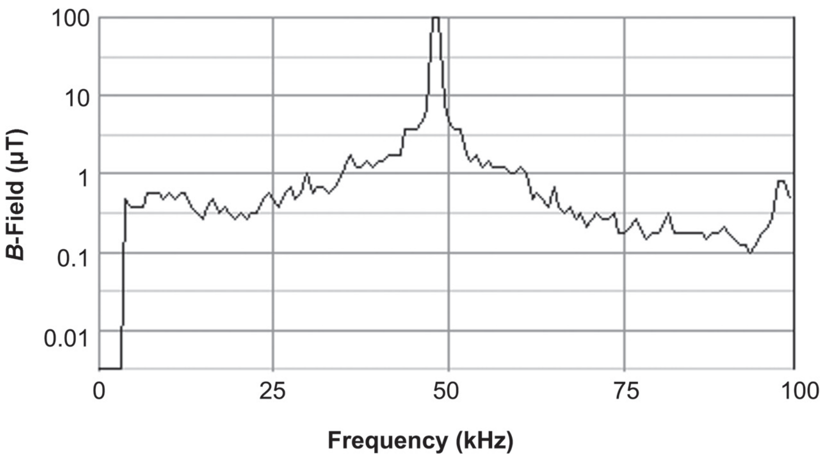


**Figure 8. Spectral analysis of induction heater No. 7.** *Notes*. Wide band at 4 m from heater: 116 µT, *B*-field—magnetic flux density.

Figure 3 shows that the magnitude of the wide band B-field at operator distance was 107 µT with the peak level at the fundamental frequency of 2.5 kHz and some smaller peaks around the second harmonic of about 7.5 kHz. Though harmonic filters are generally placed in the front (cancel the harmonics of the mains) and the back (cancel the harmonics of the converter) of the frequency converter, it seems that they are not completely filtered out. Anyway, as shown in Figure 3, the second harmonic is about 5 µT, which is in compliance with the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [4] exposure limit of 30.7 µT.

## 4.3. Measured Data Versus ICNIRP Reference Levels

Figure 9 shows that the strength of the observed B-field ($R_{rms}$) at operator distance often exceeds the reference levels recommended by ICNIRP [4] for occupational exposure.

Only the B-field of the two heaters with an operating frequency of less than 500 Hz does not exceed their associated ICNIRP reference levels respectively.

The reference levels and the base restrictions of ICNIRP [4] are the same as the action values and the exposure limit values of the Directive 2004/40/EC [1] respectively. Therefore, for the cases when the action values are exceeded, Directive 2004/40/EC recommends that the employer shall

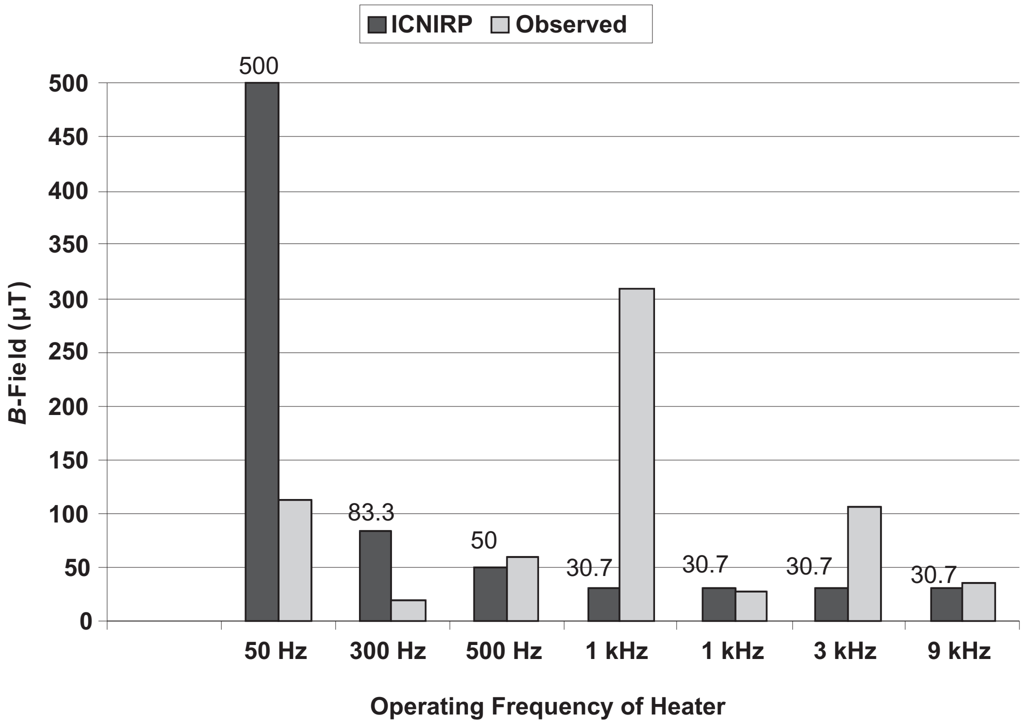


**Figure 9. Observed B-field versus the corresponding exposure reference levels of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [4].**

implement an action plan comprising technical and/or organizational measures intended to prevent exposure exceeding the limit values and taking into account in particular

(a) other working methods that entail less exposure to electromagnetic fields;
(b) the choice of equipment emitting less electromagnetic fields, taking account of the work to be done;
(c) technical measures to reduce the emission of electromagnetic fields including, where necessary the use of interlocks, shielding or similar health protection mechanisms;
(d) appropriate maintenance programs for work equipment, workplaces and workstation systems;
(e) the design and layout of workplaces and workstations;
(f) limitation of the duration and intensity of the exposure;
(g) the availability of adequate personal protection equipment (p. 10–11).

As for existing heaters, which were designed and installed before the occupational EMF-concept was industrially introduced or recognized, the measures in items b, c, e and g are hardly feasible. Since the strength of the B-field of coils decreases with the cube of the radial distance ($1/r^3$), enlarging the distance between the heater and the operator (without production loss) is the most efficient and least expensive mitigation solution. However, it supposes that the installation room/hall/workplace is large enough for this action. Unfortunately, small induction heaters are often installed in rather small melting rooms where distance-related B-field reduction cannot be applied. Therefore, and in the framework of Directive 2004/40/EC [1], it is important to introduce the EMF-reducing engineering concept (i.e., simulation and optimization modeling) in the design of new heaters, on the one hand, and the architecture of the installation place, on the other hand. This concept should be applicable for all kinds of high EMF-emitting occupational sources and installations [5]. As for item g, passive mitigation by placing a ferromagnetic (μ-metal or steel) or a high conductive (Al and Cu) screen[1] between the operator and the heater limits/reduces the working ability of the operator. Therefore, and though it is a difficult task, one should think about the development of B-field partial or whole-body reducing clothing in the ELF (extremely low frequency) and IF (intermediate frequency) frequency ranges respectively.

## 5. CONCLUSIONS

The polarization analyses showed that the body was not homogeneously exposed at an operator –heater distance shorter than 1.5 m but that it was at over 1.5 m. Spectral analyses showed that the observed harmonics had no weight and were consequently of no importance in the totality of the exposure.

The comparison of the measured B-fields with the reference level of ICNIRP [4] guidelines and the action values of Directive 2004/40/EC [4] revealed that some safety actions should be undertaken to protect workers more efficiently against the B-field of the induction heaters and arc ovens. However, only a few actions based on reducing exposure time can be undertaken; active and passive shielding are difficult to apply in existing induction heaters. Since existing induction heaters are most often installed in small melting rooms, B-field reduction by lengthening the distance between the operator and the heater is mostly unfeasible. The development of low frequency protecting clothing should be encouraged and, last but not least, simulation models should be the basis for optimizing EMF exposure in the development of new induction heaters and their housings.

## REFERENCES


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[1] The shielding efficiency ($SE_{dB}$) of a screen depends on the reflection ($R_{dB}$) and the absorption ($A_{dB}$) characteristics of the material: $SE_{dB} = R_{dB} + A_{dB}$, where $R_{dB} = 14 \bullet 6 \bullet 10 \log_{10} \frac{\mu_r}{f\, r^2 \sigma_r}$ and $A_{dB} = 1.3 t \sqrt{f \mu_r \sigma_r}$. The shielding factors $\mu_r$, $f$, $r$, $\sigma_r$ and $t$ are the relative permeability of the material, the wave frequency, the radial distance to the source, the relative conductivity, and the thickness of the screen, respectively.