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The European Directive 2004/40/EC related to microwave exposure in the workplace: a case study

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1 INTRODUCTION

Recently, the European Parliament/Council launched the Directive 2004/40/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from Electromagnetic Fields (EMF's) in the frequency range from 0 Hz to 300 GHz. The Directive refers to the risk for the health and safety of workers due to known short-term effects. These effects are caused by induced currents for what about low frequency fields on the one hand and by energy absorption for what about high frequency radiation such as radiofrequency and microwaves. The Directive doesn't take into account long-term effects.

The Directive consists of 15 articles which have to be taken into account by the employer when the directive will be implemented in April 2008. The articles are summarized in Directive [1] given in the annex of the proceedings.

At present there is a lack of data about the compliance of the leakage radiation of industrial microwave ovens with the emission standard IEC (1983) [2] and exposure standards of the Directive 2004/40/EC respectively. On the basis of of a study case we want to gain some insight in this problematic by testing the leakage radiation of an industrial microwave oven on its compliance to the IEC emission standard and the action value of the Directive 2004/40/EC respectively.

2 DIRECTIVE 2004/40/EC VERSUS ICNRIP GUIDELINE (1998)

Though the exposure limit values of the Directive are the same as those given in the ICNIRP Guideline [3], the nomenclature is different. As shown in table 1, the exposure limit values and action values of the Directive correspond to the basic restrictions and reference levels of ICNIRP (1998)

Table 1: Directive versus ICNIRP nomenclature

Directive 2004/40/EC	**ICNIRP(1998)**
Exposure Limit Values	**Basic restrictions**
Limits on exposure to EMF which are based directly on established health effects and biological considerations.	
Action Values	**Reference levels**
The magnitude of directly measurable parameters at which one or more of the specified measures in this Directive must be undertaken. Compliance with these values will ensure compliance with the relevant exposure limit values.	

Table 2 shows the exposure limit values of the directive 2004/40/EC in the frequency range 0 Hz – 300 GHz.

Table 2: Exposure limit values

Frequency range	Current density for head and trunk J (mA/m²) (rms)	Whole body average SAR (W/kg)	Localised SAR (head and trunk (W/kg)	Localised SAR (limbs) (W/kg)	Power density S (W/m²)
Tot 1 Hz	40	-	-	-	-
1 – 4 Hz	40/f	-	-	-	-
4 – 1 000 Hz	10	-	-	-	-
1 - 100 kHz -	f/100	-	-	-	-
100 kHz – 10 MHz	f/100	0,4	10	20	
10 MHz – 10 GHz ***(2450 MHz microwaves)***	-	0,4	10	20	
10 – 300 GHz	-	-	-	-	50

SAR: specific absorption rate
F: frequency in Hz

Depending on the frequency the following physical quantities are used to specify limit values of EMF:

1. exposure limit values are provided for current density for time-varying fields up to 1 Hz, in order to prevent effects on the cardiovascular and central nervous system
2. between 1 and 10 MHz exposure limit values are provided on current density in order to to prevent effects on central nervous system functions
3. between 100 kHz and 10 GHz exposure limits on SAR are provided in order to prevent whole-body heat stress and excessive localised heating of tissues. In the range 100 kHz to 10 MHz exposure limit values on both current density and SAR are provided.
4. between 10 GHz and 300 GHz an exposure limit value on power density is provided in order to prevent excessive tissue heating at or near the body surface.

For what about the industrial microwave ovens which operate at a frequency band of 2450 MHz, point 3 has to be applied. Thus, if non-compliance of measured leakage radiation with the action value is decided, the SAR has to be calculated in order to decide if the whole-body heat stress and excessive heating of tissues conform with the exposure limits given in table 2.

In case of the 2450 MHz microwave leakage radiation, the SAR has to be averaged over every six-minute period. The localised SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR thus obtained should be the value used for estimating exposure. These 10 g of tissue are intended to be a mass of contiguous tissue with nearly homogeneous electrical properties.

Since the current density and the SAR are calculation metrics for setting basic restrictions (ICNIRP, 1998) or exposure limits (directive 2004/40/EC), reference levels (ICNIRP) or action values (2004/40/EC) were obtained from the basic restriction by mathematic modelling and by extrapolation from the results of laboratory investigation at specific frequencies. Compliance testing is based on the comparison of the measured EMF quantities (electric field (E), magnetic field (H), magnetic flux density (B) and power density S) with the action values of the directive.

Table 3 shows the action values for the electromagnetic fields in the frequency range of 0 Hz – 300 GHz.

Table 3: Action values

Frequency	Equivalent plane wave power density [S_{eq} (W/m²)]	Electric field (kV/m)	Magnetic flux density (µT)
10 – 110 MHz	10	0,61/f	2/f
110 – 400 MHz	10	0,061	0,2
400 – 2000 MHz	f/40	$0{,}003f^{1/2}$	$0{,}01f^{1/2}$
2 – 300 GHz 2450 MHz (microwave ovens)	***50***	*0,137*	*0,45*

The action values referring to the frequency of 2450 MHz industrial microwave ovens are situated in the 2 to 300 GHz range of table 3. The action value of 50 W/m² is intended to be spatially averaged over the entire body of the exposed individual but with the important proviso that the basic restriction or exposure limit values on localized exposure are not exceeded.
This means that the average whole body leakage irradiation exposure of the operator and/or surrounding other workers may not exceed a power density of 50 W/m² (5 mW/cm²). This value corresponds with an electric field of 137 V/m and a magnetic flux density of 0,45 µT. Thus, if an adequate exposure assessment of the microwave oven under test reveals that the limit of 50 W/cm² has been exceeded the employer has to undertake some actions in order to reduce the radiation leakage to a level below the limit. The most plausible and often the most efficient action is passive mitigation by sealing the oven fissures by means of microwave absorbing rubber. If this action fails, the employer has to undertake some other

adequate actions in order to keep the possible risk of the microwave exposure as low as possible.

3 EMISSION STANDARDS VERSUS EXPOSURE LIMITS FOR MICROWAVE LEAKAGE RADIATION

Whereas emission standards are limits intended for the constructors of microwave ovens, exposure limits are intended for workers and the general public respectively. Both standards aim to protect people against the possible reverse effects of leakage radiation. Whereas there is an emission standard for household microwave ovens (50W/m for 2450 MHz ovens in use) [2] it doesn't exist for industrial microwave ovens.

Whereas the directive 2004/40/EC recommends only occupational action values, the ICNIRP guideline (1998) recommends basic restriction and reference levels respectively for workers as well as for the general public. The microwave (2 GHz – 300 GHz) reference levels recommended by ICNIRP(1998) are 50 W/m² (5 mW/cm²) and 10 W/m² (1 mW/cm²) for the exposure of workers and the general public respectively. This means that the general public reference level should be 5 times smaller or stronger than the occupational reference level for microwaves in the 2450 MHz frequency band. By extrapolating the factor 5 difference between both groups from exposure limits to emission standards, the emission standard for industrial microwave ovens should be 5 times the 50 W/m² emission standard for household microwave ovens which is intended for the general public. Such an extrapolation would enhance an emission standard for industrial microwave ovens of 250 W/m². By applying such an extrapolation the emission standard for industrial microwave ovens should be 250 W/m². Anyway, in the absence of theoretical or experimental evidence that this value may be applied, in the present case study we tested compliance against the 50 W/m² emission standard for household microwave ovens.

By applying the quadratic law based on the plane wave theory, we derive that an emission standard of 50 W/m² (5 mW/cm²) at 5 cm from the oven corresponds to an exposure level of about 3 W/m² (0,3 mW/cm²) at operator distance of about 20 cm from the oven.

Notice that at present no data are available on the relation between emission standards and the reference levels or action values of the exposure standards.

4 COMPLIANCE TESTING OF RADIATION LEAKAGE OF INDUSTRIAL MICROWAVE OVEN: A CASE STUDY

Though the operators and industrial safety staff should be aware of the power density of the leakage radiation of industrial microwave ovens up to now their knowledge is rather inadequate and superficial. In contrast to household microwave ovens [4 - 7] data on leakage radiation of industrial microwave ovens are scarce.
The present study case deals with the compliance testing of the leakage radiation at a distance of 5 cm from the radiation hot spots of a 2450 MHz CERA DRY 32 microwave oven provided with 16 microwave power output units of 2 kW each. The oven is used for drying powder for electronic applications.

The measurements were performed according to the IEC-335-2-25 standard (1988)[2] by using a 'Narda Model 8100B Electromagnetic Leakage Monitor' provided with the following measurement NARDA probes:
- model 8120A power density range: 10 µW/cm² to 2 mW/cm²
- model 8121A power density range: 100 µW/cm² to 20 mW/cm²
- model 8122A power density range: 1000 µW/cm² to 200 mW/cm²

In a first step the oven was scanned with the adequate probes in order to determine the oven points with the maximum leakage radiation: these points were found at the corners of the oven splits.

Figure 1 shows the power density (mW/cm²) averaged over 6 minutes at a distance of 5 cm from the points where the leakage radiation was highest.

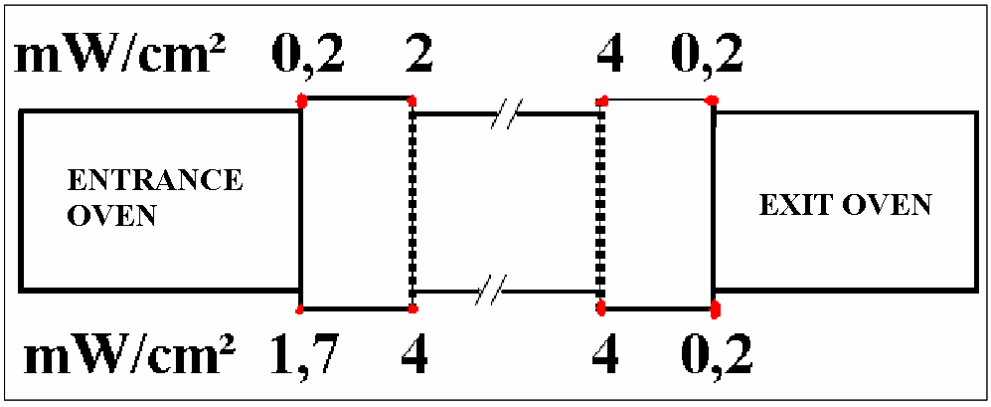

Figure 1: Power density of radiation leakage of Cery Dry microwave oven

By comparing these data with the emission standard limit of 5 mW/cm² at 5 cm from the oven, it is concluded that the leakage radiation is conform with this standard. Moreover, all measured power density values are in agreement with the 5 mW/cm² (50 W/m²) action value recommended by the directive 2004/40/EC. In agreement to the interpretation of this directive and the ICNIRP-guideline (1998) respectively, no additional measures have to be undertaken by the employer in order to give additional protection to the workers.
However, since the power density in some points are close (4/5th) to the emission standard we have to pay attention to the fact that we are only dealing with a case study which gives only a trend without any degree of certainty about the observed/standard leakage relation. Therefore the sample size is not representative for drawing conclusions about the magnitude of the leakage radiation of all industrial microwave ovens regardless of their being the same or different makes. By lack of repeated measurement on the same and different oven types respectively, we have no knowledge about the reproducibility, variability, certainty and uncertainty of the present results on the one hand and about the real exposure and possibly associated risks of microwave ovens on the other hand. In the framework of the new EC-directive which has to be implemented in April 2008, it is advised that constructors and users of industrial microwave ovens perform a representative microwave exposure assessment [8] in order to evaluate whether the leakage radiation of their microwave ovens is conform with the action value of the directive.

5 REFERENCES

[1] Directive 2004/40/EC of the Europe Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

[2] IEC-335-2-25, 2nd edition (1988), Safety of household and similar electrical appliances. Part 2: Particular requirements for microwave ovens.

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