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STUDY OF EXTREMELY LOW FREQUENCY ELECTROMAGNETIC FIELDS IN INFANT INCUBATORS

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Abstract

Objectives: The aim of the work was to present the results of measurements of extremely low frequency electromagnetic fields (ELF EMF), namely the magnetic flux density, inside infant incubators, and to compare these results with the data published by other authors who point out to a possible association between leukemia or other diseases observed in newborns kept in incubators after the birth and the ELF EMF exposure in the incubator. The measured magnetic flux densities were compared with the reference values for this frequency range indicated in the European Union (EU) recommendations. **Materials and Methods:** The repeated measurements in incubators were made with a calibrated magnetometer EFA 300 in the frequency range of 5-30 kHz. Effective values of magnetic flux densities of ELF EMF were determined taking account of the reference values. **Results:** The results of many repeated measurements showing the values of magnetic flux density in modern incubators with plastic supporting frame, were compared with those obtained in old type incubators with iron skeleton. A power frequency of 50 Hz was detected in the incubator and the ELF EMF values were by over two orders lower than the EU reference values. **Conclusions:** The paper emphasizes the need to take a special care of newborns kept in incubators even if only the sub-reference values are detected. The EU reference values are intended for the adult human population. A baby in an incubator has much smaller dimensions, higher electric conductivity and maybe trigger another mechanism of response to ELF EMF than that indicated in this paper.

Key words:
Electromagnetic field, European Union legislation, Infant incubators, Measurement, Magnetic flux density

INTRODUCTION

The reference papers [1,2,3] discuss the effects of extremely law frequency electromagnetic fields (ELF EMF) on human health and consider the effects of their magnetic component – the value of the magnetic flux density vector $|\vec{B}(\omega)|$. The research carried out by Söderberg et al. [2] is concentrated on babies placed in incubators immediately after birth; G. Anger, a Swedish authority on protection of man against non-ionizing radiation, observed in 1994 that children placed in incubators were exposed to magnetic flux density up to 5.10^{-6} T (T – tesla, unit of magnetic flux density); Ch. Polk of the University of Rhode Island, specializing in studies of effects of EMF on human organisms, reports magnetic flux density reaching in incubators as much as 3.10^{-5} T [2]. The exposure of newborns to ELF EMF in incubators vs. incidence of leukemia has been studied by specialists in the Institute of Environmental Medicine and Department of Medical Epidemiology, Karolinska Institute, Stockholm, Department of Women's and Children's Health, Section

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for Pediatrcs, Uppsala University, Uppsala and Swedish Radiation Protection Institute, Stockholm, Sweden. Statistical data showing the incidence of leukemia as a function of the newborn's sojourn in an incubator do not bring any unambiguous evidence that could indicate a positive relation between ELF EMF magnetic component and the incidence of leukemia in early infancy. Yet the results of research concerning infant incubators should not be generalized because of the assumption [2] that there is some relationship between infants's body exposure to ELF EMF and leukemia. Some studies take it for granted that the exposure to magnetic flux density exceeding $|\vec{B}(\omega)| \geq 4.10^{-7}$T may have certain association with the incidence of leukemia in infancy. It is thought that the exposure to ELF EMF of different intensities and frequencies may be responsible for disorders of the nervous, cardiovascular and immune systems, hematogenesis, and incidence of chronic diseases in the general population of various age groups. There also exists a certain probability of the development of cerebral tumors and leukemia [3].

The assumed mechanism causing the effects of low-frequency electromagnetic fields (including also power frequencies of 50Hz, their sub-harmonic and higher harmonic frequencies) is due to electric conductivity of living human bodies. Electromagnetic fields (considering the effects of the magnetic component of ELF EMF) emitted by electric equipment are assumed to activate electric currents induced in human body which may disturb the function of vital human organs. The following general formula [5] is used to calculate the induced current density J(ω) in human body of constant electric conductivity σ and magnetic flux density vector $|\vec{B}(\omega)|$ – for the case where magnetic field is a prevailing component of ELF EMF – and frequency f is given by relation:

$$|J(\omega)| = |K(\omega)|\frac{r}{2} \text{ and } |K(\omega)| = \sigma\omega\mu|H(\omega)|,$$
$$\text{where } |\vec{B}(\omega)| = \mu|\vec{H}(\omega)| \quad (1)$$

This current density is a function of radius r of human body cross-section, electric conductivity σ of human body, frequency f ($\omega = 2\pi f$), magnetic flux density $|\vec{B}(\omega)|$, permeability μ of environment, $|\vec{H}(\omega)|$ intensity of magnetic field. These values of induced current density are derived from the average electric conductivity σ (ω) of human body. Medical studies show that the electric conductivity of human body varies with age, being the highest in sucklings and small children [4,5].

The alternating magnetic fields can also induce magnetic dipole transitions between electron spin states of atoms and molecules (electron paramagnetic resonance). In addition, these fields can induce transitions between nuclear magnetic spin states (nuclear magnetic resonance). In a typical case, the frequency of transition is a function of the direct current magnetic fields, and the transition rate is proportional to the alternating current field strength. Signals from these transitions have been found to be very useful in determining the concentration of various types of ions for medical diagnosis.

The reference ELF EMF levels to be applied in the countries of the European Union (EU) were set in the Council Recommendation (1999/519 EC) of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields for frequencies 0 Hz–300 GHz [6]. Its content is based on the proposals of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [7]. It has been endorsed by the Commission's Scientific Steering Committee. The framework of the Recommendation has to be regularly reviewed and reassessed in the light of new knowledge and developments in technology as well as of novel applications of sources and practices giving rise to exposure to electromagnetic fields. To assess the compliance with basic restrictions of the Recommendation, the national and European bodies for standardization (e.g., CENELEC = CEN) should be encouraged to develop standards within the framework of the Community legislation for the purposes of equipment designing and testing [6]. The member states have been recommended to keep the reference values of exposure to EMF in the national legislation. According to paragraph III(c) of the Recommendation [6], the member states, in order to facilitate and promote the respect of the basic restrictions for the value of induced current density in human organism, given in its Annex II (L199/64), may take into account criteria, where appropriate, such as duration of exposure, exposed parts of the body, age and health status of the public.

Table 1 includes an extract from the table given in Annex II [6] for maximum admissible induced current densities in human body and the magnetic flux density as a function of frequency. The chosen section is only for very low frequencies from 0 Hz to 1 KHz, including the power frequency. EMF in infant incubators was measured within this range of frequencies.

Table 1. Basic restriction of current density for the frequency range 0–1000 Hz

Frequency f/Hz	Current density $J_{RMS}/A.m^{-2}$
> 0–1	8.10^{-3}
1–4	$8.10^{-3} / f$
4–1000	2.10^{-3}

J_{RMS} – the effective value of induced current density.

The stated current density is the maximum admissible density induced in human tissues. It is calculated with respect to the variable conductivity of human body for 1 cm^2 area perpendicular to the direction of the current induced. The basic restrictions given in Table 1 are set so as to account for uncertainties related to individual sensitivities, environmental conditions, and for the fact that the age and health status of members of the public vary.

Table 2. Reference levels for effective value of Magnetic flux density and Electric Field Intensity – frequency range from 0 to 1000 Hz

Frequency f / Hz	Magnetic flux density B / T	Electric field intensity E / $kV.m^{-1}$
> 0–1	4.10^{-2}	-
1–8	$4.10^{-2} / f^2$	10
8–25	$5. 10^{-3} / f$	10
25–800	$5. 10^{-3} / f$	250 / f
50	$1. 10^{-4}$	5

To illustrate the connection between units of value magnetic flux density $|\vec{B}(\omega)|$ and value of magnetic fields intensity vector $|\vec{H}(\omega)|$ in the systems SI (System international – m.kg.s. and CGS (cm.g.s) the following conversions of units are presented. The conversion of value magnetic flux density vector $|\vec{B}(\omega)|$ from the old unit gauss (G) in CGS into tesla units (T) in the system SI is made by the formula: 1 G = 10^{-4} T. The magnetic flux density vector $|\vec{B}(\omega)|$ is converted to magnetic fields intensity vector $|\vec{H}(\omega)|$ in the system SI by the relation $|\vec{B}(\omega)| = \mu_0 \mu_r |\vec{H}(\omega)|$ [T, $H.m^{-1}$, -, $A.m^{-1}$], where μ_0 is magnetic permeability of vacuum $4\pi.10^{-7}$ $H.m^{-1}$ (H = henri), μ_r is dimensionless relative magnetic permeability, and the unit of magnetic field intensity vector $|\vec{H}(\omega)|$ is $A.m^{-1}$ (A= ampér). The relations applied in the CGS system are $|\vec{B}(\omega)| = \mu_0 \mu_r |\vec{H}(\omega)| = \mu_r |\vec{H}(\omega)|$ [G, -, Oe], $\mu_0 = 1$, μ_r is dimensionless, Oe (oerstedt) is the unit $|\vec{H}(\omega)|$ in the given system. The presented relations apply also to equi-directional vectors $|\vec{B}|, |\vec{H}|$.

The reference levels for ELF EMF given in 1999/519/EC are indicated in Table 2. They are established from the effective (RMS) values of electric field intensities E_{RMS} (ω) and magnetic flux density B_{RMS} (ω). The presented values are only those concerned with low frequencies. No higher reference values are admitted, not even for short-time exposures. In many cases where the reference values are exceeded it is necessary to find the maximum admissible induced current density for human body. The levels are usually not exceeded because there exists only a weak connection between the fields and the human body.

MATERIALS AND METHODS

In connection with the results of the study carried out by Söderberg et al. [2], ELF EMF (i.e., sizes of magnetic flux density $|\vec{B}(\omega)|$) were measured in incubators and additional medical equipment of the Faculty Hospital (Bohunice, Brno, Czech Republic) in the department of intensive care for newborns. The frequency range concerned was that of ELF EMF- power frequency of 50 Hz. The measurement was made with a calibrated magnetometer EFA 300, placed in the incubator. The magnetometer evaluates both the effective $B_{RMS} = B_{ef}$ (values of magnetic flux density vector) and also the maximum value of magnetic flux density vector B_{PEAK}.

The effective values B_{ef} of magnetic induction (corresponding to reference values of EU legislation) in the given place are equal to the radical of the time average of magnetic flux density square with the period $T=\frac{1}{f}$ of the pertinent oscillating magnitude of frequency f. The effective value of magnetic flux density vector is given in the formula:

$$B_{ef} = \frac{1}{T^2} \sqrt{\int_t^{t+T} B^2(t)dt} \text{ , where } |B(t)| = \sqrt{B_x^2(t) + B_y^2(t) + B_z^2(t)} \quad (2)$$

where:

$B_x(t)$, $B_y(t)$, $B_z(t)$ are instantaneous values of rectangular components of the time variable vector **B**(t).

The magnetometer allows selective (16Hz, 50Hz, 60Hz, 400 Hz) as well as broadband measurements (5Hz – 30 kHz). It works within the magnetic induction range 100 nT–10 mT. The magnetometer device has an in-built three-dimensional isotropic probe which allows to analyze magnetic fields without using external probes. It is possible to reach a measuring accuracy of 3–5%, depending on the measuring range in use. The device is provided with an in-built frequency counter, and allows to set limits for optical or acoustical signaling used to monitor limiting values. The detection of measured values can be manual as well as automatic. The data obtained can be transmitted in optical way to a computer to be graphically processed. The maximum sensitivity of the device is 10^{-10} T. The device EFA 300 measures alternate components of magnetic fields.

To detect stationary magnetic fields an extremely sensitive magnetometer VEMA 030 was used. The device analyzes very weak stationary magnetic fields also with sensitivity of 10^{-10} T. The magnetometer was specially developed within the framework of the European project COST 244 designed to monitor effects of ELF EMF on human organisms. In our case, it was used to detect deformed geomagnetic fields within the incubator of older type with iron skeleton.

RESULTS AND DISCUSSION

The first type to be measured was a modern incubator with plastic skeleton. The incubator has an in-built electric equipment for heating, ventilation and illumination. It is connected with further electric instruments placed about 50–100 cm away. In our case it was a breath-supporting device-neonatological fan (Babylog), a volumetric infusion pump and an injection pump. The first value to be measured was the magnetic flux density in the background of the incubator (Fig. 1).

The measurement was made in the incubator room with all electronic devices switched off, including the incubator electric supply. Heating, ventilation and illumination were also switched off. Magnetic flux density of the background reached very small values within the interval

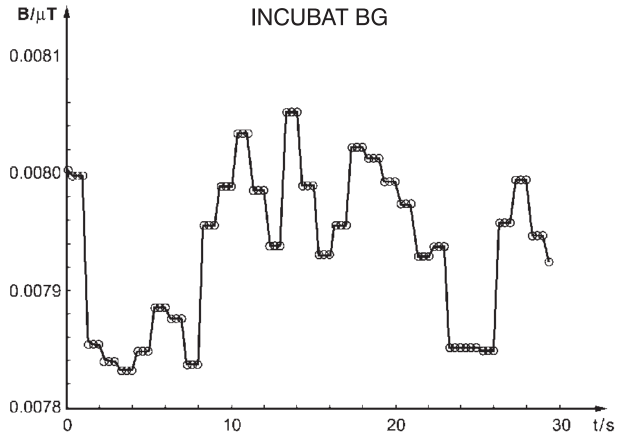

Fig. 1. Detection of ELF EMF (magnetic flux density – RMS) in the incubator background. The measurement was made with all electronic devices switched off.

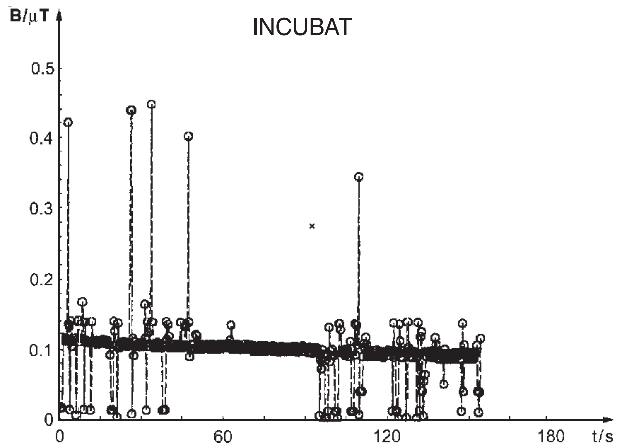

Fig. 2. Detection of ELF EMF (magnetic flux density– RMS) in the incubator with the heating, ventilation and illumination switched on. In operation were also all devices the newborn is usually connected to neonatological fan, injection pump, infusion pump.

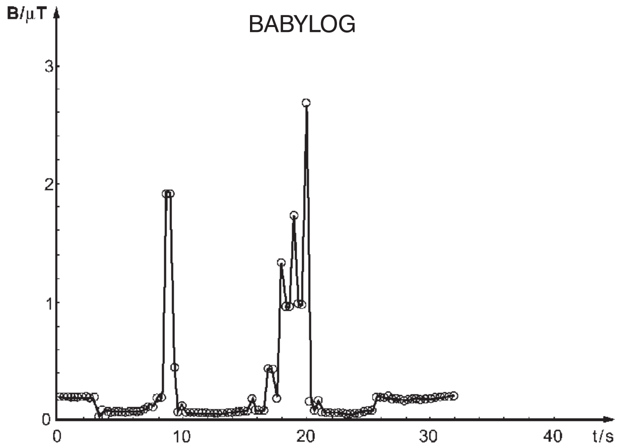

Fig. 3. Emission of ELF EMF (magnetic flux density - RMS) from the neonatological fan (Babylog).

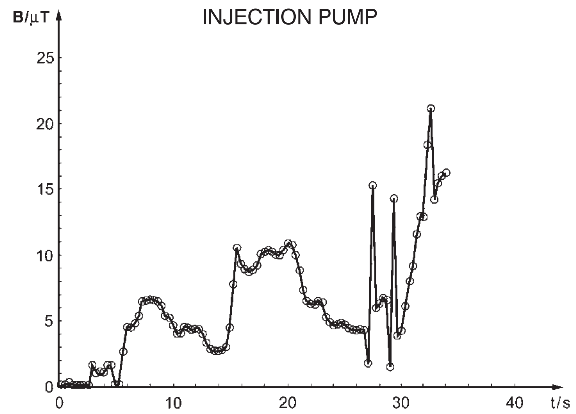

Fig. 4. Detection of ELF EMF (magnetic flux density - RMS) in the proximity to the injection pump.

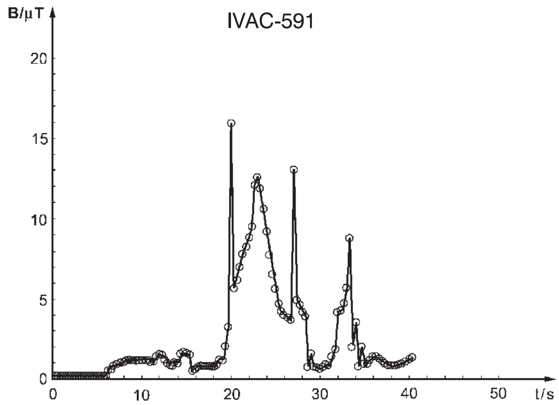

Fig. 5. Detection of ELF EMF (magnetic flux density - RMS) in close proximity to the infusion pump (IVAC).

(0.00783–0.00805) μT = (7.83–8.05) 10^{-9} T. These very low background values can be detected only by very sensitive appliance. The fluctuation of values in this low order is due to the operation of electric equipment in surrounding premises.

Figure 2 shows the detected magnetic flux density with running electric supply of the incubator (heating, ventilation and illumination switched on). There is evident increase in magnetic flux density to values of about 1.10^{-7} T, which is nearly 1.5 order higher than in the background of the incubator. The figure clearly indicates peaks (about 5.10^{-7} T) of magnetic flux density from the neonatological fan, the volumetric infusion pump, and the injection pump.

The emissions of these devices are shown in Figs 3, 4 and 5. Fig. 3 gives the results obtained in measuring emission of ELF EMF from the neonatological fan (Babylog). This fan is designed for premature newborns and its maximum extent is 20 kg. As is obvious from the emission of EMF, the functioning of the device is set for intervals of about 10 s. The maximum value of magnetic flux density induction reaches (2–2.7) μT = (2–2.7). 10^{-6} T. By virtue of the distance of this device, the magnetic flux density inside the incubator is decreased by one order. The incubator is also traversed by an ELF EMF from the injection pump (Fig.4) with maximum ELF EMF emission of about 20 μT = 20. 10^{-6} T and from the infusion pump (IVAC) (Fig. 5) with maximum ELF EMF emission 17 μT = 17.10^{-6} T. The detected ELF EMF values (magnetic component) are measured in the RMS regime, which corresponds to the values given in Table 2. In our case, ELF EMF levels detected in the incubator in the RMS regime, were very low.

The magnetometer VEMA 030 was also used to measure the older type of incubator with iron skeleton. The skeleton becomes magnetized in the natural geomagnetic field inside the incubator. The deformed geomagnetic field is illustrated in Fig. 6. The geomagnetic field in the incubator reaches about 50 μT = 50.10^{-6} T. When the resultant vector of the deformed geomagnetic field is in accordance with the direction of the resultant vector of direction found for the alternate component of magnetic flux density from additional electronic systems, the values of magnetic induction will be summed up.

In these types of incubators we can expect higher value of magnetic flux density than in incubators with plastic

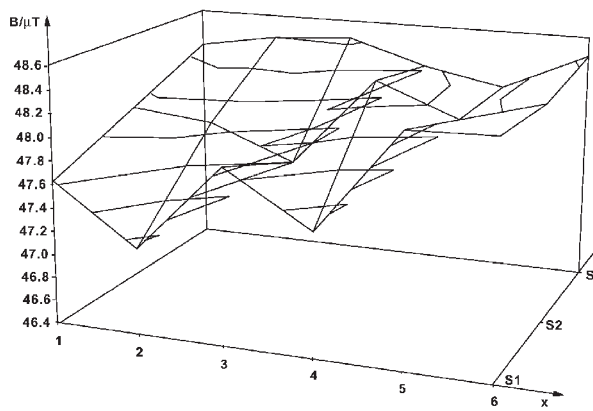

Fig. 6. Deformation of the geomagnetic field in the incubator with iron skeleton.

frames. But these are already old types of incubator not very much in use at the present time.

The measurements of the tested incubator (with plastic skeleton) showed the maximum levels of ELF EMF, namely the value of magnetic flux density of 5.10^{-7} T, for frequency 50Hz. The ELF EMF level was then much lower than that mentioned in the Introduction section. The EU reference values of magnetic induction (for 50Hz) are 1.10^{-4} T. The ELF EMF emission (values of magnetic induction) in the incubators was by 2.5 orders lower. The results obtained by magnetometer EFA 300 when using a broad band filter (5 Hz–30 kHz) showed the majority power frequency of 50 Hz.

The incubators with iron skeleton are not suitable. If the resultant vector of the deformed geomagnetic field is in accordance with the direction of the resultant vector of direction found for the alternate component of magnetic flux density from additional electronic systems, then the sizes of magnetic induction are summed up and higher value of magnetic flux density can be expected.

The comparison of reference magnetic flux density emitted by electrical appliances used in EU countries and that found in incubator magnetic flux density shows that the incubators for newborns are quite safe. Yet one thing should be borne in mind – a very small dimensions of a baby's body in incubator and its electric conductivity σ (formula (1) of the exposed human organ or tissue). Reigel et al. [4] and the European Standard EN 50357:2001 [8] imply that the electric conductivity of premature newborns is about 10 times the electric conductivity of adult persons. An equal magnetic flux density causes ten times the values of induced current density in the body of new-born child. The extent to which the sublimate current densities J(ω) induced in human body are dangerous for newborns [6] can be verified by a study covering a larger statistical set of infant incubators than that discussed by Söderberg et al. [2]

CONCLUSIONS

Since Söderberg et al. [2] tend to evidence the effects of ELF EMF on health of small children, not only due to incubator but also to other internal and external sources of ELF EMF, and Ahlborn et al.[3] assume ELF EMF effects also in the adult population then one may expect that there is also another mechanism inducing electrical current in human body than the one given by Baraton [5] (see equation (1)). It is therefore recommended, from the physical point of view, that the principle of preliminary precaution should always be observed and not only in low frequencies.

REFERENCES

1. *Incubator Study.* Microwave News 2002; 22(1): 2–4.
2. Sőderberg KC, Naumburg E, Anger G, Cnattingiuis S, Ekbom A, Feychting M. *Childhood leukemia and magnetic fields in infant incubators*. Epidemiology 2002; 13: 45–9.
3. Ahlbom A, Cardis E, Green A, Linet M, Savity D, Swerdlow A, et al. *Review of the Epidemiologic Literature on EMF and Health.* Environ Health Perspect 2001; 109(6): 911–34.
4. Reigel DH, Dallman DE, Scarf TB, Woodford J. *Transcephalic impedance measurement during infancy.* Dev Med Child Neurol 1977; 19(3): 295–304.
5. Baraton P, Hutzler B. *Magnetically Induced Current in the Human Body.* Alexandria: IEC Technology Trend Assessment; 1995.
6. *Council Recommendation 1999/519/EC of July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz–300 GHz).* Off J Eur Communities 1999: L 199/59–70.
7. International Commission of Non-Ionizing Radiation Protection (ICNIRP). *Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields up to 300 GHz.* Health Phys 1998; 74(4): 494–522.
8. EN 50357:2001. *Assessment of man's exposure to electromagnetic fields due to systems of electronic protection of goods*. Brussels: European Standard Norm; 2001.