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# The Evolution of Electromagnetic Field Standards– case study of ICNIRP's Standards

***Abstract.*** *The paper aims at showing how the standarization of ELF (extremely low frequency) electromagnetic field looks like in the light of two documents of ICNIRP. The history of the norms and the methodology of their establishing are also shown.*

***Streszczenie****. Artykuł ma na celu pokazanie jak wygląda standaryzacja w obszarze pola elektromagnetycznego niskiej częstotliwości (ELF) w świetle dwóch dokumentów ICNIRPu. Pokazano również historię norm pola elektromagnetycznego, jak również metodykę ustanawiania tych norm. (****Ewolucja standardów pola elektromagnetycznego – studium przypadku standardów ICNIRPu****)*

**Keywords**: electromagnetic field, norms, ICNIRP
**Słowa kluczowe:**: pole elektromagnetyczne, normy, ICNIRP

## Introduction

The problem of electromagnetic field and its influence on environment is as old as the first discoveries connected with electricity and magnetism, i.e. the time of William Gilbert's activity. In the first centuries after this time the researchers' interest was mainly focused on the possibility of application of electromagnetic field into therapy. The problem of electromagnetic hazards became essential towards the development of electrical and telecommunication engineering. Then a public concern has been evoked and it lasts continuously till the present time, sometimes consciously generated by politicians and journalists. That is why, the public health protection institutions as well as the emitters of electromagnetic field started to create the limits for the electromagnetic field existing in the human environment.
In the paper the electromagnetic field of low frequency (ELF) is considered only since the recent change is connected with this range of frequency

## A short history of norms

The introducing of norms and standards concerning the limitation of electromagnetic field exposure has a long history and results from the development of power engineering (low frequency) and wireless telecommunication (high frequency). As the first standards were introduced locally for one state or even for one particular manufactory it is difficult to find one common idea in these procedures. The precursors of such procedures were American companies, e.g. Bell Telephone (Bell), American Telephone and Telegraph (AT&T) or General Electric (GE) [1].

As the time was passing the standardization was becoming more and more unified and the world-wide and European organizations initiated the process of multi-national standardization. In the 70-ties and 80-ties of the XX century such organizations as IEC, CENELEC, ANSI and IEEE produced the standards which were valid in the group of states or, at least, generated the pattern for one-state system of norms.

The first document regulating the non-ionizing radiation was launched by ICNIRP in 1998 and it was the very base for preparing the EU Recommendation [3]. The document, both ICNIRP's article and EU Recommendations were the ground for national regulations for more than 10 years. The EU Directive EU 2004/40 concerning the EMF limitations in the labour environment was based on [3]. In 2010 the paper in Health Physics was published in which the ICNIRP group published new document changing the hitherto standards twice [4]. This will be discussed later as the case study of norm evolution.
To make the evolution of standards closer let us observe the Polish standards which changed within a dozen of years to a great extent.

Table 1 History of standards in Poland

| year of issue | Electric field strength E | Magnetic field strength H (magnetic flux density) |
|---|---|---|
| 1980 | I zone >10 kV/m | Not standarized |
| | II zone 1-10 kV/m | Not standarized |
| 1988 | 10 kV/m | 80 A/m, (0,1 mT) |
| 2003 | 10 kV/m | 60 A/m, (0,08 mT) |

The evolution of the standards is of radical nature as the first approach (1980) did not take into account the magnetic component H. Also, the first norm introduced zones (safe and safe under some circumstances) which do not appear in the later issues. It shows that the standardization is being done arbitrarily to some extent.

## The determination of the norms

What is the scientific *background* for establishing the norms? Where these or those values are from? It seems to be justified to say that the fundamental source for the norms in low frequency range is the paper by J. H. Bernhardta, published in 1979 [2]. He, for the first time, classified health effect of electromagnetic field , linking them with the current which flows though the human tissues and organs. It does not matter in his analysis where the current is from, but in this paper the current induced by magnetic field (eddy current) is considered. The values of current density as well as the health effects are given in Tab. 2 [2]

Table 2 Possible dysfunctions due to EM

| Current density [mA/m$^2$] | Expected effects |
|---|---|
| ≤ 1 | Lack of influence |
| 1-10 | Non-essential influence |
| 10-100 | Documented interactions, especially magnetophosphenes can occur |
| 100-1000 | Changes in central nervous system, magnetic stimulation of tissues, possibilities of health problems |
| >1000 | Life hazard |

Thus, according to Table 2, magnetic field component should not generate in the tissues the current of density exceeding 1 mA/m$^2$.

As the generation of eddy currents is based on Faraday's Law, one can use it in this case. In general such procedure May be mathematically complex as one has to calculate the integral, But norm-creating people went through much simpler way: they substitute the head shape by the sphere. Then, if such an object is exposed on electromagnetic field the current flowing in these sphere may be computed from formula

$$j_{\max} = \pi r f \gamma B_{\max}$$

- $j_{max}$ – admissible value of current density,
- $r$ – radius of disc,
- $f$ - frequency,
- $\gamma$ – electric conductivity,
- $B_{max}$ - admissible magnetic flux density

For $j_{max}$ = 1 mA/m$^2$, $r$ = 0,1m , $f$ = 50 Hz, $\gamma$ = 0.1 S/m one obtains:

$B_{max}$ 0.636 mT

If one introduces the safety coefficient, say equal to 5, then the admissible value of magnetic flux density is about 0.1 mT which is the value around which all the world norms circulate.

**Comparison of the norms**

As it was written above the world norms are different and they approach only the results of analysis shown above. For the comparison the magnetic and electric components of electromagnetic field will be considered at 50 Hz. The values of them which are admitted in some selected countries, both EU members and non-members, are shown in Tab.3.

Tab.3 Standards in exemplary countries

| state | E (kV/m) – 50 Hz | B (mT) – 50Hz |
|---|---|---|
| EU (recommendation) | 5 | 0,1 |
| Poland | 10 | 0,08 |
| Germany | 5 | 0,1 |
| USA | 14,7 | 0,984 |
| Japan | 3 | - |
| Australia | 5 | 0,1` |
| Italy | 3 | 0,025 |
| Russia | 5 | - |

Fig. 1 A Japanese street

It is readily seen that there is some discrepancy between the norms in particular countries. There is no physical nor technical justification for such a situation. The differences come mainly from economical/political and urban reasons. For example, as one can see in Japan the magnetic component for 50 Hz is not regulated, but if one looks at Japanese city (Fig.1) the reason for this becomes clear – the overhead lines may generate magnetic field in the houses greater than 0.1 mT.

The fact that the norms are different is not the evidence that people in one country are better protected than people in another one. It is more clever to say that the hazard is not as big as some journalists and politicians want to convey to the public.

**Evolution in ICNIRP's approach**

One of the most influential institution in electromagnetic standardization is International Commission on Non Ionizing Radiation Protection (ICNIRP) which was established in 1992 in Germany. ICNIRP was chartered by IRPA (International Radiation Protection Association) as an independent commission during its meeting In Montreal. ICNIRP's charter was based on the highly successful model of the International Commission on Radiological Protection (ICRP) that develops guidance on protection for ionizing radiation. After several years, ICNIRP guidelines have now been widely accepted. ICNIRP has close co-operation with the World Health Organization and other international agencies to achieve the highest standards of health risk assessment from which non-ionizing radiation exposure limits can be developed.

Its principal aim is to disseminate information and advice on the potential health hazards of exposure to non-ionizing radiation to everyone with an interest in the subject. ICNIRP's information and advice covers all of the non-ionizing radiations including:

- the optical radiations (ultraviolet, visible and infrared - and lasers),
- static and time-varying electric and magnetic fields
- radiofrequency (including microwave) radiation,
- ultrasound

As it was written above there are two crucial documents launched by ICNIRP in the area of standardization in 1998 and 2010 [3,4]. The paper is to show what the revolutionary difference between two documents is. The last article of ICNIRP confined the range of frequencies 0- 100 kHz. It shows that the comparison of two documents will be carried out on the base of low frequency.

The evolution in ICNIRP's approach lies not only in numbers but also in the philosophy of the standardization, i.e. in the answer to the question: what the limitation of EMF is for. The below passage will show the change of the approach.

Let us compare the subchapters of two documents which summarize the list of morbid hazards connected with the exposure to electromagnetic field.

The document from 1998 quotes some possible adverse effects of electromagnetic field of low frequency. Although the authors of the document are skeptical as to the results presented in cited sources but they use them as the foundations of standards.

New ICNIRP's document presents quite different approach, especially in the area of acute effects. The approach consists in the analysis of visual effects of magnetic component, called magnetophosphenes, which was discovered independently by Jacques Arsene d'Arsonval and Silvanus P. Thompson in the turn of 19th and 20th centuries [5]. The visual effect is strictly connected with the nerve system. Electric component of electromagnetic field of low frequency acts on human body, in the opinion of the discussed document, in generating electric charge on the surface of the body. As the effect is painful just it is addressed to the reference level.

The document of 2010 introduces also the so called chronic effects. In this aspect of the matter the authors refer to the IARC (International Agency for Research of Cancer) which evaluates the cancerogenicity of agents, mixtures and exposure circumstances. IARC classified magnetic field of low frequency in category 2B, which consists of the situations for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals. The category 2B is wide enough as to the agents belonging to this group – one can find there such factors as coffee, vegetables, etc.

The difference in opinions after 12 years between two documents finds its visualization in numbers. Below the reference values in electric and magnetic field quantities in the frequency range 1 – 100 kHz are shown. Table 4 gives the values taken from the old document, Table 5 shows the values of new document.

Table 4. Values in old ICNIRP's document

| Frequency range | E-field strength ($Vm^{-1}$) | H-field strength ($Am^{-1}$) | B-field (μT) |
|---|---|---|---|
| 1-8 Hz | 10 000 | $3{,}2 \times 10^4/f^2$ | $3{,}2 \times 10^4/f^2$ |
| 8-25 Hz | 10 000 | 4/f | 5/f |
| 0,025-0,8 kHz | 250/f | 4 /f | 5/f |
| 0,8-3 kHz | 250/f | 5 | 6,25 |
| 3-150 kHz | 87 | 5 | 6,25 |

Table 5. Values in new ICNIRP's document

| Frequency range | E-field strength ($Vm^{-1}$) | H-field strength ($Am^{-1}$) | B-field (μT) |
|---|---|---|---|
| 1-8 Hz | 5 000 | $3{,}2 \times 10^4/f^2$ | $4 \times 10^4/f^2$ |
| 8-25 Hz | 5 000 | $4 \times 10^3/f$ | $5x\ 10^3/f$ |
| 25-50 Hz | 5 000 | $1{,}6 \times 10^2$ | $2 \times 10^2$ |
| 50-400 Hz | $2\ 500 \times 10^2/f$ | $1{,}6 \times 10^2$ | $2 \times 10^2$ |

To transfer the arithmetic relations to the clear numbers the values for 50 Hz are shown in Table 6.

Table 6. Comparison for 50 Hz

| Frequency – 50 Hz | E-field strength ($Vm^{-1}$) | H-field strength ($Am^{-1}$) | B-field (μT) |
|---|---|---|---|
| old ICNIRP | 5 000 | 80 | 100 |
| new ICNIRP | 5 000 | 160 | 200 |

As one can see the magnetic field strength increases two times in the new document. The same movement has been made for occupational exposure: B-field has been changes from 0,5 mT to 1 mT, also twice.

New document did not change the value of electric component at 50 Hz but, according to newest reports, electric component does not create any special hazard – IARC included this component into group 3.

It is worth noting that ICNIRP does not propose for assessment the current induced in the body but electric component of electromagnetic field only. One can computes the current density from electric field by Ohm's law and then one has to know the conductivity of the tissue which is not unique value. Therefore, it is more correct to assess the current density for each particular case. Comparing two documents their reader can find that for $\gamma$ = 0,1 S/m the values of current density admissible inside the body are the same and equal to 2 $mA/m^2$.

It is also interesting that the basic restrictions in the new document are given in two options: for the part of organism connected with central nervous system (CNS) and for the part of a body connected with peripheral nervous system (PNS). It is mainly connected with the visual effect (magnetophosphenes) for CNS but also it helps in assessing the current density in metallic orthopedic implants (PNS). The current density in implant can exceed the standards taken for CNS [6].

**Conclusions**

As it is highly likely that the ICNIRP postulates will be again the base for EU Recommendation or Directive one can conclude that the direction of standards is just to liberalize them, at least not to strengthen them. It is also well seen in academic and scientific publications. Again, taking into account that the norm values can increase twice almost suddenly, the public concern diminishes to a great extent

It should be stressed here that the opinion of the direction in which standards follow is concluded from the ICNIRP article but it is recently recognized that ICNIRP's opinions are binding for EU.

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