Observation

NON-IONISING RADIATION HUMAN EXPOSURE ASSESSMENT NEAR TELECOMMUNICATION DEVICES IN CROATIA*

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This paper gives an overview of the regulatory acts in non-ionising radiation in the world, with a special emphasis on basic guidelines issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). ICNIRP Guidelines are implemented in many countries worldwide. Croatia has also implemented them indirectly through the European Recommendation 1999/519/EC. The Croatian regulatory acts include the Non-Ionising Radiation Protection Act, Ordinance on Electromagnetic Fields (EMF) Protection, and the Ordinance on Basic Requirements for Devices which produce Optical Radiation and Measures for Optical Radiation Protection. Dosimetry and densitometry are compliant with relevant international and European standards. The paper presents an example of densitometric human exposure assessment in complex indoor exposure conditions. In spite of a high number of indoor and outdoor sources and the "worst-case exposure assessment", the results are within the limits defined by the Croatian EMF Ordinance.

KEY WORDS: *densitometry, dosimetry, electromagnetic field, regulatory acts*

Fast-paced application of new wireless technologies makes electromagnetic fields (EMF) ever more present in human society, increasing their total level in the environment. Since the 1950s, a lot of research has been done in the field of biomedical effects of electromagnetic fields. Historical reasons for starting this research are related to exposure to radars (1). Now the research covers two main areas: application of electromagnetic fields for diagnostics and treatment in medicine and studying of effects of new industry applications on human health. The latter has recently gained in importance due to an omnipresence of mobile telephony base stations. As the general public, especially the one living in urban environments, are not used to such a dense positioning of aerials, they have expressed concern about possible biomedical effects of exposure to them. Thus in some parts of the world the citizens insist on being informed and updated about the latest scientific research in the field. They also very often refer to the World Health Organization (WHO) International EMF Project. One of the main goals of this large and widely recognised project is to harmonise world legislation in non-ionising radiation. The most notable document in the field are the guidelines for limiting exposure to electric, magnetic and electromagnetic fields published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in 1998 (2). The European Council published a Recommendation on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (3) which is entirely based on the physical quantities defined in the ICNIRP guidelines for the part related to general public. Among many other countries, Republic of Croatia has included the 1999/519/EC Recommendation in the relevant legislation. The Directive of the European Parliament and Council (4) requires that all European Union countries should comply with the exposure limits and action values and is also based on the ICNIRP guidelines. The Republic of Croatia is working on the implementation of this Directive into its legislative acts.

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INTERNATIONAL LEGISLATION

In adopting EMF exposure legislation, most countries throughout the world do the following: 1) directly include the international ICNIRP guidelines into national legislation; 2) indirectly include the ICNIRP guidelines; 3) include the ICNIRP guidelines with certain precautions; 4) develop own national standard; 5) adopt other standard; and 6) issue precautionary/environmental guidelines.

Table 1 *The legislative instruments to implement non-ionising radiation protection, classified according to the relationship with the ICNIRP guidelines.*

Act	Voluntary	Mandatory
1. ICNIRP 1998 guidelines for general population	Malta Republic of Korea Singapore South Africa Taiwan	Czech Republic Germany
2. Indirect ICNIRP 1998 guidelines (1999/519/EC)	Luxembourg Romania Sweden UK	Estonia Finland France Hungary Ireland Lithuania Portugal Spain
3. ICNIRP 1998 guidelines with a precaution factor	Greece	Luxembourg Poland Croatia
4. National Act		Japan Russian Federation
5. Another standard: The withdrawn Pre-ENV 50166-1995	Austria Latvia	
6. Precautionary/ environmental guidelines	Sweden	Italy Slovenia Switzerland

As it is shown in Table 1, the most observed document in the world are the ICNIRP guidelines (2) and most countries have included them directly into their national laws either as binding or non-binding instruments.

According to the second scheme, the ICNIRP guidelines are adopted through another document. For example, the European Union included the limit values and physical quantities from the ICNIRP guidelines into two of the main EU documents: the European Recommendation for general population 1999/519/EC (3) and the Directive of the European Parliament and of the Council, 2004/40/EC (4). This means that most EU countries implement the ICNIRP guidelines indirectly through these two documents. According to the third scheme, the ICNIRP guidelines are adopted, directly or indirectly, with an instrument of precaution, mostly due to societal reasons. Some countries such as those of the former Soviet block, however, have adopted their own national standard for many years, based on their own research and experiences. Other countries, in turn have chosen to adopt another standard such as the Pre-ENV 50166-1995, CENELEC of 1995 (5). These European countries are currently working on adopting the ICNIRP guidelines. Finally, some countries appoint a special national or international board to devise so-called precautionary or environmental guidelines that are based on latest research. Usually, these legislative acts are not related to ICNIRP.

Since most European countries (including Croatia) have adopted the ICNIRP guidelines indirectly through the documents of the European Council and Parliament, this paper will focus on the most important highlights related to the assessment of human exposure to non-ionising radiation from telecommunication devices.

The ICNIRP is the most important independent non-governmental organisation founded in 1992 with the aim to establish the critical mass of knowledge of non-ionising radiation effects on human health. The basis for the ICNIRP guidelines are scientific papers in the field, published in peer-reviewed journals. The ICNIRP acts as a scientific advisory body, which means that all the political, social or economic connotations are excluded. Its expert members do not have any kind of a conflict of commercial or industrial interest. Its latest guidelines in the frequency range from 0 GHz to 300 GHz were published in 1998 (2).

The ICNIRP guidelines provide two-tier limit values for occupational and for general public exposures.

This is why the European Council issued the two mentioned documents: the Council Recommendation and Directive. In these documents, the restrictions or limits defined for human EMF exposure are called *basic restrictions* and *reference levels*.

Basic restrictions are restrictions on exposure to time-varying electric, magnetic and electromagnetic fields, which are based directly on established health effects and biological considerations. The basic restrictions are based on the following physical quantities: magnetic flux density (B), current density (J), specific energy absorption rate (SAR), specific energy absorption (SA), and power density (S). The use of the physical quantity that best describes the basic restrictions depends on the used part of the electromagnetic spectrum. Compliance with the basic restrictions will ensure protection against all known adverse health effects.

Reference levels are derived from the basic restrictions for the condition of maximum coupling of the electromagnetic field to the exposed individual in order to facilitate practical exposure assessment. Since the derivation is based on providing maximum protection, reference levels determine whether the basic restrictions are exceeded, or whether the exposure conditions are well under biological consideration levels. Reference levels consist of the following physical quantities: electric field strength (E), magnetic field strength (H), magnetic flux density (B), power density (S), and limb current (J_L). Besides these, the reference level used to describe perception and other indirect effects is contact current (I_C). Reference levels are calculated from the basic restrictions to accommodate for "the worst–case scenario". This means that the compliance with a reference level will ensure compliance with the related basic restriction. However, if the measured value exceeds the reference level, this does not necessarily mean that the basic restriction will be exceeded, but rather that it is necessary to perform further evaluations (calculations/ measurements of the basic restriction) to determine compliance with the basic restriction.

The ICNIRP guidelines also define combined exposure to multiple frequency fields for electrical stimulation (from the induced current density as well as from electric and magnetic field strength) and for thermal effects (handling of SAR and power density, as well as for electric and magnetic field strength and limb and contact currents).

EMF REGULATION IN CROATIA

The field of bioelectromagnetics is quite complex for legislation, because it involves interdisciplinary action of several ministries, which usually draft and motion bills in Croatia. Still, the most important is the role of the Ministry of Health and Social Welfare, since the only important issue in the interaction between electromagnetic fields and a human being is whether there is a health effect or not. In Croatia the Ministry of Health and Social Welfare coordinates the drafting of the legislation on biomedical effects of ionising and non-ionising radiation. There are several acts and ordinances in effect at this point: the Non-Ionizing Radiation Protection Act (NIRPA) (6), Ordinance on Electromagnetic Fields Protection (7), and the Ordinance on Basic Requirements for Devices Which Produce Optical Radiation and Measures for Optical Radiation Protection (8). The Ordinance on Ultrasound Protection and the Ordinance on Occupational Non-Ionizing Radiation Protection are being drafted and will soon be passed in Parliament. NIRPA defines a general framework, whereas the Ordinance on EMF Protection provides limit EMF values pursuant to Article 10 of the NIRPA, methods for checking EMF values in the human environment and conditions for getting permission for applying the methods, as well as special requirements for devices, industrial areas and buildings that are or contain EMF sources.

The EMF Ordinance (7) defines EMF sources and detailed requirements that health institutions and companies have to meet in terms of putting the EMF sources on the market and in the service. It also defines the frequency and types of measurements to check the compliance with the requirements.

Limit values are defined for the areas of increased sensitivity and areas of occupational exposure. According to the EMF Ordinance, the areas of increased sensitivity include residential areas, schools, kindergartens, hospitals, tourist objects and playgrounds. The areas of occupational exposure exclude areas of increased sensitivity, but include working places where individuals stay for up to eight hours a day, and whose exposure is monitored constantly.

As in the 1998 ICNIRP guidelines, the Ordinance defines physical quantities as the basic restrictions and reference levels.

The basic restrictions relevant for wireless telecommunication systems are the Specific Absorption Rate (SAR) and power density (S). Their

Table 2 *Basic restrictions relevant for wireless telecommunication systems, as defined in the Croatian Ordinance on Electromagnetic Fields Protection for occupational exposure*

Frequency (*f*)	Specific Absorption Rate averaged over the whole body *SAR* / W kg^{-1}	Specific Absorption Rate localized in the head and trunk *SAR* / W kg^{-1}	Specific Absorption Rate localized in the extremities *SAR* / W kg^{-1}	Power density *S* / W m^{-2}
10 MHz–10 GHz	0.4	10	20	
10 GHz-300 GHz	-	-	-	50

Table 3 *Basic restrictions relevant for wireless telecommunication systems, as defined in the Croatian Ordinance on Electromagnetic Fields Protection for the areas of increased sensitivity*

Frequency (*f*)	Specific Absorption Rate averaged over the whole body *SAR* / W kg^{-1}	Specific Absorption Rate localized in the head and trunk *SAR* / W kg^{-1}	Specific Absorption Rate localized in the extremities *SAR* / W kg^{-1}	Power density *S* / W m^{-2}
10 MHz–10 GHz	0.08	2	4	
10 GHz-300 GHz	-	-	-	10

Table 4 *Reference levels relevant for wireless telecommunication systems, as defined in the Croatian Ordinance on Electromagnetic Fields Protection for occupational exposure*

Frequency (*f*)	Electric field strength E / V m^{-1}	Magnetic field strength H / A m^{-1}	Magnetic flux density B / μT	Equivalent plane wave power density S_{eq} / W m^{-2}
10 MHz–400 MHz	28	0.073	0.092	2
400 MHz–2000 MHz	1.375 $f^{1/2}$	0.0037 $f^{1/2}$	0.0046 $f^{1/2}$	f/200
2 GHz–10 GHz	61	0.16	0.20	10
10 GHz–300 GHz	61	0.16	0.20	10

Table 5 *Reference levels relevant for wireless telecommunications system, as defined in the Croatian Ordinance on Electromagnetic Fields Protection for the areas of increased sensitivity*

Frequency (*f*)	Electric field strength E / V m^{-1}	Magnetic field strength H / A m^{-1}	Magnetic flux density B / μT	Equivalent plane wave power density S_{eq} / W m^{-2}
10 MHz–400 MHz	11.2	0.0292	0.0368	0.326
400 MHz–2000 MHz	0.55 $f^{1/2}$	0.00148 $f^{1/2}$	0.00184 $f^{1/2}$	f/1250
2 GHz–10 GHz	24.4	0.064	0.08	1.6
10 GHz–300 GHz	24.4	0.064	0.08	1.6

values for occupational exposure are given in Table 2. The values for areas of increased sensitivity are given in Table 3.

The reference levels relevant for wireless telecommunication systems are the electric field, magnetic field, magnetic flux density, and power density of the equivalent plane wave. The values for areas of occupational exposure are given in Table 4. The values for areas of increased sensitivity are given in Table 5.

The EMF Ordinance defines exposure to multiple frequencies/sources. The ratio of measured/calculated basic restriction values and limit basic restrictions should be calculated for all present sources in the whole frequency spectrum (from 100 kHz to 10 GHz) with the requirement for the final sum to be less than 1:

$$\sum_{100kHz}^{10GHz} \frac{SAR_f}{SAR_{g,f}} \leq 1 \qquad [1]$$

In the whole relevant frequency spectrum (from 100 kHz to 300 GHz) an exposure ratio can be defined as a square of the ratio of measured/calculated reference level, E_f, H_f and limit reference level, $E_{g,f}$, $H_{g,f}$: $\left(\frac{E_f}{E_{g,f}}\right)^2$, $\left(\frac{H_f}{H_{g,f}}\right)^2$.

Total exposure in the frequency spectrum above 100 kHz is defined as in (3), i.e., the sum of exposure ratios from 100 kHz to 1 MHz and from 1 MHz to 300 GHz for electric field strength and from 100 kHz to 150 kHz and from 150 kHz to 300 GHz for magnetic field strength. The final value of total exposure should be less than 1.

DOSIMETRY AND DENSITOMETRY OF THE TELECOMMUNICATION DEVICES

Dosimetry measures the energy absorbed by a person whereas densitometry measures exposure to an electromagnetic field in an absence of a human (9). We can therefore say that dosimetry is oriented toward quantification of basic restrictions and densitometry toward reference levels. The fact that it is not possible to measure the induced fields inside the human body directly under the exposure conditions couples dosimetry and densitometry tightly together.

Reference levels are calculated from the basic restrictions for the condition of maximum coupling of the electromagnetic field to the exposed individual. Following current knowledge, if the measured reference level quantity is below the defined reference value, then the compliance of the reference level means also compliance of the basic restriction. Since this is the case for most measurements performed near telecommunication devices throughout Croatia, this section will focus on densitometry only.

Densitometry of telecom devices depends on the distance from the source and can be divided in near- and far-field densitometry. In the near-field exposure, relevant quantities are electric and magnetic fields; in the far-field exposure the relevant quantity is power density (10). In practice, measurements are performed in the far-field, which means that it is necessary to measure only one electromagnetic field component (either electric or magnetic field strength) .

The selection of the method and instruments depends on the frequency, output source power, modulation type, duty factor, pulse width, pulse-repetition frequency, intermittency, spurious frequencies including radiated harmonics, and the number of radiating sources. Before starting the measurements, it is necessary to check source properties and the EMF propagation properties. They include the distance between the source and the test site, type of aerial, gain, beam width, orientation and physical size with respect to the distance from the area which is being surveyed, polarization of the E- and H- fields, and the existence of absorbing or scattering objects likely to influence the field distribution at the test site (11).

The measuring devices for field strength and/or power density consist of a probe, connecting leads, and instrumentation. The probe includes field-sensing elements; for an electric field, a dipole and for a magnetic field, a loop. Isotropic probe has three field-sensing elements. Before starting measurements with a particular instrument, it is necessary to check the isotropicity of the probe, responses to light, response of the probe only to a specific parameter, response time of the instrument, frequency band of the instrument, stability of the instrument, out-of-band response, dynamic range of the instrument, probe dimensions, perturbations of the leads from the sensor to the meter, generation of scattering induced by the instrument and the E- and/or H-calibration of the probe.

METHODS AND RESULTS

In 2004, the Faculty of Electrical Engineering of Zagreb University carried out an investigation on the top floor offices of the Ericsson Nikola Tesla company building to see if EMF exposure was within the Ordinance limits (7). The measurement method defined in the EMF Ordinance (7) follows the HRN/IEC/EN 61566 standard which defines densitometric measurements in an exposure area (11). Exposure field strength is defined as the whole space which can be occupied by a person, but measured without a human body. This is applicable for a specific or representative space. The measurements are performed in phases, as follows:

1. Before starting a survey it is required to determine as many characteristics of the sources as possible. This phase helps to make a better estimate of the expected field strengths and a more appropriate selection of test instruments and test procedures.
2. The second phase depends on the results of the first phase: 2a. If the information about the

source and environment is well-defined, then the survey can be performed with the simplest adequate single-frequency equipment. The results of the survey will be compared with the estimates of expected field strengths and in the outdoor environment they should not be too different.

2b. If the information is not well-defined (which is the case either for the unknown sources or for the environment that fosters a complex electromagnetic field distribution), then it is necessary to perform a number of exploratory measurements around the test site. The exploratory measurements include the application of broad-frequency equipment. If the field strength is non-uniform, then the measurements are performed inside a unit space assumed to be occupied by the human body. As a result, the final value is spatial average.

3. Time averaging is required for successful measurements results.

The investigated indoor office environment on the top floor of the building, that is, just below the roof, is extremely complex for electromagnetic field distribution. There are many interference patterns produced by the combining of energy received directly or as reflected and diffracted signals from objects in the environment arriving from three EMF sources, i.e., two GSM base stations on the roof and the indoor micro GSM antenna. In this multi-path environment, the phase of the reflected and diffracted signals can be at any angle with respect to that of the direct signal. Thus, the reflection and diffraction can either enhance or diminish the strength of what would have otherwise been a direct signal. The distances between maxima and minima are a function of wavelength, and so they may vary from a fraction of a centimeter to many meters. At locations with emitters operating at various frequencies like in the investigated office space, the field strength pattern is particularly complex.

The consequence is that the measuring equipment has to be sophisticated; an isotropic broadband dipole antenna and spectrum analyzer are required to measure the whole GSM 900 downlink frequency band (935 MHz to 960 MHz). Broadband antenna makes it possible to distinguish and measure the electric field strength of various sources. The exposure field strength, E_i, at every single frequency is calculated according to the following formula:

$$E_i = \sqrt{E_x^2 + E_y^2 + E_z^2} \qquad [2]$$

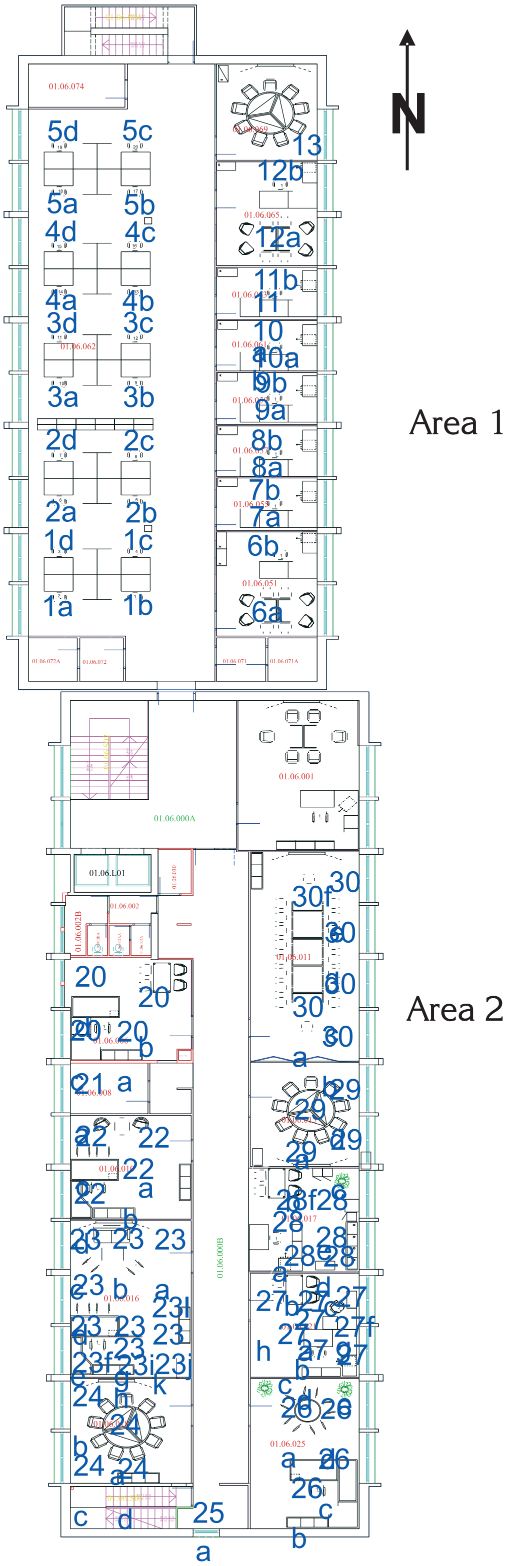

Figure 1 *Offices (Area 1 and 2) on the top floor of the Ericsson Nikola Tesla company building where EMF measurements were taken.*

The composite strength, E_c is given by the square root of the sum of the squares of three exposure field strengths of each wave, E_i :

$$E_c = \sqrt{E_1^2 + E_2^2 + E_3^2} \qquad [3]$$

At every point of investigation in the assessment of whole-body exposure, spatial average means the root mean square of the field over an area equivalent to the vertical cross section of the adult human body. The spatial averaged value is measured by scanning a planar area equivalent to the area occupied by a standing, or in this case, sitting adult human. In most instances, a simple vertical, linear scan of the fields over a height of 0.5 m to 1.5 m above foot level and over a width of 0.4 m, with a step of 0.01 m. The measuring over a specified averaging time, in this case any continuous 6 minutes, contributes to the specification of the maximum occurring values of the RF field strength.

The measuring areas 1 and 2 are typical modern offices and are shown in Figure 1. Since the offices are full of office desks and computer equipment, there are many reflections and diffractions of the electromagnetic field. In spite of it, the measurements in the sitting position confirmed that the magnetic field was negligible and pointed to far-field power density as a more relevant physical quantity. The only rationale to it is the fact that indoor antenna contributes mostly to the RF exposure. Figure 2 shows the three components of the electric field and their sum. The results of power density measurements in the Area 1 show that the highest temporal and spatial averaged value of power density (1.73 mW m^{-2}) was recorded at point 2a (see Figures 2 and 3). It is approximately 400 times lower than the limit value set by the Croatian EMF Ordinance (0.758 W m^{-2}).

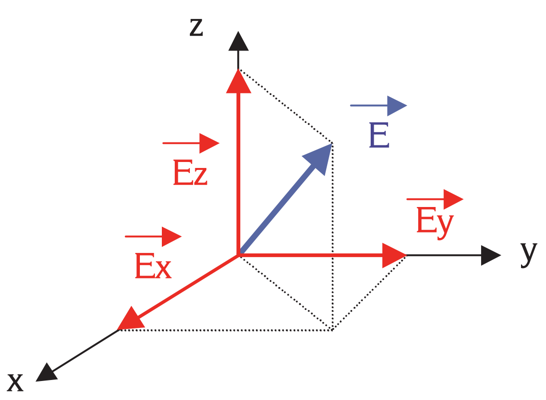

Figure 2 *Three components of the measured electric field.*

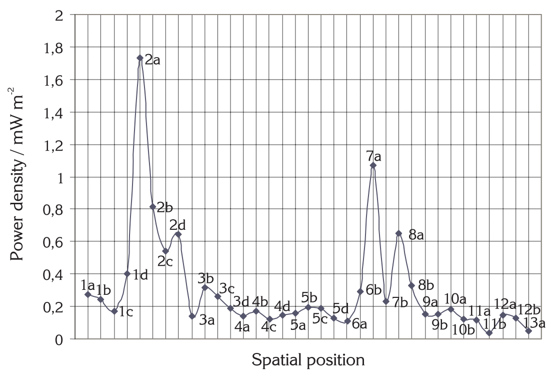

Figure 3 *Averaged power density in the part of office Area 1 (Figure 1), with the highest recordings.*

DISCUSSION AND CONCLUSION

Croatian regulatory acts in the field of EMF protection comply with the European legislation and world trends. Current Non-Ionising Radiation Protection Act and Ordinance on Electromagnetic Fields Protection define the exposure limits for general and occupational exposure. The EMF Ordinance has its exposure assessment based on the international and European standards. At the moment, exposure assessment is dominated by densitometry, oriented toward the general public. The pending Ordinance on Occupational Non-Ionising Radiation Protection drafted by the Ministry of Health and Social Welfare is likely to come up with the same or even higher activity levels. Recently, the issue of correct assignment of the "worst-case" reference levels to basic restrictions levels has been raised. If the near future shows that there is a difference between the current reference levels and basic restrictions, then the only valid exposure assessment will be by appropriate dosimetry, which will require a reliable dosimeter. By then, densitometric methods remain in use, but only with an excellent instrumentation and knowledge of electromagnetism.

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Sažetak

EVALUACIJA LJUDSKE IZLOŽENOSTI NEIONIZIRAJUĆEM ZRAČENJU U BLIZINI TELEKOMUNIKACIJSKIH UREĐAJA U REPUBLICI HRVATSKOJ

Članak daje pregled zakonodavnih akata u svijetu uz popratno objašnjenje ICNIRP naputaka. ICNIRP naputci primjenjuju se u mnogo zemalja diljem svijeta na izravan ili neizravan način. Republika Hrvatska također primjenjuje ove naputke, i to neizravno, prema Preporuci Vijeća Europe 1999/519/EC. U članku je nadalje objašnjeno hrvatsko zakonodavstvo u području neionizirajućeg zračenja. Osnove dozimetrije i denzitometrije su pojašnjene za specijalan slučaj telekomunikacijskih uređaja. Prikazan je jedan primjer mjerenja u unutrašnjosti zgrade s relativno kompleksnom izloženosti GSM osnovnih postaja, jer se radi o postavljenim vanjskim osnovnim postajama, kao i o postajama u unutrašnjosti zgrade. Na kraju su prikazani rezultati mjerenja i uspoređeni s relevantnim vrijednostima u postojećem hrvatskom Pravilniku.

KLJUČNE RIJEČI: *denzitometrija, dozimetrija, elektromagnetsko polje, norme, zakonodavstvo*

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