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AN OVERVIEW OF 1998 VERSUS 2020 EDITION OF GUIDELINES FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS

Abstract: *One of the most important documents defining recommendations for limiting exposure to almost inevitable electromagnetic radiation was released in 1998 by International Commission on Non-Ionizing Radiation Protection (ICNIRP). This document is "Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)". However, the growing knowledge about the electromagnetic field (EMF)-tissue interaction and appearance of innovative telecommunication technologies, raised the need for the improvement of these Guidelines. Thus, the ICNIRP published the latest version of its recommendations in 2020. The purpose of this paper is to briefly present some important differences between the ICNIRP 1998 and 2020 Guidelines and to enlighten their reflection on national EMF legislation.*

Key words: electromagnetic fields, EMF exposure, ICNIRP.

INTRODUCTION

The operation of the majority of devices (mobile phones and accompanying telecommunication infrastructure, Bluetooth, Wi-Fi, etc.) is based on the emission of electromagnetic fields (EMFs). Thus, an unavoidable EMF radiation is present in the surrounding environment, raising concerns on potential adverse effects on human health [1]-[5]. For that reason, recommendations for limiting exposure to EMF have been defined in "Guidelines for Limiting Exposure on Time-varying Electric, Magnetic and Electromagnetic Fields (up to 300 GHz)", which was published in 1998, by International Commission on Non-Ionizing Radiation Protection (ICNIRP) [6].

Considerable developments of numerous technologies that use EMF, over a wide spectrum range, have happened since that time. Therefore, the relation between EMFs and potentially adverse health outcomes became more important for the general public. Accordingly, the Guidelines 1998 had to be revised and updated in order to follow the advances in relevant scientific knowledge.

The ICNIRP has updated the radio-frequency part of the 1998 Guidelines, through the "Guidelines for Limiting Exposure to Electromagnetic Fields", issued in 2020 [7]. Here are considered some adequate measures for the protection of human exposure to radiofrequency EMFs in the range from 100 kHz to 300 GHz.

The main objective of research in this paper is to compare those two Guidelines, presenting their main differences and enlightening their deliveries to the national EMF legislation [8].

In-depth analyses of the 1998 and 2020 Guidelines will be performed, while comparison will be made taking into account the overall protection approach, the technical changes to the basic restrictions, as well as to the everyday used reference levels.

THE 1998 GUIDELINES

At the beginning of the 1990s, a powerful development of modern technologies occurred. For that reason, the World Health Organization (WHO) initiated the investigation of the biological effects of radio-frequency EMFs effects. The guidelines for limiting exposure to EMFs with a purpose to protect people and the environment were adopted in 1998, as a consequence of performed research. These Guidelines have been developed by ICNIRP, in partnership with WHO.

The 1998 Guidelines were the basis of EMF legislation in many countries, and around that time, the progressive limitation of EMF exposure was established, providing protection against adverse health effects.

In the 1998 Guidelines, the results of laboratory and epidemiological studies, the basic exposure criteria and reference levels for practical hazard assessment were assembled. Presented Guidelines have been applied to public exposure, as well as occupational exposure. Besides, the results of studies on direct and indirect effects of EMF on people were presented. Direct effects result from direct interaction of fields with the body, while indirect involve interactions with an object at a different electric potential from the body.

THE 2020 GUIDELINES

The production process of Guidelines 2020 lasted for seven years. In March 2020, 22 years after the publication of Guidelines 1998, ICNIRP stated: "The guidelines have been developed after a thorough review of all relevant scientific literature, scientific workshops and an extensive public consultation process. They provide protection against all scientifically substantiated adverse health effects due to EMF exposure in the 100 kHz to 300 GHz range" [7].

In general, Guidelines 1998 were conservative; however, the Guidelines 2020 continued with this

approach preserving the main restrictions same as in Guidelines 1998. Improved scientific accuracy led to an update of limits, which provided the restrictions for exposure circumstances, that have not been considered in the ICNIRP Guidelines 1998.

It should be emphasized that there is an ICNIRP recommendation for countries to update their national regulations in line with the Guidelines 2020.

RESULTS AND DISCUSSION

In general, the scope of both Guidelines is very similar. However, the Guidelines 2020 has some freshly added EMF restrictions, and changes to the old restrictions, while some restrictions have been removed.

The new restrictions are associated with novel technological developments, particularly 5G network technology. Relying on more precise scientific knowledge regarding the relation between spatial averaging of exposure and temperature rise, some restrictions have been changed. Also, in some situations it was proven that some restrictions were not necessary to provide protection from adverse health effects, so they were removed.

An important difference between the two Guidelines is that Guidelines 1998 did not make a distinction between pregnant and non-pregnant women in terms of occupational exposure restrictions. There is no evidence showing that occupational exposure of the fetus would result in adverse health effects. The fetus might be exposed above the more conservative general public restrictions, and, in Guidelines 2020, the fetus and pregnant women were associated with the general public.

Furthermore, the research of the impact of warming from other sources on health was quite advanced compared to the research done 20 years ago, so the ICNIRP filled that part in the new Guidelines.

Also, every step in enacting restrictions can be seen in the Guidelines 2020, due to a large amount of scientific research. The level of transparency is increased and this is one of the important differences.

Finally, the scope of these Guidelines is very similar – whether the adverse effects appear as a consequence of acute or chronic exposure, aside from age or health and of the biophysical mechanism responsible for the effect, the guidelines provide protection against all adverse effects.

Differences in basic restrictions

Basic restrictions are restrictions on exposure to time-varying electric, magnetic and electromagnetic fields that are based directly on established health effects [7]. They are linked with occurrences in the human body.

The physical quantities used to specify basic restrictions in Guidelines 1998 include current density, specific energy absorption rate (*SAR*), and power density (*S*).

The quantity *SAR* is used for the whole-body exposure restriction in both Guidelines, where their differences are presented in Table 1.

Table 1. *Differences between whole-body average SAR in basic restrictions; occupational (O) and general public (GP) exposures*

1998			2020		
f	Whole-body average SAR		*f*	Whole-body average SAR	
	O	GP		O	GP
100 kHz-10 MHz	0.4	0.08	100 kHz-6 GHz	0.4	0.08
10 MHz-10 GHz	0.4	0.08	6 GHz-300 GHz	0.4	0.08

The restrictions in Guidelines 1998 are for frequencies up to 10 GHz, but novel technologies are using much higher frequencies. Thus, to ensure that exposure to new technologies does not lead to an excessive rise in body temperature, the restrictions in the Guidelines 2020 cover the range up to 300 GHz.

Research has shown that Guidelines 1998 restrictions were even more conservative than it was thought in the beginning, so the SAR values did not change. However, the averaging time for whole-body averaged SAR was changed from 6 to 30 minutes in Guidelines 2020.

Regarding local exposures, the SAR was used up to 10 GHz and power density was used above 10 GHz, in Guidelines 1998. Unfortunately, the superficial exposure at higher frequencies can be underestimated by SAR, while deeper exposures at lower frequencies can be underestimated by power density. Thus, the transition frequency (frequency at which quantity changed) is reduced from 10 GHz to 6 GHz, in Guidelines 2020, as shown in Tables 2 and 3.

Table 2. *Basic restrictions for frequencies between 100 kHz and 300 GHz (local SAR – head and thunk, and limbs; and power density); occupational (O) and general public (GP) exposures; 1998*

f	Local SAR (head and thunk)		Local SAR (limbs)		Power density	
	O	GP	O	GP	O	GP
100 kHz-10 GHz	10	2	20	4	-	-
10 GHz-300 GHz	-	-	-	-	50	10

Protection against excessive local temperature rise, in both directions, uses the same SAR that was averaged over 6 minutes. However, a better approximation is provided by the difference in spatial averaging. While SAR is averaged over a 10-g contiguous tissue region in Guidelines 1998, in Guidelines 2020, it is averaged over a 10-g cubic region.

In both Guidelines, different exposure limits for different body regions are defined. Nevertheless, there are small differences in the way body parts are defined. One of them is that the pinna is treated as superficial

tissue (such as the skin), instead of treating it like tissue, which needs more stringent limitations.

Table 3. *Basic restrictions for frequencies between 100 kHz and 300 GHz (local SAR – head/torso and limb; and local Sab); occupational (O) and general public (GP) exposures; 2020*

f	Local SAR (head and torso)		Local SAR (limbs)		Local S_{ab}	
	O	GP	O	GP	O	GP
100 kHz-6 GHz	10	2	20	4	-	-
6 GHz-300 GHz	-	-	-	-	100	20

Local exposures above 6 GHz also contain some changes. Incident power density is a quantity used for frequencies between 10 GHz and 300 GHz, in Guidelines 1998 (Table 2). Because up to 50% of incident power density is reflected away from the body, this is not a measure of exposure of the body. A new quantity, known as absorbed power density (S_{ab}), is used for frequencies between 6 GHz and 300 GHz, in Guidelines 2020.

Power densities are to be averaged over any 20 cm^2 of the exposed area, but in Guidelines 2020, local S_{ab} is to be averaged over a 4 cm^2 surface area of the body. With the application of this change, an acceptable exposure over 20 cm^2 cannot be concentrated in a small region and rise temperature excessively.

There is an additional constraint for frequencies above 30 GHz: exposure averaged over a square 1 cm^2 surface area of the body is restricted to two times that of the 4 cm^2 restriction. The degree of focus increases with an increase in frequency. The beams below 30 GHz are not focused enough to make damage there, so this restriction was introduced only for frequencies above 30 GHz. Changes in the averaged area and the introduction of an additional limit for highly focused beams above 30 GHz are especially important for ensuring safety with 5G and future technologies.

Equivalent maximum exposures in the body (above and below 6 GHz) are provided by setting the values of basic restriction for EMFs, whose frequency is greater than 6 GHz. For that reason, the larger values are set for S_{ab} in Guidelines 2020, in comparison to values for incident power density in Guidelines 1998. However, the peak exposure in the body for frequencies larger than 6 GHz is now lower than it was in the Guidelines 1998, because the 20 cm^2 averaging area has been replaced with 4 cm^2.

The excessive temperature in local tissue can be raised by brief, intense exposures, although the average power over 6 minutes is smaller than the 6 minutes average restrictions. For that reason, there are additional restrictions in Guidelines 2020, applicable to continuous and discontinuous EMF. They depend on the exposure duration and guarantee that brief intervals of exposure do not cause excessive temperature rises.

These restrictions are applicable only for frequencies above 400 MHz, since an excessive temperature rise could not occur in this way below 400 MHz. The specific energy absorption (*SA*) is a quantity used for frequencies between 400 MHz and 6 GHz, whereas absorbed energy density (U_{ab}) is used for frequencies above 6 GHz. The functions for *SA* and U_{ab} are presented in Table 4, where *t* is time in seconds.

Table 4. *Basic restrictions for frequencies between 400 MHz and 300 GHz (local SA – head/torso and limb; and local U_{ab}); for intervals <6 min; occupational (O) and general public (GP) exposures*

400 MHz-6 GHz	Local Head/Torso *SA*	O	$3.6[0.05+0.95(t/360)^{0.5}]$
		GP	$0.72[0.05+0.95(t/360)^{0.5}]$
	Local Limb *SA*	O	$7.2[0.025+0.975(t/360)^{0.5}]$
		GP	$1.44[0.025+0.975(t/360)^{0.5}]$
6 GHz -300 GHz	Local U_{ab}	O	$36[0.05+0.95(t/360)^{0.5}]$
		GP	$7.2[0.05+0.95(t/360)^{0.5}]$

Due to these restrictions, 5G and other future technologies that are in compliance will not cause excessive temperature rise due to brief exposures.

Also, in Guidelines 1998, there is a restriction regarding situations in which sub-millisecond EMF pulses can create audible sound. This restriction is not used in Guidelines 2020, since it has been shown to be a sensory phenomenon and to have no adverse health effect.

Differences in reference levels

The reference levels have been derived by ICNIRP from computational and measurement studies. They have a practical means of demonstrating compliance using quantities that are evaluated more easily than the basic restrictions. Nevertheless, these quantities provide an equivalent level of protection for conditions of maximum exposure scenarios.

Reference levels for continuous whole-body were provided in Guidelines 1998. However, not all types of basic restrictions were covered by Guidelines 1998 reference levels. However, in Guidelines 2020, there is a corresponding reference level for every basic restriction – making it one of the differences between the Guidelines. Unfortunately, situations, where it is not possible to use reference levels, will continue to occur, because of complexities associated with near and far-field differences.

Quantities which define reference levels are measurable. Guidelines 1998 include electric field strength (*E*), magnetic field strength (*H*), magnetic flux density (*B*) and power density (*S*). In Guidelines 2020, they are known as incident electric field strength (E_{inc}), incident magnetic field strength (H_{inc}) and incident power density (S_{inc}), plane-wave equivalent incident power density (S_{eq}), incident energy density (U_{inc}), and

plane-wave equivalent incident energy density (U_{eq}). All of them are measured outside the body. There is also a current measured inside the body (I).

It was noticed that above approximately 2 GHz, values of E-field and H-field do not always provide adequate evaluation and thus, for whole-body reference levels above 2 GHz, they are not used in Guidelines 2020.

Reference levels for contact currents were also included in Guidelines 1998. However, they are not defined in Guidelines 2020, because it is necessary to take into account various parameters that cannot be specified in advance.

Reference levels for EMFs in the far-field zone are defined in Guidelines 1998. These reference levels, according to Guidelines, can also be used in the near-field zone. However, matching with basic restriction and introducing additional reference levels, leads to the complexity of near-field measurements. Hence, reference levels are differently defined in the far-field zone, radiative near-field zone and reactive near-field zone.

Other factors which are out of the scope of the Guidelines 2020 also affect how well the reference levels correspond to the basic restrictions. Due to this, other essential characteristics of the exposure scenario (e.g. size and shape of the antenna) need to be thought out for precise specification of the far-field, radiative near-field and reactive near-field zones. To ensure consistency between reference levels and basic restrictions, the input from a technical standards body needs to be specified.

The Guidelines from 2020 clearly state that in situations where EMF levels are not sufficiently informative to ensure that reference levels meet basic restrictions, reference levels cannot be used, but basic restrictions must be respected.

As mentioned previously, in Guidelines 2020, there is a range of new reference level categories. Because limited research below 30 MHz was available in 1998 when reference levels were set, reference levels are very conservative. In Guidelines 2020, there are updated reference levels, because of novel information on the relationship between basic restrictions and both the electric and magnetic field reference levels provided by research and scientists (it does not affect the basic restrictions). As higher values of reference levels are needed to achieve the basic restrictions, the reference levels are therefore increased. For that reason, E-field and H-field reference levels are higher in Guidelines 2020 than in Guidelines 1998, for the frequencies between 100 kHz and 30 MHz.

The monotonic increase in the values of the reference levels of E- and H-fields with decreasing frequency, starting from 30 MHz, is present in Guideline 2020. Also, there are no differences in whole-body average reference level values above 30 MHz between the Guidelines. Nevertheless, the same reference level values will result in different magnitudes of exposure to a person, because of different rules for the application of reference levels.

As it is said before, one of the differences is that separate reference level values for exposures in the far- and near-field zones were not specified in Guidelines 1998, and in the near-field zone, the values of the reference level of the far-field zone were used. In Guidelines 2020, reference levels in the near- and far-field are separated. For that reason, there will certainly be no excessive exposure in the near field zone.

Another difference is that in the Guidelines 2020, for frequencies above 2 GHz in the near field zone, a measure of power density is used instead of E-field and H-field (which was used in the Guidelines 1998 for average whole body reference levels over the entire frequency range of 100 kHz to 300 GHz).

Differences in simultaneous exposures to multiple frequency fields

Changes in basic restrictions and reference levels cause the corresponding changes in the equations, which describe simultaneous exposures to multiple frequency fields.

As power density is no longer a quantity used for whole-body exposures, that collection is deleted in the equation for the whole-body average basic restrictions (for frequencies in the range of 10 GHz and 300 GHz).

In the Guidelines 1998, there is no equation for the local SAR and the local absorbed power density, but in new guidelines, there are derived following equations, (1) and (2).

$$\sum_{i=100\ \mathrm{kHz}}^{6\ \mathrm{GHz}} \frac{SAR_i}{SAR_{BR}} + \sum_{i>6\ \mathrm{GHz}}^{30\ \mathrm{GHz}} \frac{S_{ab,4cm,i}}{S_{ab,4cm,BR}} + \sum_{i>30\ \mathrm{GHz}}^{300\ \mathrm{GHz}} MAX\left\{\left(\frac{S_{ab,4cm,i}}{S_{ab,4cm,BR}}\right),\left(\frac{S_{ab,1cm,i}}{S_{ab,1cm,BR}}\right)\right\} \le 1. \quad (1)$$

$$\sum_{i=100\ \mathrm{kHz}}^{400\ \mathrm{MHz}} \int_t \frac{SAR_i(t)}{360 \times SAR_{BR}} dt + \sum_{i>400\ \mathrm{GHz}}^{6\ \mathrm{GHz}} \frac{SA_i(t)}{SA_{BR}(t)} + \sum_{i>6\ \mathrm{GHz}}^{30\ \mathrm{GHz}} \frac{U_{ab,4cm,i}(t)}{U_{ab,4cm,BR}(t)} + \sum_{i>30\ \mathrm{GHz}}^{300\ \mathrm{GHz}} MAX\left\{\left(\frac{U_{ab,4cm,i}(t)}{U_{ab,4cm,BR}(t)}\right),\left(\frac{U_{ab,1cm,i}(t)}{U_{ab,1cm,BR}(t)}\right)\right\} \le 1. \quad (2)$$

Equation (1) is for time intervals larger than 6 minutes, and equation (2) is for time intervals smaller than it. The equations for electric and magnetic fields strength (incident fields) are also updated, in line with changes in the reference levels.

The impact of Guidelines 2020 on national EMF legislation

The Serbian legislation regarding protection to EMF exposure was issued in 2009 and it is based on Guidelines 1998. However, in order to follow scientific advances and new knowledge on EMF, changes should be made in national legislation to follow the latest Guidelines. Basic restrictions and reference levels must be changed (their quantities and limit values), as well

as in the equations which express the simultaneous exposure to fields of different frequencies. Some proposals for changes in Serbian legislation are offered in [8].

CONCLUSION

The modernization of EMF Guidelines was absolutely necessary, since the Guidelines 1998 is not fully in line with the progress of telecommunication technology.

The newest issue of Guidelines for limiting exposure to electromagnetic fields is for the protection of humans exposed to radiofrequency electromagnetic fields in the range from 100 kHz to 300 GHz.

The Guidelines cover many novel applications such as 5G technologies, Wi-Fi, Bluetooth, mobile phones, and base stations. However, it should be expected that recommendations from 2020 will be updated in the next few years, following the forthcoming developments in new-age technologies.

Finally, the Guidelines 2020 should be adopted in our national legislation, in order to reflect modern recommendations for limiting exposure to EMFs.

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BIOGRAPHY of the first author

Teodora Gavrilov was born in Novi Sad, Serbia, in 1994.

She received her B.Sc. and M.Sc. degree in Electrical and Computer Engineering, at the Faculty of Technical Sciences, University of Novi Sad, at the Department of Power, Electronics and Telecommunication Engineering.

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Her scientific area is theoretical electrotechnics, while her research interests are in the field of theoretical electrical engineering, and theoretical and applied electromagnetics.

Pregled razlika između preporuka iz 1998. i 2020. godine za ograničavanje izloženosti elektromagnetnim poljima

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Rezime: *Jedan od najvažnijih dokumenata koji definišu preporuke za ograničavanje izlaganja gotovo neizbežnom elektromagnetnom zračenju objavila je 1998. godine Međunarodna komisija za zaštitu od nejonizujućeg zračenja (eng. International Commission on Non-Ionizing Radiation Protection - ICNIRP). Ovaj dokument je „Smernice za ograničavanje izlaganja vremenski promenljivim električnim, magnetnim i elektromagnetnim poljima (do 300 GHz)". Međutim, usled značajnog napretka u znanju o interakciji između elektromagnetskih polja i tkiva i pojavi inovativnih telekomunikacionih tehnologija, zasnovanih na elektromagnetnom polju (eng. electromagnetic field - EMF), ove Smernice su morale biti proširene, ažurirane i dalje unapređene. Stoga je ICNIRP objavio najnoviju verziju svojih preporuka 2020. godine. Svrha ovog rada je da ukratko predstavi neke važne razlike između ICNIRP smernica iz 1998. i 2020. godine i da pojasni kako bi se te razlike odrazile na nacionalne pravilnike koji se tiču elektromagnetnih polja.*

Ključne reči: elektromagnetna polja, izlaganje elektromagnetnim poljima, ICNIRP.