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ELECTROMAGNETIC FIELD BIOLOGICAL EFFECTS STUDIES AS IMPORTANT PRINCIPLE OF HYGIENIC STANDARDIZATION IN THE RUSSIAN FEDERATION

Abstract: *The main principles of occupational and general public exposure to electromagnetic field (EMF) in the Russian Federation have been presented. EMF hygienic standardization in Russia is based on the results of complex hygienic, clinical, physiological, epidemiological and experimental studies with peer-reviewed data. The concept of threshold principle of occupational and environmental factors exposure hazard effects is the basis of EMF permissible levels substantiation. The data of experimental studies allow the receipt of EMF hazard effects threshold levels. The main criteria of EMF exposure hazard effects in evaluation of experimental study data are the determination of long-term exposure effect threshold levels as well as acute exposure effects. Dose (and time-dependence) approach, which is included in hygienic regulation, allows specifying the value of EMF permissible levels depending on time (exposure duration). This approach is realized in occupational hygienic standards by introduction of "power exposition" and "maximal permissible level" terms, and in general public EMF hygienic standards by permissible levels dependence on the possible duration of exposure.*

Key words: biological effects, electromagnetic field, hygienic regulation.

INTRODUCTION

The problem of occupational and general public electromagnetic safety is very urgent in terms of environmental electromagnetic pollution and human health risks increase. The main sources of electromagnetic field (EMF) are the equipment of power- and radio transmission objects, radar and navigation systems. Today, mobile and wireless telecommunication systems play an essential role in electromagnetic pollution. Therefore, general public EMF exposure may be almost equal to the occupational ones.

PRINCIPLES OF EMF HYGIENIC REGULATION

The concept of threshold principle of occupational and environmental factors exposure hazard effects has been used for different frequency ranges of EMF permissible levels substantiation. The data of EMF biological effects experimental studies allow the receipt of the levels of hazard threshold. The main criteria of EMF exposure hazard effects in evaluation of experimental study data are the determination of long-term (chronic) exposure effects threshold levels as well as acute exposure effects. The main discrepancy between the Russian and the international EMF hygienic standardization approaches are in different concepts of "cumulative" or "acute" effects. Since EMF hygienic norms in Russia are time-dependent, the principle "protection by time" is based on biological responses realization [1].

The Russian concept of EMF exposure biological effects (depending on intensity) is divided into 3 zones: sub-threshold zone, the zone of adaptive perception, and the zone of hazard effects [2]. Each step of reaction can be characterized by its own threshold EM values of intensity and development times. The magnitude of effect increases not only with the exposure intensity but also with the time of exposure. Progress through stages of reactions to EMF exposure of various intensities is possible in order to define outcomes range. This range can be divided into some areas. In the ideal case, the transitions between areas represent the thresholds of the exposure effects as shown in Figure 1.

EMF hygienic standards in the former USSR and in the Russian Federation today have developed, as a rule, on the basis of hygienic, clinical and physiological, experimental, and recent epidemiological studies, as well as scientific publication in the peer-reviewed journals data. Hygienic researches are carried out with the purpose to determine time-level EMF exposure parameters in real conditions; clinical and physiological studies are directed towards the analysis of physiological functions of unfavorable changes; epidemiological investigations are carried out to analyze the remote consequences of factor exposure;

and experimental studies should analyze the features and character of EMF biological effects. The main bases of EMF hygienic norms setting are the experimental data of EMF exposure hazard and biological effects threshold determination. Experimental studies play the leading role in hygienic norms substantiation, taking into account the experimental results, from animals to human transfer criterion and hygienic safety factor (they differ according to frequency ranges and emission modes). Therefore, the Russian hygienic norms are more strict than the "reference levels" which are defined in the International guidelines [3,4].

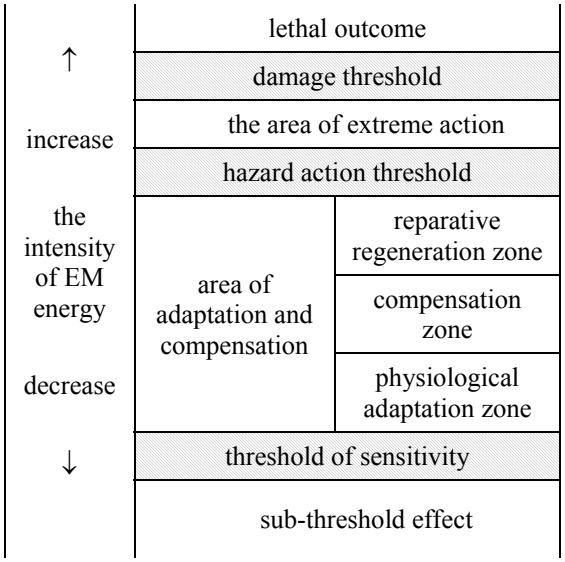

Figure 1. *The scale of biological effects depending on different EMF exposure*

For example, in case of 50 Hz EMF hygienic standardization electric field, E (kV/m) and magnetic induction (mT, μT) level are set as ICNIRP [5] reference levels and Action levels (AL) for magnetic fields in EU Directive [6]. These parameters are used for practical EMF exposure assessment. Furthermore, Directive EU [6] introduces two distinct thresholds for both the ELVs and the ALs for occupational exposure conditions: low and high.

Protection by shortening exposure time is the key topic in Russian occupational exposure hygienic norms [7] and general public exposure norms [8], which vary across the territories. The main distinctive characteristic in the International hygienic guidelines are based on the definition of EMF long-term exposure adverse human health effect threshold and the concept of EMF cumulative effects.

The power frequency of electric and magnetic field international reference levels, EU Directive on ALs, and maximum permissible levels in Russia are compared in Table 1.

Table 1. *Power frequency permissible limit values*

Hygienic guideline	Min	Max
Permissible level E, kV/m		
Occupational exposure		
ICNIRP 2010	10	
Directive 2013/35/EU	10	20
SanPiN 2.2.4.3359-16	5	25
General public exposure		
ICNIRP 2010	5	
Directive 1999/ 519/EC	5	
SanPiN 2.1.2.2801-10	0.5	1-20*
Permissible level B, mT		
Occupational exposure		
ICNIRP 2010	1	
Directive 2013/35/EU:		
whole body	1	6
local to limb	18	
SanPiN 2.2.4.3359-16:		
whole body	0.1	2
local to limb	1	8
General public exposure		
ICNIRP 2010	0.2	
Directive 1999/ 519/EC	0.1	
HN 2.1.8/2.2.4.2262-07	0.005	0.02

* 20 kV/m - Remote district

EU Directive permits two external electric field thresholds for occupational exposure, in particular, 10 and 20 kV/m, as low and high AL respectively. Low AL is equal to ICNIRP reference level and is based on limiting the internal electric field below the ELVs (1.1 V/m for health effects and 0.14 V/m for sensory effects) and limiting spark discharges in the working environment [6]. Occupational exposure levels below high AL (20 kV/m) mean that the internal electric field does not exceed the ELVs and annoying spark discharges are prevented, provided that the protection measures have been taken [6].

As shown in Table 1, Russian norms permit 50 Hz electric field occupational exposure levels in the range from 5 to 25 kV/m, according to time dependency presented in Figure 2.

Russian hygienic norms substantiation is based on the long-term experimental studies with the goal to determine the threshold of adverse health effects. These data (with hygienic safety factor including) together with hygienic, epidemiological and peer-reviewed publications are substantiated by dose-dependent hygienic norms.

According to SanPiN 2.2.4.3359-16 [7], minimum (5 kV/m) permissible level of power frequency electric field occupational exposure is permitted during all working day (8 hours). The maximum (25 kV/m) permissible level is permitted during a short period up to 10 min per day while other exposure at work should be lower than 5 kV/m. In case when electric field levels ranges between 5 kV/m and 20 kV/m, permissible occupational exposure changes. Power frequency of

electric field in occupational exposure hygienic norms is different according to the exposure time, which is represented by equation (1) as principle of protection by time (Figure 2).

$$T = \frac{50}{E} - 2 \quad (1)$$

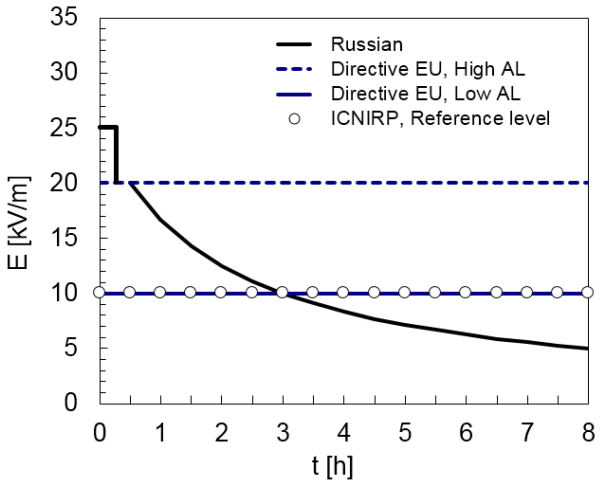

Figure 2. *50 Hz electric field occupational exposure limits depending on work hours*

If occupational exposure level is higher than 25 kV/m the worker should use protective means, which reduces the exposure level reduction below permissible levels. Otherwise, working in such conditions is not allowed.

It is possible to compare Russian and EU permissible levels by means of time dependency shown in Figure 2. For example, low AL (10 kV/m) is permitted for a few hours of exposure during the day in the EU, and 3 hours per day in Russia.

As presented in Table 1, 50 Hz electric field permissible level for general public exposure is equal in ICNIRP guidelines and EU Directives. However, these values are higher than Russian norms. In addition, SanPiN 2.1.2.2801-10 [8] permits several hygienic norms for general public depending on possible residence time and place. Inside of residential, public and office buildings, the power frequency electric field exposure should not exceed the minimum permissible level (0.5 kV/m). The permissible exposure level on a housing estate territory is 1 kV/m as well as at the border of 330–1150 kV overhead transmission lines right-of-way (sanitary-protective zones).

The principal protection by exposure time for the general public is achieved by taking into account the different type of territory and the length of general public stay. In addition to the data from Table 1, permissible level in residential areas is 1 kV/m; in populated areas outside the residential buildings permissible level is 5 kV/m; at intersections with I-IV class roads - 10 kV/m and in unpopulated areas - 15 kV/m.

Permissible levels of occupational exposure to power frequency magnetic field differ for total (whole body) and local (limb) exposure.

Low AL (1 mT) is derived from the sensory effects ELV and high AL (6 mT) is derived from the human health effects. Also, ELV for internal electric field related to electric stimulation of peripheral and autonomous nerve tissues in head and trunk [6]. AL for limbs exposure is derived from the health effects, whereas ELVs for internal electric field is related to electric stimulation of the tissues in limbs by taking into account that the magnetic field is coupled more weakly to the limbs than to the whole body [6].

Table 2 shows that Russian norms of 50 Hz magnetic induction occupational exposure differ in case of the whole body exposure from 0.1 to 2 mT, for limbs exposure from 1 to 8 mT, and are significantly lower than EU Directive for ALs. Russian norms of magnetic induction exposure depend on work time per day and are presented in Figure 3 in case of whole body exposure.

According to SanPiN 2.2.4.3359-16 [7], whole body minimum (0.1 mT) permissible level of magnetic induction occupational exposure is permitted for all working hours (8 hours) and maximum (2 mT) permissible level is permitted up to 1 hour per day.

As shown in Figure 3, low AL (1 mT), permitted for all work hours per day in EU and 2 hours per day only in Russia. High AL (6 mT) is not allowed for whole body occupational exposure in Russia, and for limb exposure during 1.5 hours per day only.

As presented in Table 1, 50 Hz magnetic field permissible level for general public exposure are the highest in ICNIRP guidelines.

Russian hygienic norms permits different 50 Hz magnetic field levels for general public exposure depending on possible exposure time [8, 9]. The minimum permissible limit value is 5 μT in premises, educational and medical institutions.

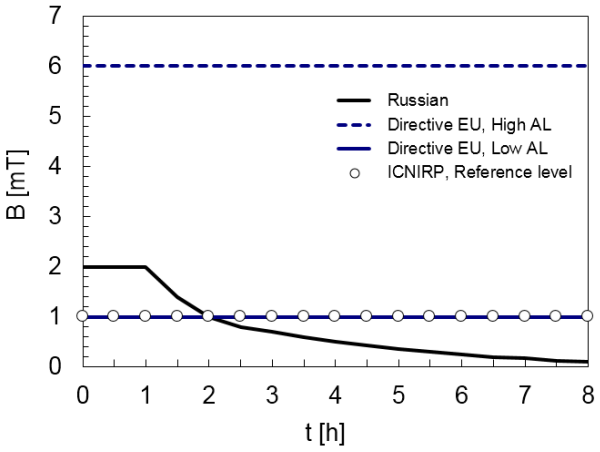

Figure 3. *50 Hz magnetic induction occupational exposure (whole-body) in hygienic norms depending on work hours*

Hygienic norm is 10 μT for uninhabited premises of residential buildings, public and office buildings, manned territories; 20 μT - for occupied district outside

the zone of a housing estate, overhead transmission lines and cable transmission line zone above 1 kV including human activities other than power objects maintenance.

The main differences between occupational and general public radiofrequency EMF exposure in hygienic norms in the Russian Federation and the western countries are similar to basic differences in approaches to standardization, and they involve: the application of various criteria of effects evaluation (acute exposure effects as main criteria, "continuous" standardization, “basic restriction”, “reference levels”, specific absorption rate (SAR) from one side and chronic (long term) exposure effects as main criteria, cumulative effects, power density, power exposure from another). Strong restriction in EMF hygienic norms improvement, taking into account Russian and International criteria, is an EMF dose concept. Russian approach based on EMF cumulative effects does not take into account the correction factors that depend on radiation level. This parameter named “power exposition” is not completely adequate to “dose” definition, but takes into account possible effects of radiofrequency EMF energy storage. This approach allows the specification of EMF permissible levels which depend on exposure duration within the workday. Also, it provides more adequate evaluation of personnel exposure by introducing “power exposition” (PE) and “maximal permissible level” values – Table 2 and Table 3 [7]. Power exposition is calculated by multiplication of electric field, or magnetic field value (E and H) square to duration of exposure per workday, or multiplication of power density value to duration of exposure per workday.

Table 2. *Power exposition values for different radiofrequency EMF according to frequency ranges*

Characteristics	PE maximum permissible values in different frequency ranges, MHz			
	0.03-3.0	3.0-30.0	30.0-300.0	300.0-300,000
PE_E , $(V/m)^2 \cdot h$	20,000	7,000	800.0	-
PE_H, $(A/m)^2 \cdot h$	200.0	-	-	-
PE_{PD}, $(\mu W/cm^2) \cdot h$	-	-	-	200.0

Table 3. *Maximum permissible limit values for EMF radiofrequency according to different frequency ranges*

Characteristics	Maximum permissible limits for different frequency ranges, MHz			
	0.03-3.0	3.0-30.0	30.0-300.0	300.0-300,000
E, V/m	500.0	300.0	80.0	-
H, A/m	50.0	-	-	-
PD, μW/cm2	-	-	-	1,000

More close to dose concept may be an approach that includes SAR for exposure levels evaluation in the near field. The Russian approach is based on radiofrequency EMF physical characteristics while SAR approach is based on the electric field strength and dielectric characteristics of human body.

CONCLUSION

The EMF Russian permissible levels are stricter than other national and international reference levels, because norms are based on EMF "cumulative" biological effects approach. This approach used the Russian concept of biological effects of EMF exposure on the factor intensity and time. This concept is realized in the shortest time possible with maximum permissible level of occupational exposure and longer exposure to lower EMF levels. Also, general public EMF permissible levels also depend on exposure time.

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BIOGRAPHY of the first author

Sergey Perov was born in Moscow, USSR, in 1980.
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He is currently working as a leading researcher at the Izmerov Institute of Occupational Health.

STUDIJE BIOLOŠKOG DEJSTVA ELEKTROMAGNETNIH POLjA KAO VAŽNO NAČELO HIGIJENSKE STANDARDIZACIJE U RUSKOJ FEDERACIJI

Perov Sergei, Nina Rubtsova, Elena Makarova-Zemlianskaia

Rezime: *U radu su predstavljeni glavni principi za uspostavljanje standarda izloženosti stanovništva elektromagnetnim poljima (EMP) i izloženosti radnika tokom profesionalnog angažmana u Ruskoj Federaciji. Standardizacija u oblasti EMP u Rusiji zasniva se na rezultatima složenih higijenskih, kliničkih, fizioloških, epidemioloških i eksperimentalnih studija iz kojih su objavljeni naučni rezultati. Koncept praga opasnosti u radnoj i životnoj sredini se zasniva na dozvoljenim nivoima EMP-a. Podaci iz eksperimentalnih studija omogućavaju uočavanje pragova pri biološkim efektima EMP-a. Glavni kriterijumi za uočavanje opasnosti pri izloženosti EMF-u su evaluacija podataka eksperimentalnih studija pragova pri dugoročnoj izloženosti i akutnih efekata izloženosti. Dozno (vremensko) zavisni pristup koji obuhvataju higijensku regulaciju, omogućava određivanje vrednosti dozvoljenih nivoa EMF-a u zavisnosti od vremena (trajanje izloženosti). Ovaj pristup se realizuje u profesionalnim higijenskim standardima uvođenjem termina „izloženost snage“ i „maksimalno dozvoljenog nivoa“, i uopšteno javnim higijenskim standardima EMF-a prema dozvoljenim nivoima zavisnosti od mogućeg trajanja izlaganja.*

Ključne reči: biološki efekti, elektromagnetno polje, higijenska regulacija.