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Review

PROSPECTS OF USING BIOLOGICAL TEST-SYSTEMS FOR EVALUATION OF EFFECTS OF ELECTROMAGNETIC FIELDS

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Electromagnetic fields (EMF) can occur both naturally and due to human activity. Nowadays, through the innovative communication technologies, the new sources of artificial EMFs are widely disseminated. Therefore, one needs to study the artificial EMFs and mechanisms of their influence on biosystems. The paper deals with the issues of the influence of artificial EMFs on human health, environment and biological objects. The experimental and theoretical investigations concerning an action of EMF are analyzed. The description of principles of standardization of non-specific EMFs and protection from the influence of man-made fields is presented. Possible mechanisms of EMF and electromagnetic radiation (EMR) action on biological objects, including those due to the accumulation of biogenic magnetic nanoparticles in an organism, are discussed. The aim of the research is to review state-of-the-art methods for detecting the biological effects of non-thermal non-ionizing EMF and EMR and to determine the prospects of using biological test-systems for evaluation of effects of EMFs. Hereby, the main attention is drawn to EMF sensors based on the cultures of microorganisms. The classification of existing test-systems is proposed according to criteria: 1) vitality of cells; 2) motor activity of cells; 3) bioluminescence and color changes under the influence of EMF. The need to develop simple and reliable biological indicators for various types of EMFs, especially for ultrahigh-frequency radiation in connection with the introduction of 5G communications technology, is substantiated. The necessity of standardized test-protocols for comparison of research results is emphasized. It is shown that the description of corresponding experiments should be accompanied by the following features: 1) name of the cell culture; native or modified cells; 2) physical characteristics of EMF or EMR (frequency, power, modulation, source type); 3) exposure duration of; 4) list of parameters to be investigated; 5) research methods; 6) absolute measurements, results and the relative magnitude of an effect; 7) what does the influence depend on (temperature, age of cell culture, composition of the nutrient medium); 8) inheritance of changes in cells; 9) relaxation time of the effect.

Keywords: man-made electromagnetic fields; electromagnetic radiation; biological effects; test-systems; classification of test-systems; 5G.

Introduction

The development of technologies leads to facilitating and improving human life and at the same time yields the inevitable deterioration of the environment, change of ecosystems and has an effect on human health [1]. The corresponding example is electromagnetic field (EMF) which can occur both naturally and due to human activity. Nowadays, through the innovative communication technologies, the new sources of artificial EMFs are widely disseminated. Therefore, one needs to study the artificial sources of EMFs and mechanisms of their influence on biological systems. Sometimes that connection is not obvious and requires proper evidence. It is not always possible to demonstrate the long-term effects of environmental changes due to laboratory reference standards. The issue concerns geophysical and technogenic electromagnetic effects, including new 5G technologies of a mobile network. From this, the elaboration of effective and demonstrative biological test systems which are able to determine irrefutable results of the influence of electromagnetic fields (EMF) is one of the urgent nowadays tasks.

Classification of non-ionizing non-specific electromagnetic fields

Since International Meeting on the Effects of ionizing and non-ionizing radiation on human health in 1971, the thermal effects of electromagnetic waves are considered as the most important ones [2]: because of the heating of tissues under the influence of EMF and an inability to dissipate excess heat (slow heat conductivity in the air).

It is experimentally determined that human organs and tissues with less blood supply, such as lens of an eye, are the most vulnerable. Pathological changes occur already at the flux density starting from 100 mW/cm^2. Under certain conditions (in particular for a certain radiation frequency) the effect of EMF with the flux density from 1 to 10 mW/cm^2 can lead to the heating of biological tissue (but not necessarily to damage). In 1996 the World Health Organization introduced the concept of "global electromagnetic pollution of the environment" ("Electrosmog" or "Electromagnetic smog") and founded the International Project on Electromagnetic Fields – the International EMF Project. The term "Electrosmog" refers to all artificially generated EMFs in the environment and is classified as non-ionizing radiation. This means that Electrosmog does not produce the energy required to remove electrons from atoms and molecules [3].

One must differentiate the specific and non-specific heating effects related to the biological objects [4]. Following many reports and epidemiological studies, a group of international experts from the European ECLIPSE web-project proposed a more detailed classification of anthropogenic types of EMFs with the corresponding frequencies of waves (the Table) [5].

As one can see in the Table, several types of electromagnetic radiation of different spectra can act simultaneously on the inhabitants of the metropolis, for the identification of which different types of devices are needed. Formally, such a problem may be solved more or less easy. How? For example, it is possible to purchase or rent specialized equipment for measuring all physical characteristics of EMFs: starting from constant magnetic to extremely high-frequency EMF. Modern intelligent measuring devices can signal the excess of the established maximum permissible level of EMF, display the distribution maps of the intensity of the field, to conduct long registration in automatic mode. Unfortunately, in real life it is not an easy and low-cost way.

Another important problem is related to the introduction of new communication technologies (5G technologies of a mobile network) when the electromagnetic impact on an ecosystem becomes global. Operators begin to occupy high frequency about 30–40 GHz and above (i.e, millimeter wavelength range) in order to increase data transmission speed and bandwidth of communication lines. Emitter satellites are launch into Earth orbit. Hereby, existing safety requirements are based on the hypothesis that the only thermal effect of EMFs is most important and crucial (standards of radiation from cellular phones are based only on the thermal effect). However, under much pressure from international mobile operators, sanitary norms are reviewed towards reducing. In Ukraine, in 2017 the maximum permissible level of EMF for radio technical objects operating in the ranges of very high (30–300 MHz), ultrahigh (300 MHz–3 GHz), superhigh (3–30 GHz) and extremely high (30–300 GHz) frequencies was increased four times. Furthermore, now it is allowed the placement and operation of mentioned radio technical objects on roofs and inside the buildings. Hence, if they will be installed directly in residential houses, schools, etc., people will not have a safe place.

Table: Classification of types of non-ionizing non-specific EMFs*

Category of EMF	Identification of frequencies of EMF
Non-specific magnetic fields	Static magnetic field Extremely low frequencies (<1 kHz)
Non-specific electric fields	Static electric field Extremely low frequencies (<1 kHz)
Non-specific radiofrequencies	Between 1 kHz and 6 GHz
Non-specific microwaves	Between 6 GHz and 300 GHz
Non-specific infrared	Between 300 GHz and 430 Thz
Application specific exposure	Power lines magnetic field (50 or 60 Hz) Power lines electric field (50 or 60 Hz) Analog broadcasting-like signals (TV, radio) Digital broadcasting-like signals (TV, radio) 2G base station-like signals (GSM) 3G base station-like signals (UMTS) 4G base station-like signals Radar-like signals

*Information based on data [5].

Concerning Ukraine, the situation with radiation standards resembles 1986, when, after Chernobyl, the authorities reassured that the radiation was within the normal range, but did not report that norms for the civilian population were raised to wartime standards. In other countries, there are attempts to legally abolish government oversight of compliance with EMF levels.

Looking on international practice, it is worth noting that most developed countries already introduced certain limitations on a power or radiation dose of sources of EMFs in the vicinity human residence. For example, in 1996 the Federal Communications Commission of USA adopted limitations expressed in terms of electric (in V/m) and magnetic (in A/m) fields and power density (in mW/cm^2) for transmitters operating at frequencies from 300 kHz to 100 GHz. It was also determined limitations for portable transmitters that take into account localized ("partial") absorption. These exposure limits are based on criteria that are quantified by the level of specific absorption rate (SAR) and are divided into a controlled and uncontrolled duration of EMF exposure. In the case of professional exposure, they were 0.4 W/kg for the whole human body and 8 W/kg for a separate area, for example, the head. At the same time, for the general population exposition, these same indices were 0.08 and 1.6 W/kg, respectively [6].

In theoretical studies, one can find the methods of determining of microwave radiation action for human health, including long-term effects. The corresponding analysis shows the most useful tools that can be used to assess epidemiological studies of such influence and new advantages of questionnaires and other subjective methods [7].

Epidemiological studies in different countries are based mainly on state programs on public health. Such investigations are being conducted for a regular survey of people who are permanently resident in a certain territory, and for a comparison with the data of sanitary-hygienic measurements of various contaminations of this territory. Now it becomes clear that to distinguish an electromagnetic factor is possible only in the case of long integrated monitoring of the EMF levels and the health of people.

Because of the uncertainty about the level of harmful effects, new protective methods are elaborated based on the different methods: reducing the time of EMF action, increase the distance to the source of radiation and the use of various means of protection such as shielding EMF, reducing intensity radiation, use of individual protective accessories, etc. [8–10].

One of the methods of protection against microwave radiation in a modern city can be building materials with a protective coating. A measuring system has been developed and various building panels have been described to assess the screening. Hereby, the frequency dependence of screening in modern cellular systems as a function of the frequency and quality of included supplements is found [11].

However, in the presence of global radiation in the millimeter and submillimetre avoid exposure to EMF are likely to fail. This applies to people as well as to all ecosystems that include flora and fauna. Results of epidemiological studies of environmental damage caused by EMF on woods [12], plants (including corn, roses, peas, fenugreek, duckweed, tomatoes, onions and mangoes) [13], ants [14–16], bees [17, 18], drosophila's [19], birds [20–22], animals [23–26], compel us to think about consequences from the point of view of bioethics.

Hypotheses on mechanisms of influence of electromagnetic field

Despite a large number of experimental investigations on the influence of non-thermal level of EMF on biological objects, there is still no theoretical possibility to predict and calculate the result on a molecular level [27].

For example, one of the problems is the so-called "kT problem". The hypothesis assumes the existence of currents induced by alternating EMFs that arise in a biological system. Denial is a low physiological significance of such currents, compared with those caused by normal thermal fluctuations [28].

Another theoretical approach explains the effect of weak EMF on radical pairs involved in enzymatic processes associated with reorientation of spins, which may affect the intermediate states and, thus, the kinetics of enzymatic processes. The disadvantage of such an explanation is also the lack of experimental confirmation of the mechanism for the field strength below 500 mT [29].

Some authors suppose that microwave radiation can change the conformational state of enzymes and other macromolecules, affecting their biological activity [30].

The ion cyclotron resonance model relates to ELF (Extremely low frequency) exposure (although higher frequency harmonics may also affect) the transfer of physiologically important cations through a membrane [31] or enzyme activation [32]. Within this hypothesis, there is also an interpretation of the estimation of the probability of ion-protein complex dissociation [33], thermal energy distribution [34], or a violation of the hydrophilic-hydrophobic balance in colloidal systems [35].

Recently authors of work [36] presented mechanisms of the influence of EMF on significant molecules that affect the transcription of certain inflammatory molecules (on the example of the chemokine MCP-1, which regulates the migration and infiltration of memory T-cells, monocytes and epithelial cells). It may be a mechanical effect on intracellular or membrane proteins involved in the operation of ion channels, membrane receptors, and enzymes. Such a mechanism does not contradict the presence of the dependence of the effect on frequency, flow density and time of influence.

In other research [37] authors showed the role of Ca^{2+} as a membrane mediator of signal transfer in the effects of magnetic field effects on the immune system [38] and the role of prolongation of the existence of reactive oxygen species (ROS) and other free radicals.

The effect of EMF on biogenic magnetic nanoparticles (BMNs) present in living organisms is also discussed for the cases of weak EMF and strong constant magnetic fields influencing on the behavior of bees [39, 40].

The BMNs (Fe_3O_4 magnetite) have been detected in the human body. It is a good absorber in the microwave range [41] and, hence, the impact of EMF millimeter range should be taken into account as well. It is known that the amount of BMNs increases in the body with age, and in the case of pathological processes. This may be due to metabolic disorders (namely, iron), and due to inflammatory processes involving microorganisms that contain BMNs. These particles are found in the brain in the case of neurodegenerative diseases, atherosclerotic plaques, tumors [42]. Remembering the increased reaction of the sick people to the action of EMF, we can assume the indirect effect of EMF by the mediation of BMNs, deposited in tissues after the pathological process (illness).

An indirect confirmation of exposure to EMF by mediation of particles that have magnetic moment may be the work [43], in which shown an inhibition of polymerase β and the rate of DNA synthesis in cell culture myeloid leukemia HL-60 in the presence of magnetic isotope ions $^{25}Mg^{2+}$ or $^{67}Zn^{2+}$ in the catalytic site in the magnetic field of the Earth. Under the influence of a magnetic field of 160 mT, the rate of DNA synthesis increased three to five times in the presence of magnetic isotopes.

The effect may also be due to the hyperthermia in a magnetic field [44]: wound healing caused by *Staphylococcus aureus* was better after exposure to an EMF at 80 kHz with an intensity of 6.9 kA/m due to hyperthermia mediated by magnetotactic bacteria with antibodies containing BMNs.

But in the work [45] postulated as the use of radio wavelength hyperthermia in the treatment of Lewis lung carcinoma, a different conclusion was made about the mechanism of magnetic field influence on the tumor using magnetically sensitive composites, namely: changes in the electron transport chain of carrier proteins in the lipid bilayer of the mitochondria.

Biological tests of the influence of microwaves

Let us zoom in on the problem of extremely high frequency (EHF) EMR from man-made resources related to 5G technologies of a mobile network. Huge funds for new equipment are paid by consumers, which operators are forcing new services and conditions. At the same time, methods for evaluation of the biological effects of EHF EMR are not developed and are not certified. Usually, only heating on mannequins is measured.

However, since the influence of EMF is not really limited to thermal effects, it is necessary to develop methods that take into account the cumulative exposure of various sources of radiation [46]. Individual counters for various components of EMF and for various anatomical parts of the body are relevant. This is necessary in view of the fact that it is not possible to predict changes and correlations of types of radiation depending on the distance to the base stations.

Another aspect of the problem is the unknown long-term effects of exposure. Experiments on animals mainly fix defects of development, premature aging, changes in brain activity. Large, homogeneous groups of animals need to be used for statistically reliable data.

Therefore, it seems promising to use microorganisms as sensors of weak external EMR. In general, one can introduce the classification of existing test-systems according to three main criteria: 1) vitality of cells; 2) motor activity of cells; 3) bioluminescence and color changes under the influence of EMF. Let us consider the proposed classification in more details due to the review of various methods for detecting the biological effects.

Criterion 1 – vitality of cells. In one of the investigations, as test cultures, strains of pathogenic *Corynebacterium diphtheriae* is used [47]. Test tubes with cultures were located at a distance of 5–7 cm from the hole of the emitter, the flux density was 0.1 mW/cm^2, the exposure time was 3 hours. It was established that microwave radiation in the 61.0 GHz range stimulated the ability of bacteria to form biofilms in 2 times. On the contrary, irradiation of bacteria in the range of 42.2 GHz reduced the ability of culture to form biofilms, which directly affects the viability and pathogenicity of bacteria.

An investigation of the influence of a static magnetic field on bacterium *Nitrosomonas europaea* shows increased growth and increased rate of oxidation of ammonia when the bacteria were exposed to a static field at 17 mT [48].

In other work it was found that the effects of the EMR with a frequency of 42.25 GHz on the micro alga *Scenedesmus quadricauda* depend on the stage of development of culture: the older is the culture, the faster is the reaction to irradiation (although no gene responsible for the formation of BMN has been found yet) [49].

Recently operative biotesting of the ecological effect of EMR in the vicinity of users of personal computers is carried out [50]. It is known that *Saccharomyces* yeast experiments represent a traditional test of the effect of the investigated factor on the permeability of the cell membrane. As a result of such consideration, a significant increase in the permeability of the membranes was found due to the exposure of the EMR of the computer. Furthermore, for a person, this effect can lead to violations of the blood-brain barrier, which causes changes in the level of physiology of the nervous system.

The possibility of using cell cultures as sensors of EMR impact on biological objects is shown in experiments with suspensions of yeast *Saccharomyces cerevisiae* UKM Y-517 [51]. As stress factors, fungicidal antibiotic nystatin and hormone adrenaline were used. The CRT monitors (1997 and 2003) and LCD (2005), EMG 900 MHz (0.5 W), 39.49 GHz (2 mW) were the irradiation sources. The effects of different non-ionizing radiation were evaluated by hydrated environment parameters of yeast cells, which were determined by Microwave Dyelectrometry and in parallel biological evaluation of cell viability. It is obtained that in order to have a minimum reliable response, an exposure of at least 1 hour is required, and cell viability is directly dependent on the distance from the radiation source.

In the case of yeasts *Saccharomyces cerevisiae* and *Shizosaccharomyces pombe* (which are recognized models for the study of eukaryotic organisms) it has been established changes in the population, cellular and molecular genetic levels under the influence of non-ionizing electromagnetic radiation of the radiofrequency range [52]. In particular, after exposure, the effect of non-specific cell resistance (including antibiotics) was noted. The assumption about the possible role of anthropogenic non-ionizing electromagnetic radiation in the growth of the antibiotic resistance phenomenon is expressed.

In our previous work on irradiation changes of the generative activity of various strains of *Saccharomyces cerevisiae* we determined significant frequencies (41.76 GHz, 54.2 GHz, and 61 GHz) as well as some technological parameters of fermentation [53–55].

Criterion 2 – motor activity of cells. Due to the investigation of changes in microorganisms under the influence of a certain external factor, it is possible to draw conclusions about the biological significance of that factor, since the motor activity is a sensitive functional indicator of the quality of environment in which organisms exist [56].

It is known that the system of motility and chemotaxis of bacteria reacts to different classes of chemical compounds: amino acids, sugars, metal ions, opiate proteins, antibiotics, toxins, poisons of natural and artificial origin, medicines, and similar compounds. Such sensitivity exists due to the presence of specific receptors on the surface of the cell. In addition to the specific reaction of binding of receptors to the substrate, the smallest changes in the electrical potential on the membrane result in the motor reaction of microorganisms [57].

In a recent report on this topic, the system of chemotaxis of bacteria is used for the development of sensory systems of higher organisms [58]. Spatially charged structures that are capable of receiving electromagnetic microwave radiation may not be stable, but arise in a living cell for a certain time. The most substantiated explanation is based on the consideration of the interaction of external EMF with the dynamic structure of biopolymers.

In the paper [59], it is shown that the EMF of the microwave in the frequency range of 53–75 GHz affects the mobility of inflammatory parasites of

Paramecium saudatum (Ehrb.). Namely, depending on the parameters, irradiation conditions, state and properties of the object under study, electromagnetic waves can both activate and inhibit the cellular activity.

The studies of the influence of EMR in the frequency range of 37–65 GHz with a power density of 3–10 mW/cm^2 on *E. coli* bacteria and *D. viridis* algae confirm the universal biological law that taxis arise only in unfavorable conditions for cells. The magnitude of the effect, that is, the biological effect of the EMR of the microwave, is estimated quantitatively as the ratio of the concentrations of moving cells during irradiation of a fixed volume, and in the absence of a microwave field. This value is reproduced according to the determined parameters of the experiment (EMR frequency of microwave, age of cell culture, medium composition, temperature). Cell culture, at temperatures that are lower than optimal for them, is more sensitive to the action of microwaves. With increasing of temperature, the activity of moving cells increased, the concentration of cells in the suspension fluctuated significantly. Against this backdrop, the influence of the microwave EMR became almost invisible. It also mattered in which environment the cells were located: if the cultures were in the physiological solution, their reactions to microwave radiation were more strongly than in the medium rich in nutrients. The direction of movement of microorganisms was different and depended on the frequency of the EMR. Characteristic reaction time of the cells to the action of microwaves was 3–5 min [60].

Criterion 3 – bioluminescence and color changes. Bioluminescence and color changes are observed in experiments with microwaves effect on sea bacteria *Photobacterium leiognathi* [61, 62]. It is established that after the action of EMR with wavelengths of 6.96 mm and 4.16 mm and exposure of 10 minutes, the extinction of the bioluminescence of bacteria occurs. The largest effect was observed at a wavelength of 6.96 mm when the cells became most sensitive in the late-steady-state phase of growth (the intensity of luminescence after irradiation decreased by 25–30%). Most researchers assume that the quenching of bioluminescence is primarily due to the structural rearrangements of cell membranes under the influence of the EMR. The bioluminescence activity is also reported for the changes of the geomagnetic field [63].

Recently Ukrainian researchers calculated the correlation coefficients between the values of daily bioluminescence intensity of bacteria and of the K-index and Ap-index values, "Wolf numbers" and the values of the flux of solar radiation. It is shown that in the case of an increase in the intensity of variations of the geomagnetic field, there is a decrease in the values of the specific intensity of the bioluminescence of bacteria. The use of an automated system for monitoring the intensity of glow of luminescent bacteria makes it possible to predict in time the presence of perturbations of the magnetic field of the Earth [64].

Influence of ultrahigh frequency irradiation on *Photobacterium phosphoreum luxb* gene expression was developed in other work [65]. Authors created an experimental sample of a biosensor for assessing the biological effects of non-ionizing electromagnetic radiation (2.45 GHz) of the radio frequency band.

An interesting bioindication may also be the change in the color and mobility of volutin granules ("*dancing bodies*") of the yeast *Saccharomyces cerevisiae*. The relationship of the metachromatic reaction of volutin granules with the perturbation of the magnetic field of the Earth and the activity of the Sun is already confirmed in [66]. This may indicate the effect of EMF on the metabolism of phosphates. Furthermore, it is found that the age of culture does not affect the metachromasia of cells [67]. Consequently, the possible acceptor of EMF energy should be sought among the enzymes involved in such an exchange.

It is necessary to realize that the estimation of the biological effects of weak EMFs is still not completed. The human generation that lives at an unusually high level of exposure has not changed yet. Evolutionary, from the periodic, local influence of EMF, we turn to chronic action, and the intensity, density, and frequency of radiation increase. Today, a typical resident of a big metropolis, (even if he is not an active user of a mobile phone and Internet), receives exposure comparable with one of a worker of harmful job associated with electromagnetic fields.

The problem is similar to problems of radioactivity discovery and new chemical compounds with an unknown influence on living organisms. That is why we believe that it is necessary to include the restrictions on the use of EMR too.

It is worth noting as well that it is not always possible to evaluate the effect of EMF as "bad" or "good". On the one hand, it is obvious that for a person to stay in the "hot spots" of biologically active radiation should be limited. On the other hand, such radiation can be used for certain needs (acceleration of fermentation, biodegradation of waste, energy generation, etc.). In any case, the development of simple and reliable biological indicators of different types of EMF is relevant.

As can be seen from our overview, the biological effects of EMR are very diverse. Usually, each scientist has his own "know-how". Therefore, there is a problem of low reproducibility of the results of experiments. At the same time, one needs simple and reliable biological indicators for various types of EMFs, especially for ultrahigh-frequency radiation in connection with the introduction of 5G communications technology. As a possible way to solve the mentioned problem, we see the unification of the description of experimental methods. According to such an approach, the description of corresponding experiments should be accompanied by the following features:

1) name of the cell culture; native cells or modified;
2) physical characteristics of EMF or EMR (frequency, power, modulation, source type);
3) duration of exposure;
4) list of parameters to be investigated;
5) research methods;
6) absolute measurements, results and the relative magnitude of an effect;
7) from what the influence depends on (temperature, age of cell culture, composition of the nutrient medium);
8) inheritance of changes in cells;
9) relaxation time of the effect.

To our opinion, in order to create a general database on the biological effects of EMF on cells, it is necessary from separate research in various fields (biophysics, microbiology, biotechnology, medicine, materials science) to move to a standardized research protocol that covers all cases of preparation of test systems, characteristics of EMF. It will allow solving the issue with regard to the reliability, stability, and inheritance of effects.

Conclusions

On the legislative level, the thermal effects of electromagnetic waves are considered as the most important. That is why heretofore control of EMF levels is mainly consisted of measuring the physical characteristics of the field. We show that it is also important to determine and predict biological effects EMF, which is much more complicated.

EMF can occur both naturally and due to human activity. Special attention must be drawn on new sources of artificial EMFs because of the innovative use of cellular phones with antennas. Unfortunately, the effect is the long-term, not obvious and requires proper evidence. In other words, the statistics of diseases associated with elevated levels of EMF, the determination of the mechanisms of EMF in cells, require time, and experiments on volunteers or animals have limitations from the point of view of bioethics.

EMF acts on the human body, immune cells, red blood cells, pathogenic bacteria in the air and microorganisms in food products. To take into account all these diverse interactions, it is necessary to use the test systems of the EMF of different types. We believe that one needs sensitive test-systems with correct and fast response to external EMF: the result can be seen rather quickly, fix and match exactly with biological action (impact on viability). As possible biological test-system, we consider the cultures of microorganisms.

The biological effects of EMR are very diverse and there is a problem of low reproducibility of the results of experiments. A possible way to solve the mentioned problem is based on the unification of description of experimental methods which should be accompanied by the key features, discussed in our work.

A general database on the biological effects of EMF can be systematized and accumulated in the frame of a standardized research protocol that covers all cases of preparation of test-systems and characteristics of EMF.

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ПЕРСПЕКТИВИ ВИКОРИСТАННЯ БІОЛОГІЧНИХ ТЕСТ-СИСТЕМ ДЛЯ ОЦІНКИ ЕФЕКТІВ ЕЛЕКТРОМАГНІТНИХ ПОЛІВ

Електромагнітні поля (ЕМП) можуть виникати як природно, так і внаслідок людської діяльності. У сучасних умовах стрімкого поширення набувають нові джерела штучних ЕМП через інноваційні технології зв'язку. Тому виникає потреба у дослідженні техногенних ЕМП і механізмів їх впливу на біосистеми. У роботі розглядається питання впливу штучних ЕМП на здоров'я людини, довкілля та біологічні об’єкти. Проаналізовано експериментальні та теоретичні роботи стосовно дії ЕМП. Наведено опис принципів нормування рівнів неспецифічних ЕМП і захисту від впливу техногенних ЕМП. Обговорюються можливі механізми дії ЕМП та електромагнітних випромінювань (ЕМВ) на біологічні об’єкти, в тому числі через накопичення біогенних магнітних наночастинок в організмі. Метою дослідження є огляд сучасних способів виявлення біологічних ефектів нетеплових неіонізуючих ЕМП і ЕМВ та визначення перспектив використання біологічних тест-систем для оцінки ефектів ЕМП. Найбільшу увагу приділено сенсорам ЕМП на основі культур мікроорганізмів. Запропоновано класифікацію існуючих тест-систем за критеріями: 1) життєздатності клітин; 2) рухової активності клітин; 3) біолюмінесценції та змін кольору під впливом ЕМП. Аргументовано потребу в розробці простих і надійних біологічних індикаторів різних видів ЕМП, насамперед надвисокочастотного випромінювання, у зв’язку з впровадженням технології 5G-зв’язку. Наголошено на необхідності стандартизованих протоколів випробувань для порівняння результатів досліджень. Показано, що опис відповідних експериментів доцільно супроводжувати такими ознаками: 1) назва культури клітин; нативні клітини або модифіковані; 2) фізичні характеристики ЕМП або ЕМВ (частота, потужність, модуляція, вид джерела); 3) тривалість впливу; 4) перелік досліджуваних параметрів; 5) методи дослідження; 6) абсолютні виміри і результати та відносна величина ефекту; 7) від чого залежить вплив (температура, вік культури клітин, склад живильного середовища); 8) успадковування змін у клітинах; 9) час релаксації ефекту.

Ключові слова: техногенні електромагнітні поля; електромагнітні випромінювання; біологічний вплив; тест-системи; класифікація тест-систем; 5G.

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ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ БИОЛОГИЧЕСКИХ ТЕСТ-СИСТЕМ ДЛЯ ОЦЕНКИ ЭФФЕКТОВ ЭЛЕКТРОМАГНИТНЫХ ПОЛЕЙ

Электромагнитные поля (ЭМП) имеют как естественное происхождение, так и являются результатом человеческой деятельности. В современных условиях стремительное распространение получили новые источники искусственных ЭМП из-за появления инновационных технологий связи. Поэтому возникает потребность в исследовании техногенных ЭМП и механизмов их воздействия на биосистемы. В работе раскрыты вопросы влияния искусственных ЭМП на здоровье человека, окружающую среду и биологические объекты. Проанализированы экспериментальные и теоретические работы, касающиеся действия ЭМП. Приведено описание принципов нормирования уровней неспецифических ЭМП и защиты от влияния техногенных ЭМП. Обсуждаются возможные механизмы действия ЭМП и электромагнитных излучений (ЭМИ) на биологические объекты, в том числе в результате накопления биогенных магнитных наночастиц в организме. Целью исследования является обзор современных способов выявления биологических эффектов нетепловых неионизирующих ЭМП и ЭМИ и обозначение перспектив использования биологических тест-систем для оценки эффектов ЭМП. Наибольшее внимание уделено сенсорам ЭМП на основе культур микроорганизмов. Предложена классификация существующих тест-систем по критериям: 1) жизнеспособности клеток; 2) двигательной активности клеток; 3) биолюминесценции и изменения цвета под влиянием ЭМП. Аргументирована потребность в разработке простых и надежных биологических индикаторов разных видов ЭМП, прежде всего сверхвысокочастотного излучения, в связи с внедрением технологии 5G-связи. Подчеркнута необходимость стандартизованных протоколов испытаний для сравнения результатов исследований. Показано, что описание соответствующих экспериментов целесообразно сопровождать такими признаками: 1) название культуры клеток; нативные клетки или модифицированные; 2) физические характеристики ЭМП или ЭМИ (частота, мощность, модуляция, вид источника); 3) длительность влияния; 4) перечень исследуемых параметров; 5) методы исследований; 6) абсолютные значения, результаты и относительная величина эффекта; 7) от чего зависит влияние (температура, возраст культуры клеток, состав питательной среды); 8) наследование изменений в клетках; 9) время релаксации эффекта.

Ключевые слова: техногенные электромагнитные поля; электромагнитные излучения; биологическое воздействие; тест-системы; классификация тест-систем; 5G.