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STUDY OF THE EFFECTS OF ULTRA-LOW INTENSITY ELECTROMAGNETIC FIELDS ON BIOLOGICAL OBJECTS

The object of research is the efficiency of exposure to electromagnetic field (EMF) of ultra-low intensity on biological objects, which is formed by a generator of broadband radiation. The principle of action of the generator is based on formation of electromagnetic radiation induced by periodic pulsed gas discharge in coaxial system of electrodes, which is loaded on a dielectric rod antenna. The method of selection of signals and corresponding equipment, which energy characteristics of radiation correspond to the criterion of non-thermal influence on bioobjects, is developed for obtaining a comparative assessment of influence bioefficiency. The proposed new method for processing experimental data using statistical calculations that meet the requirements for the processing and interpretation of the results. The seeds of wheat and interaction of millimeter range electromagnetic oscillations with bone marrow cells of rats were used as biological objects for investigating the effect of millimeter range electromagnetic oscillations. A biosensory effect was obtained when exposed to broadband radiation of ultra-low intensity, compared to the control sample. A change in the properties of the seeds, in particular, heat resistance, is observed. According to the experimental data, seeds turn out to be less susceptible to heat as a result of their pretreatment with EMF. The biological response is observed to depend on the frequency and time of irradiation. Also, the dependence of the decrease in the number of dead cells on the time of EMF irradiation was experimentally proved. The equation of dependence of selective average proportion of dead cells in rat bone marrow on irradiation time was calculated. Biosensory effect of exposure to broadband ultra-low intensity EMF of the developed emitter was revealed. It was established and statistically proved that the minimum time with the maximum positive effect of exposure to electromagnetic radiation of millimeter range on bone marrow cells of rats is 30 minutes, compared with an unirradiated sample. The results make it possible to evaluate the positive effect of electromagnetic oscillations on biological objects and propose the results of studies for practical use in the development of medical systems.

Keywords: *information-wave technology, ultra-low intensity electromagnetic radiation, non-thermal effect, coaxial antenna, pulsed gas discharge.*

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1. Introduction

In recent years, the first reports on the therapeutic effect of low-intensity electromagnetic fields (EMFs) of ultra-high frequencies (UHF) have appeared, for which the power flux density was less than 10 mW/cm^2. Such weak EMFs affect areas of the body or acupuncture points, without causing warming of tissues, but have a pronounced therapeutic effect [1].

High therapeutic efficiency of the low-intensity EMFs, physical characteristics of which are close to the electromagnetic parameters of the structures of a living organism, was the impetus for the study of the mechanisms of ultra weak energies action on the body [2].

The starting point for the analysis of mechanisms of interaction between the human body and EMF is the idea of a living organism as a complex electromagnetic hierarchical structural system, all levels of which contain electric charges and, accordingly, generate the EMF. Thus, cells of the nervous system generate electrical impulses that adaptively control the functions of individual organs and the body as a whole. Blood, tissue and organ cells also contain electrical charges and generate EMFs, which are complexly integrated into the body's overall electromagnetic field. This field, spreading to the surrounding space, including the internal environment of the body and the skin, can be received, processed and interpreted by modern electronic devices. External and internal, natural and artificial factors and diseases affect the work of various organs and systems and lead to changes in their electromagnetic parameters and, accordingly, functional properties. Therefore, electromagnetic characteristics are used simultaneously for the diagnosis and treatment of diseases [1].

Any pathology in the body causes a violation of electromagnetic homeostasis (EMH), which is reflected in the characteristics of the electromagnetic field surrounding the living organism. The EMH recovery is carried out by the body itself, its information retrieval activities aimed at selecting the optimal electromagnetic (therapeutic) signals from the environment [2–4].

The information wave technology (IWT) is a new direction in medicine, based on the principle of information exchange between the biological system and the external environment. Information-wave technology is designed for drug-free treatment, prevention, rehabilitation of various diseases, for pain elimination, correction of physiological disorders of the human body in immunodeficiency and occupational diseases, as well as in disorders caused by radiation, to remove radionuclides and in emergency [1].

The influence of external electromagnetic fields on biological objects attracts the attention of scientists and specialists working in the fields of biology, medicine, agriculture, ecology, and others. The effect of low-intensity UHF radiation and noise radiation, which may be associated with resonances of biomacromolecules and their individual components, is of particular interest. Despite the large number of publications related to this issue, there is currently no comprehensive explanation of the mechanisms of electromagnetic fields interaction with biological objects, as well as the lack of economically available hardware for use in medical practice [3].

The influence of low-intensity millimeter-wave electromagnetic radiation on living organisms over the past decades has attracted great interest among scientists of world.

The low power of the radiation flux of EMR (electromagnetic radiation) of the MMR (micrometer range) according to the literature makes it possible to use these waves for solving a wide range of problems. At present, despite the large number of works aimed at studying the effects of low-intensity electromagnetic oscillations, the features of the interaction of EMR of the MMR with biological objects, they consider these effects only descriptively with hypothetical assumptions regarding any theoretical mechanisms [5–7].

Today, when doctors and scientists are focusing their attention on the possibility of adequate replacement or addition of traditional treatment with pharmaceuticals, the MMT (microwave technology) has proved itself as a promising and highly effective method that allows achieving a complete and lasting positive result [2]. Due to a wide range of clinical use of the MMT, it is possible to talk about the possibility of its practical application to all cases requiring the use of therapeutic drug treatment methods.

Thus, the development of new methods and the improvement of existing ones for treatment is the urgent task of scientists at the stage of preclinical trials. Therefore, today, when doctors and scientists focus on the possibility of adequate replacement or supplementation of traditional pharmaceutical treatment, the question of studying the effects of electromagnetic radiation of the millimeter range of low intensity on the human body is relevant.

Therefore, *the object of research* is the efficiency of exposure to electromagnetic field of ultra-low intensity on biological objects, formed by a generator of broadband radiation.

The aim of this article is to consider the main aspects of the IWT and its use for medical purposes. Wheat seeds and the interaction of millimetre-range electromagnetic oscillations with rat bone marrow cells were used as biological objects for studying the effect of millimetre-range electromagnetic oscillations.

2. Methods of research

Electromagnetic fields are a physical environmental factor that affects matter and living organisms at different levels of the organization.

The intensities of radiation at different frequency ranges have increased with the expansion of the areas of the EMF application and the development of new frequency bands in the anthropogenic (technogenic) component of the EMF. Each of these ranges has its own characteristics, which are associated with the depth of their penetration into the matter, range and trajectory of propagation, the ability to bypass obstacles and interact with the environment and objects of the biosphere [1].

Along with the traditional areas of the EMF application, the scope of their non-traditional applications expands significantly now. This is the widespread use of the EMFs in biology and medicine, including the non-traditional one.

Electromagnetic radiation used in modern technologies, including the IWT, can be described quantitatively and qualitatively by means of the wave theory. It is believed that the appearance of a biological response to the action of millimeter waves can be explained if, as a model, let's turn to a schematic section view of the plasma membrane of a cell (for simplicity, the spherical one) [1, 6]. Assuming that such a membrane can be a dielectric resonator, it is easy to find resonant wavelengths for such a resonator with some simplification of considerations. They will correspond to acoustic waves in speed of propagation. Therefore, the waves excited in the plasma membrane of a living cell can be acoustic-electric waves. The quality factor for the plasma membrane, as for the dielectric resonator, is equal to 10^3. This is a very high quality factor, which is not easy to obtain even in metal resonators at very high frequencies. Thus, it is possible to introduce in biology three radio engineering parameters: resonant frequency, frequency separation between types of oscillations and intrinsic Q-factor. The study of these parameters will make it possible to create medical and diagnostic devices. generating millimeter radiation more rationally.

Fig. 1 show experimental data characterizing the electrophysical parameters of individual biological tissues of the human body and the depth of penetration of electromagnetic radiation. For example, at λ=10 cm (oscillation frequency ν=3 GHz) the depth of penetration into the biological tissue can reach 15 cm, and at λ=8 mm (frequency ν=37.4 GHz) this value is only 0.3 mm. The tendency to reduce the depth of penetration is observed as long as the wavelength in the medium exceeds significantly the size of the cells or organelles included in them. At very high frequencies, tissue permeability for the EMFs begins to increase again. For example, hard X-rays and gamma radiation penetrate soft tissues almost without attenuation [1].

It has been established that all biological systems are oscillatory systems in which functions occur in closed cycles with periods from a fraction of a second to months and years. There are also biological fluctuations with periods of several days, months, years and so on. There are «circadian» (one-day), ultradian (T<24 hours), infradian (2.5 days>T>24 hours) rhythms.

The main mechanisms of the influence of EMF on biological object are presented in [1].

From the above it is possible to conclude that a biological object that has its own set of internal frequencies and wave processes, can participate in the phenomena of biological resonance at the resonance frequencies of its structural elements or their combinations.

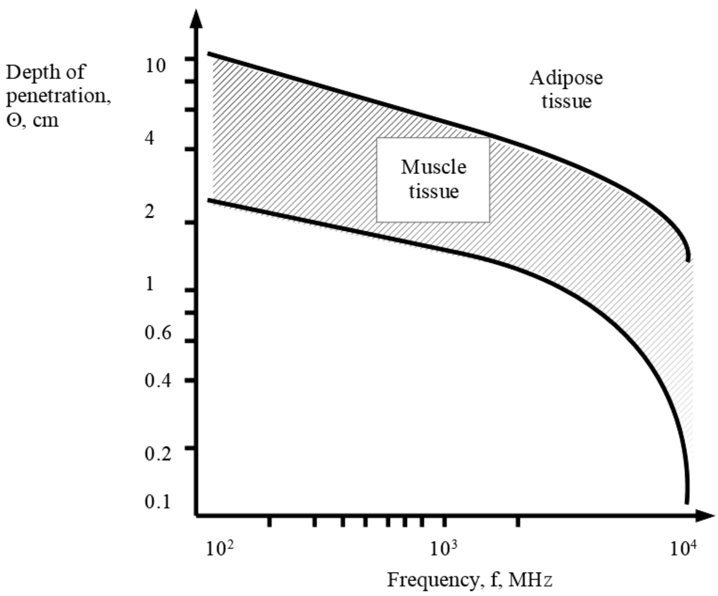

Fig. 1. The depth of penetration of the EMF into muscle and adipose tissues depending on the frequency

The corresponding resonant frequencies also depend on the dielectric and other properties of components of the biological substance. Thus, the internal biological resonance determines the entire information-wave process of a living organism. At the same time it manifests itself much more often, than external resonance, more precisely, it occurs constantly and continuously.

The external resonance is determined by the factors of environmental change and anthropogenesis, including that one used for prophylactic and therapeutic purposes. Such resonance can be used as a method of controlling a biological object.

All these conditions can be divided into states of norm (biological object is «healthy») and pathology (biological object is «sick»). The states of both norm and pathology can be many for each object, including age changes, influences of climate, geographical conditions, seasons of the year and so on. In general, the state of the norm is characterized by the corresponding information-wave processes [7].

When the living system leaves the state of norm outside the adaptation, there is a reverse effect. Affected parts influence the normal parts of the living system by a «distorted» information-wave process.

Representations of functional systems of an organism are located in zones of information-wave influence (IWI) which in many respects imitate topology of the Chinese meridians and the acupuncture points located on them. The IWI zones, however, are more general in nature and have, in contrast to adjacent morphological structures, the pronounced differential electrodynamic characteristics (impedance, biochemiluminescence, radiometric temperature in the microwave and UHF ranges, and so on). An important feature of the IWI zones is also their large (compared to the area of acupuncture points) spatial length, which methodically simplifies the information wave technology, as the design features of the emitter and the diffraction threshold of radiation do not require accurate knowledge of the IWI zone topology [8].

It is also established that the electrodynamic model of the acupuncture points makes it possible to consider them as microwave and UHF antennas, and the set of the acupuncture points on the corresponding meridian makes it possible to consider them as phased arrays even in lower frequency ranges, because the distances between individual array points are measured in proportional segments multiples of the length of the phalanx of the middle finger.

The process of EMF penetration into human tissue is described in [1].

Cells regulate their functions, eliminating the resulting disturbances and adapting to changing living conditions, using coherent acoustoelectric waves. Propagating throughout the body, these waves can promote the organization of interconnection and control of intracellular processes in general.

For a long time a number of authors put forward and considered various hypotheses about the effect of the EMF on biological systems [8–10]. They prove that living organisms do not have specific receptors for the perception of the EMF of the microwave range [11, 12].

Hypothesis put forward in [8, 12, 13] suggests that the external EMFs of the microwave range, simulating the body's own microwave radiation, synchronize, using the principle of resonance, «healthy» rhythms lost in the disease, and restore electromagnetic homeostasis. In this case, the primary processes occur in cell membranes, and the transfer of information to organs is carried out through nerve fibers. The therapeutic effect of the EMFs of the microwave range is based on their resonant interaction with the natural oscillations of molecular oscillators of the sick body. Due to this, the restoration of «normal» resonant frequencies and phase synchronization of molecular oscillations occurs under the action of the EMFs [14]. Thus, the «information» effect of the EMFs of the microwave range consists in the purposeful transmission of microwave energy quanta to «deformed» molecular oscillators of the body.

Thus, today there is no consensus on the mechanisms of interaction of the EMF with a living organism. A large number of hypotheses suggest that the EMF action is carried out in several ways, but, on the other hand, it is obvious that these mechanisms have not yet been fully explored. At the same time, it should be noted that, unlike the orthodox sciences, which ignore inexplicable facts, this concept has room for everything that is still unexplained, and at the same time there are no contradictions where the facts and models corresponding to them are strictly proven [15].

Thus, today the concept of «cellular mechanisms of millimeter wave action on the body» combines the totality of changes in the functioning of cells. That is, changes in metabolism and cellular response to the effects of these mechanisms.

3. Research results and discussion

3.1. Millimeter-wave technology and its application in medical practice. Electromagnetic radiation of the millimeter range of low intensity has long been the subject of close

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attention and clinical studies. Over the last decade, based on the results of numerous experimental and theoretical data, millimeter waves are being introduced increasingly into medical practice. Today, there are three schools of millimeter-wave (MMW) technology (MMWT): high-frequency technology (UHF technology), microwave resonance technology (MRT) and information wave technology (IWT). They differ from each other by the type of irradiation, areas of action and frequencies used during treatment [8, 11, 12].

According to the method of UHF technology, based on the nosological diagnosis, the choice of standard radiation frequency is made: 42.25 GHz (7.1 mm), 53.57 GHz (5.6 mm), 61.22 GHz (4.9 mm), 118.57 GHz (2.53 mm) and the standard range of action (sternum, occiput, epigastric region, joints).

Simulating internal signals, the electromagnetic radiation activates the available reserves and accelerates the adaptation and recovery processes aimed at eliminating damages [16].

The IWT method is based on the use of a broadband UHF noise generator, which covers all possible therapeutic frequencies used in the MRT. Due to this, the implementation of the method does not require prior search and selection of therapeutic frequencies, the patient's body adjusts itself to the required therapeutic frequency of the millimeter range.

Today, the results of numerous experimental and theoretical studies of electromagnetic radiation in the millimeter range are based on the latest methods of treatment, widely used in clinical practice [17–19].

Millimeter technology is used in the complex treatment of:

– gastroenterological diseases;
– gastric duodenal ulcer;
– gastric and peptic ulcer;
– gastritis;
– duodenitis;
– gastroesophasal reflexes;
– chronic inflammatory diseases of the liver and biliary tract;
– biliary dyskinesia;
– chronic pancreatitis;
– chronic enterocolitis, in particular ulcerative colitis.

Treatment with EMR (electromagnetic radiation) of the MMR (micrometer range) makes it possible to reduce significantly the duration of treatment, reduce the number of relapses, increase the duration of remission [20].

The use of low-intensity oscillations after surgery, reduces and relieves pain in postoperative patients, eliminates inflammatory reactions in a short time, reduces the number of postoperative complications, promotes tissue regeneration in the area of injury. The use of the MMT (micrometer technology) in surgery and anesthesiology can limit significantly and in most cases exclude the use of drugs and reduce the length of hospitalization of patients by 20–25 % [21–23].

The effect is established of electromagnetic radiation on the indicators of the blood coagulation system in diseases of the cardiovascular system, in particular, angina pectoris, myocardial infarction [24]. The use of electromagnetic radiation as a monotherapy and in combination with traditional drug therapy for the treatment of patients with coronary heart disease is effective [25]. With angina pectoris, the EMR helps to reduce the frequency and transition of the progressive angina pectoris to the stable one. As a result, the reserve capacity and aerobic capacity of the myocardium increase [26].

In order to determine the biophysical effect of EMR (electromagnetic radiation) of the MMR (micrometer range), scientists carried out a large number of experimental works, where various biological structures were used as objects of research: cultures of microorganisms, plant cells, nerve cells of mollusks, uniform blood cells, etc. [27]. Yet, among the experimental data obtained, there was no consensus on the physical mechanisms of interaction of millimeter waves with biological objects, since the key link of the interaction is unknown.

It is believed that low-intensity electromagnetic radiation is a universal mechanism for transmitting information both between living objects and between cells within a biological object.

The use of low-intensity fluctuations after surgery, makes it possible to reduce and stop the pain syndrome in postoperative patients, eliminates inflammatory reactions in a short time, reduces the number of postoperative complications, contributes to the area of injury [24, 28].

Thus, millimeter-wave technology has established itself as a promising and highly effective method that allows achieving a full and lasting positive result. Due to a wide range of clinical uses of the MMT, it is possible to talk about the possibility of using it in almost all cases requiring the use of therapeutic drug treatment methods. While noting the effectiveness of EMR, the possibility of using the MMT (micrometer technology) as a monotechnology should be emphasized, this distinguishes it from common pharmacological methods, which are not always effective and have side effects.

3.2. Experimental study of the effect of the EMF of ultra-low intensity on biological structures. For a long time, experiments were carried out on the positive effect of the EMF on biological objects. A study was also carried out on the basis of National Aerospace University «Kharkiv Aviation Institute» (Ukraine). The seeds of wheat in a state of «norm» and «pathology» were selected as biosensors (objects for research) [29].

A special stand was developed for studying wheat seeds under the action of external EMFs to reveal the biosensor effect. The choice of irradiation modes and the development of methods for conducting experiments, including preliminary preparation of the control biological objects, exposure to EMF, as well as the analysis of indicators of biological activity, were substantiated. The paper presents a methodology for statistical processing of the results. Based on the results of experimental studies, the effectiveness of the EMF action on the control biological object was established. The possibility of modifying indicators of the functional activity of biological objects by irradiating them with low-intensity EMFs, which differ in spectral-temporal characteristics, was proved. The dependence of the functional response on the frequency of the total spectrum width and the spectral distribution of the signal was revealed. Difference in the response of the control biological object under a power-law irradiation is observed and an increase in dispersion is revealed, this testifies in favor of the frontal-hierarchical model of the EMF action on the control biological object, this model belongs to the radio engineering device investigated in [21, 29].

Based on the carried out work, a previously developed stand was modified and experiments were carried out, where the object of study was the interaction of electromagnetic oscillations [30] of the MM range with the cells of the rat bone marrow. Low-intensity millimeter-wave electromagnetic waves were the subject of research [31–33].

A broadband generator of electromagnetic radiation built on the principle of a gas spark discharge in a cylindrical waveguide was used as a source of the EMF. The repetition rate of the discharge pulses is set by the clock generator, the duration of the active part of the discharge is determined by the pulse shaper, the amplitude of the voltage, that is necessary for electrical breakdown in the discharge gap, is achieved by using a pulse transformer [34]. This device generates noise signals of electromagnetic radiation in the frequency range 60–300 GHz with a flux density of 10^{-19}–10^{-21} W/Hz·cm^2. Fig. 2 shows the structure of the generator emitter [35].

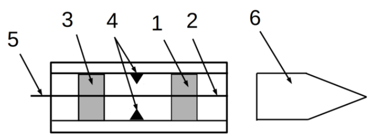

Fig. 2. The structure of the emitter of the spark discharge generator: 1 – waveguide; 2 – central rod; 3 – dielectric supports, impedance transformers; 4 – metal protrusions, discharge inhibition area; 5 – inputs of electrodes; 6 – dielectric rod antenna

A study was carried out and the safety was proved of this electronic device use in medical practice in accordance with sanitary standards [36].

The generated spectrum of electromagnetic waves contains linear (deterministic) and continuous (noise) components. The lower oscillation frequency is determined by the pulse repetition frequency (20–50 Hz), the upper one is determined by the effective radiation band of the dielectric antenna. The energy within the spectrum is distributed according to the law ~$1/fn$ (n=1–3), where f are the frequencies of the spectral components. This distribution is typical for the intrinsic thermal radiation of biological objects [37].

It is obvious that the accompanying technical diagnostics of the device is necessary for the correct introduction of the information wave technologies into clinical practice in addition to purely medical research. First of all, this refers to the main factor, namely, broadband electromagnetic radiation with a flicker-type noise spectrum, which reproduces the radiation frequency ranges of living cells with a noise power spectral density not exceeding 10–16 W/cm^2·Hz. It is the very low radiation intensity that is a significant engineering problem in diagnosing the technical condition of the device. The second most difficult problem is associated with the broadband radiation. It is believed that to ensure the necessary biological effect, the maximum radiation frequencies should be at least 60–300 GHz, which is achieved by the design features of the spark discharge generator [38, 39].

To study the effect of EMR of the MMR on the culture of rat bone marrow cells, a spark discharge generator was used in the band of biologically significant frequencies (at frequencies of 50–60 GHz) with a periodic pulse discharge in atmospheric air with a streamer nature of electrical breakdown, and an improved express method of biotesting [40–42].

The experiments were carried out on a model test system of rat bone marrow cells [43, 44] in order to establish the possible effect of EMR of the MMR on the stability of cell membranes and, as a consequence, cell viability. During the experiment, the effect of millimeter-wave electromagnetic radiation on rat bone marrow cells was investigated for 10, 20, 30, 40, 50 and 60 minutes.

Statistical evaluation of the obtained data on cell viability was carried out using a technique developed by us, in which the evaluation criterion was the calculation of the percentage of dead cells. Assessment of the effect of an external destabilizing factor (physical, chemical or mechanical) on cells was determined by its ability to damage cells or dramatically change their morphological characteristics [45, 46].

The expediency of using this statistical processing of the methodology is explained by the clarification of the following aspects:

1. The peculiarity of distributing the mass of biological objects of the same type according to any characteristic.
2. Mathematical modeling and forecasting of changes in any characteristic of a biological object with a change in an external factor affecting this characteristic.
3. The peculiarity and nature of the relationship between individual signs of biological objects in accordance with their number.
4. Revealing the nature and degree of influence of any factor on the change in the corresponding characteristics of biological objects, comparing the mean values and determining the reliability of the difference.
5. Determination of the reliability of the obtained results of experimental studies.

The above aspects are solved mainly using: correlation, regression analysis: laws of distribution of random variables.

The essence of the method is that after interaction with any external destabilizing factor, trypan blue solution was added to the cell suspension, then the functional state of the bone marrow cell membranes was assessed by the intensity of cell staining [43].

Biological membranes of the functioning cells of various types have a universal meaning due to the presence in them of specialized receptor proteins that are able to regulate energy and biochemical processes in the cell, as well as the water space inside and outside the cell [42, 43]. Literature data regarding the effect of EMR of the MMR directly on membranes include studies of excitable cells, non-excitable cells, model systems of liposomes, and bilayer lipid membranes. Therefore, an experiment was conducted to study the effect of low-intensity electromagnetic oscillations precisely at the cellular level.

In samples of rat bone marrow cells after thirty minutes of irradiation, the selective mean proportion of dead (stained) cells was 1.14 times lower than in the unirradiated control sample. After 60 and 90 minutes of irradiation, this value was 1.17 times lower than in the unirradiated control sample.

Thus, the EMR created by the proposed device has a positive effect on the viability of cells, it increases the resistivity of the membrane to external factors, as evidenced by a decrease in the level of permeability of the dye into the cell.

The calculation of the average proportion of dead cells for a series of measurements was calculated as the ratio of the number of dead cells to their total number. After this calculation, a statistical evaluation was performed in order to establish the reliability, reproducibility and statistical significance of the data. Determined the standard

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deviation of the population. the standard error of fate for a series of measurements, which make it possible to assess the accuracy of the obtained data.

The confidence interval of the values is calculated in which the true value of the parameter is found with a given confidence level and the sampling criterion is determined.

The data obtained during the 30 min irradiation show that the selective average fraction of dead cells in the rat bone marrow samples was 1.9 times lower than in the unirradiated control sample. And at 60 and 90 min of irradiation, this difference reached 2.3 times.

The calculated indicators are presented in Table 1.

During the statistical processing of the experimental data, the equations of the nonlinear regression laws were obtained by the approximation method. For experimental data obtained after 30 minutes of irradiation, the law is $y=0.06x^2-0.4x+13.5$, the degree of accuracy of the approximation is 2 and the reliability value is 0.9716. For experimental data obtained after 60 minutes of irradiation, the law is $y=0.5x^2-4.6x+14.77$, the degree of accuracy of the approximation is 2 and the reliability value is 0.9815. These results confirm the reliability and reproducibility of the experimental results. Fig. 3 shows the measurement results and the statistical model of dependence of the dead cells proportion on the exposure time and the type of approximating polynomials.

In the course of the experiment, the dependence of the number of dead cells on the time of exposure to EMR of MMR was established. The dependence of a decrease in the selective average proportion of dead cells with an increase in the time of exposure to radiation from 10 to 30 minutes was experimentally proved. With an increase in the exposure time from 30 to 60 minutes, this figure increases. Thus, the established minimum time with the maximum positive effect of the impact on the bone marrow cells of rats was 30 minutes. This was confirmed by the calculated dependency level. The obtained results show that the effect of informational electromagnetic radiation is able to modify the immune status of the organism of bioobjects, exert anti-inflammatory effect, activate physiological and reparative regeneration. But it is necessary to take into account the duration of radiation, as well as design features of the emitter.

In conclusion, it is established that the effects are of a diverse nature, ranging from indifference to stimulation and suppression. These effects are manifested differently depending on the initial state of the biological object, the type of signal modulation and their structural organization. In addition, these dependences are non-monotonous and even change the sign of the effect to the opposite one, which seems to reflect the competitive nature between the effects of stress and adaptation.

Table 1

The calculated indicators

Indicator	Radiation time, min					
	30		60		90	
	Non-irradiated control	Irradiated control	Non-irradiated control	Irradiated control	Non-irradiated control	Irradiated control
Average proportion of dead cells	5.2	2.8	9.8	4.1	11.8	5.2
Standard deviation	0.3	0.23	0.46	0.29	0.52	0.35
Upper bound of the interval	4.6	2.3	8.9	3.5	10.8	4.5
Lower bound of the interval	5.8	3.3	10.7	4.7	12.8	5.9

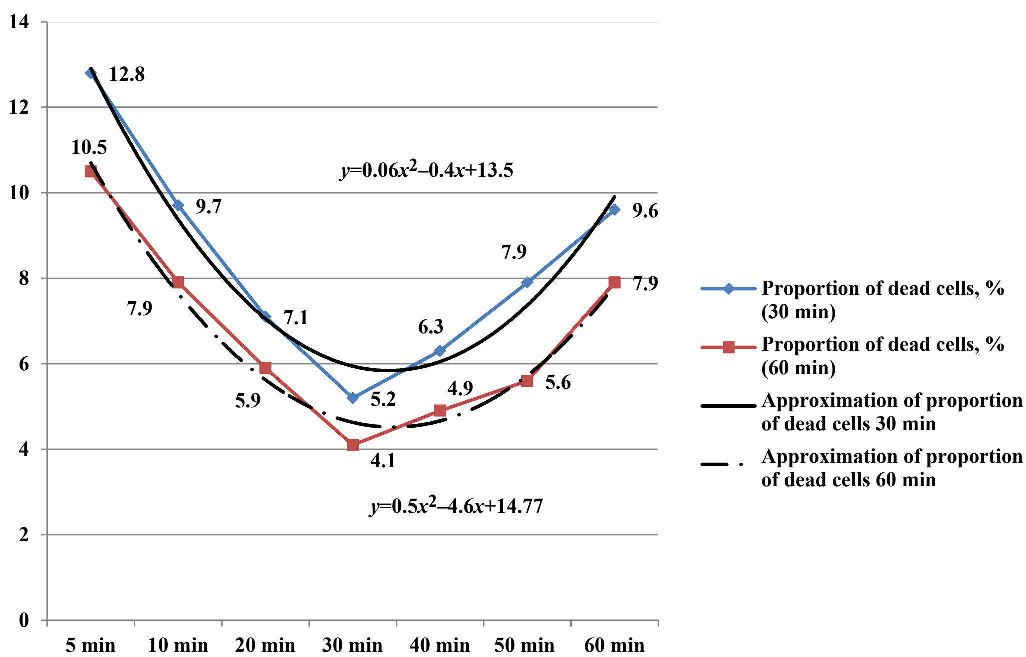

Fig. 3. Statistical model of the dependence of the proportion of dead cells on the exposure time

The proposed results can be used in the development and modernization of medical systems that operate on the principle of formation of broadband electromagnetic radiation of the millimeter range.

This study has a number of limitations. Potential distant effects, including genetic effects of exposure, need careful recruitment and accumulation of experimental data obtained under controlled conditions. The generalisation of results and the development of promising models seems to require the inclusion of new variables under which the effects will be robust and reproducible in the interest of targeted modification of plant properties. Also, significant difficulties in conducting this kind of research are caused by the fact that there are practically no appropriate predictive theoretical models, since the bioobjects under study are complex biological systems.

Thus, the above data indicate the presence of a biosensor effect when exposed to an ultralow intensity broadband electromagnetic field of the developed emitter. The quantitative characteristics of biological responses are of the same order (and in some cases higher) than those of exposure to monochromatic and narrowband noise radiation.

4. Conclusions

The paper considers the theoretical substantiation and a new solution to the scientific problem of finding ways to determine and establish the effect of low-intensity MM range electromagnetic radiation on rat bone marrow cells. A method of data statistical processing has been proposed and the dependence of the decrease in the number of dead cells on the time of irradiation has been experimentally proved, as well as an improved method for determining the effect of an external destabilizing factor on the culture of rat bone marrow cells in vitro. A new method of processing experimental data using statistical calculations is proposed. This method meets the requirements for processing and interpreting the results. Also it allows a comprehensive assessment of the performance of preclinical studies. This method clearly reflects the data obtained, allows reliability, reproducibility, determines their statistical significance.

The dependence of the decrease in the number of dead cells on the time of exposure to EMR MMR has been experimentally proved. The quadratic equation of the dependence of the selective average proportion of dead cells in the bone marrow on the time of irradiation $y=0.06x^2-0.4x+13.5$ was calculated. The minimum time with the maximum positive effect on the rat bone marrow cells was established and statistically confirmed by data processing, which was 30 minutes.

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