

## Ethological Changes and Teratogenesis of Model Organisms as an Indicator of Biotesting of the Electromagnetic Radiation Influence

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### ABSTRACT

With the development of information technology, electromagnetic radiation becomes a tangible view of the physical (wave) environmental pollution. Modern scientific research aimed at the components of the electromagnetic environment pollution problems mainly involves the anthropocentric approach. There is no procedure for determining the influence of harmful physical factors on biota, in particular in terms of water (*Daphnia magna* Straus) and air (*Drosophila melanogaster* L.) environments. A clear system of rationing of maximum permissible levels of electromagnetic radiation, including volume and ecosystems protected areas has not been developed. The article considers the relevant scientific and practical problem of creating a framework for assessing and predicting the negative impact of electromagnetic radiation on the biota related to ethological changes and teratogenesis. The characteristic of all the constituent elements of the system determines the degree of the negative impact of the induction of the magnetic field on the biota: activity, mortality; reproduction; availability, and frequency of Teratology. A method for determining the activity levels of *Daphnia* and *Drosophila* total average activity biota was developed and described. The trajectory patterns of *Daphnia* motion at low activity in the state of stability, with increased activity in the excited state, were created. The results of the research on the negative impact of electromagnetic radiation of industrial frequency on biota were presented. The critical levels of the magnetic field and noise pollution, which cause the depletion and destruction of the test object, the relationship between ethological changes and the occurrence of mutations depending on radiation levels were determined. The biological test objects were proven to minimize the error of the results of determination of electromagnetic effects on the biota, in comparison with the mathematical methods of research.

**Keywords:** bio testing, ecological safety; electromagnetic radiation; magnetic field; model organisms, activity levels, teratogenesis, mortality.

## INTRODUCTION

Assessment of the ecological situation as a diagnosis of the state of natural and natural-anthropogenic ecosystems to predict its changes is a rather complicated process, especially in the absence of clear criteria for the quality of the environment and regulatory restrictions on harmful physical factors. Intense electromagnetic fields (EMF) cause a violation of the structural and functional organization of various organs and their physiological systems in the human body: cardiovascular, neurohumoral, and reproductive, and also increase the likelihood of developing congenital teratologies. Fatigue and lethargy may appear, the accuracy of movements may decrease, blood pressure and pulse may change, the headaches and arrhythmias may occur (Burlaka and Gozhenko, 2010). Under the conditions of prolonged occupational exposure with periodic exceeding the maximum permissible levels, some people have the secretion and acidity of gastric juice changes, and biliary dyskinesias occur (Oleshko, 2011).

On the part of the endocrine system, there is an increase in the functional activity of the thyroid gland, a change in the nature of the sugar curve, etc. (Burlaka and Gozhenko, 2010). It is assumed that the dysregulation of the physiological functions of the body is due to the effect of the field on various parts of the central nervous system, the increase in excitability of which occurs due to the reflex action of the field, and the inhibitory effect occurs due to the direct effect of the field on the structures of the brain and spinal cord (Maletkin et al., 2011). It is believed that the telencephalon and diencephalon are especially sensitive to the effects of EMF.

In recent years, there have been data on the possibility of causing EMF oncological diseases. The works of British scientists have shown that a number of people suffering from allergies develop an epileptic-type reaction under the influence of the field of power lines. At the end of the last century, Weitemer and Leeper reported on the relationship between childhood leukemia and an increased level of EMF (up to 0.3–0.4  $\mu\text{T}$ ) under home conditions. Such a relationship between neoplasms and adults living under the conditions of exposure to low-frequency EMF has not been established. N.P. Zalyubovskaya found a decrease in the fertility of *Drosophila*, as well as an increase in its mortality due to an increase in the exposure time of millimeter-wave waves

(Zalyubovskaya, 1970). In a homogeneous EMF, the death of *Drosophila* is observed. The negative effect of EMF on warm-blooded animals is also known (Tomashevskaya et al., 2013; Orlyuk, 2014). Currently, the study of the effect of EMF on human health and on the biosphere as a whole is coordinated by the World Health Organization. The reason for the disagreement in the regulatory documents of various countries is the insufficient knowledge of the impact of EMF on humans and biota, high rates of introduction of new types of radiation sources and their wide distribution, as well as an increase in various types of radiation in places of permanent residence.

The problem of interaction of electromagnetic and biological systems does not lose its relevance nowadays (Zagirnyak, 2016). The influence of electromagnetic radiation (EMR) on physiological processes, biochemical changes in living organisms (insects, mammals), etc. has been studied (Chernyy et al., 2013; Podobed, 2012; Yaremchuk, 2014). The adaptive activity of the body is formed under the influence of EMR at different levels of organization (from cellular to systemic). The architecture of the functional system is specific and depends on the physical parameters of the EMP. The high intensity of the factor corresponds to a greater number of the structures participating in the reaction-response, which includes an assessment of the protective, compensatory, and adaptive capabilities of the organism. Reaction-response is based on:

- temporal synchronicity of the onset of EMP action and the response of the investigated integrative levels, which characterizes the sensitivity of systems to the influence of the factor;
- the duration of fixed changes in the studied systems, which shows the functional efficiency of the recovery processes of biosystems;
- the dynamics of changes in the functional state of the studied systems, characterize the stability, lability, and reactivity of systems.

The characteristic features of the inclusion and mobilization of the adaptive-compensatory mechanisms at the studied integrative levels are a prognostic criterion for the consequences of a damaging effect (Kukhareenko et al., 2020). Using the data of the original research they substantiate, the principles of improving the methodology for assessing and predicting the negative impact of some physical factors that form an environmental hazard, including the influence of EMF

on biological objects, as well as a system of the gradation of hazard levels, have been developed. This enables us to determine the feasibility of using specific measures aimed at ensuring environmental safety and reducing the negative impact of electrical systems on biological.

### CALCULATION METHOD AND RESULTS

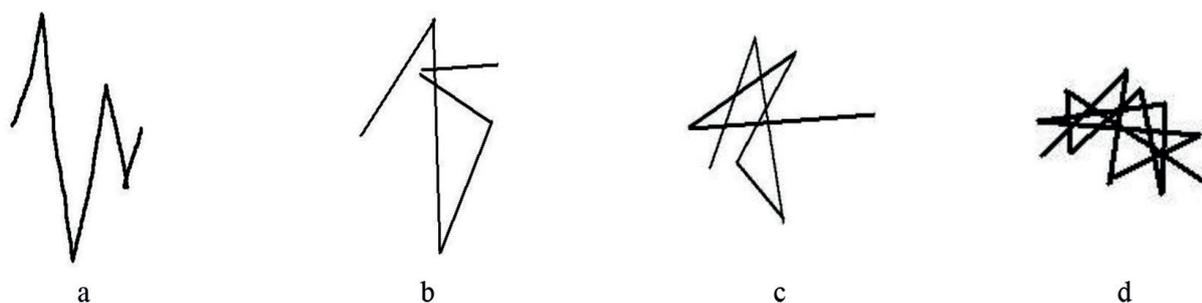
Theoretical research was based on the application of logical methods, including comparative analysis and generalization. To measure the induction of magnetic field (IMF), a TM-191 magnetometer (200-2000 MGS, 20-200  $\mu$ T, 30–300 Hz) was used. Bio testing was carried out using model organisms (MO): *Daphnia magna* Straus and *Drosophila melanogaster* L. The studies were carried out according to an original method for assessing the level of harmful effects of noise and electromagnetic pollution on MO (Sakun, 2014), including an assessment of the degree of their activity, lethality, reproductive capacity, presence

and frequency teratologies. To assess the activity of MO based on the results of laboratory studies, a point system was developed (Table 1). The criteria for establishing the conditional degrees of MO activity are the speed, trajectory, and nature of their movement (Fig. 1).

The spatial and temporal characteristics of the MO location based on the analysis of video material and serial photographs were studied by storyboarding using applied computer programs. The conditional mortality rate is the percentage of mortality from zero to three (death of one individual in the control group). The value of the reproduction of MO was calculated for each level of pollution. Various types of phenotypic manifestations of mutations and the frequency of their occurrence were recorded. During the research, constant conditions were maintained: photoperiodism, temperature 22–25 °C; pressure 756–762 mm. rt. st; humidity 40–50%. The overall average statistical activity of the MO was determined by means of the following formula (Pasenko et al., 2021; Svjatenko et al., 2021; Ushakova et al. 2021):

**Table 1.** System for assessing the activity of model organisms

Score	Activity levels	The nature of the movement and behavior of the MO	
		<i>Daphnia magna</i> Straus	<i>Drosophila melanogaster</i> L.
1	Inhibition	Movement is almost not observed: $v \rightarrow 0$ .	Subtle movement: $v \rightarrow 0$ , MO collected in the places farthest from the source of EMF.
2	Decreased	$3 \leq v \leq 6$ mm/s, freeze period 30–50 s, the trajectory of movement is a broken line with a small number of links, the movement is almost vertical (Fig. 1a).	$1 \leq v \leq 3$ mm/s, short flights (up to five per minute), stopping time up to 120 s.
3	Stable	$6 \leq v \leq 10$ mm/s, freeze period 20–30 s, the trajectory of movement is a broken line with a small number of links, the movement is vertical-horizontal (Fig. 1b).	$4 \leq v \leq 6$ mm/s, up to six jumps-flights, duration of stops 15-60 s, movement is conditioned only by physiological needs.
4	Increased	$10 \leq v \leq 20$ mm/s, freeze period 6–15 s, the trajectory of movement is a broken line with a large number of links, the movement is vertical-horizontal (Fig. 1c).	$6 \leq v \leq 10$ mm/s, the number of flights is up to 20, the time of stops is 10–15 s, they move mainly in the upper plane of the laboratory vessel.
5	Excited	$20 \leq v \leq 35$ mm/s, freeze period 1–5 s, trajectory of movement - a broken line with a large number of links, movement in a vertical-horizontal plane with many intersections of links (Fig.1d).	$v > 10$ mm/s, up to 40 jumps-flights, single stops lasting 1–2 s, chaotic movement in the upper plane of the test tube.



**Figure 1.** Projections of the trajectories of model organisms' motion on the horizontal plane: with reduced activity (a), in a stable state (b), with increased activity (c), in an excited state (d)

$$A = 1a_1 + 2a_2 + 3a_3 + 4a_4 + 5a_5 \quad (1)$$

where:  $a_{1-5}$  – score frequency/number of individuals, %.

Thus, the use of a new universal methodology makes it possible to determine the degree of influence of any stress factor on MO in aquatic (hydrobionts – *Daphnia magna* Straus) and air (aerobionts – *Drosophila melanogaster* L.) habitat. At the same time, the main system-forming indicator of the technique is the activity of the MO. The effect of EMI on the biota was studied taking into account the change in the MO response as a result of the influence of different levels of magnetic field induction. The experiment excluded the action of other factors. A comparative analysis of MO activity under short-term and long-term exposure to magnetic field induction was carried out, also after the termination of the stress factor (Nykyforov et al., 2020). Statistical

methods were used to assess the reliability of the experimental results. The received data were processed using Microsoft Office and Stat Graphics packages. Models of the regression dependence of the activity of aquatic organisms (2) and aerobionts (3) are polynomials of the second degree:

$$R_B = 3.07982 + 0.495767x_1 + 0.0000209143x_2 + 0.00000137769x_1x_2 - 0.0880847x_1^2 + 2.72533 \cdot 10^{-9}x_2^2 \quad (2)$$

$$R_B = 3.19344 + 0.524286x_1 - 0.0000191814x_2 - 0.00000704988x_1x_2 - 0.153511x_1^2 + 8.4961 \cdot 10^{-8}x_2^2 \quad (3)$$

where:  $R_L$  – MO activity, score;  $x_1$  – stress factor level;  $x_2$  – the duration of the stress factor.

An analysis of the reproduction of generations showed that an IMF in the range of

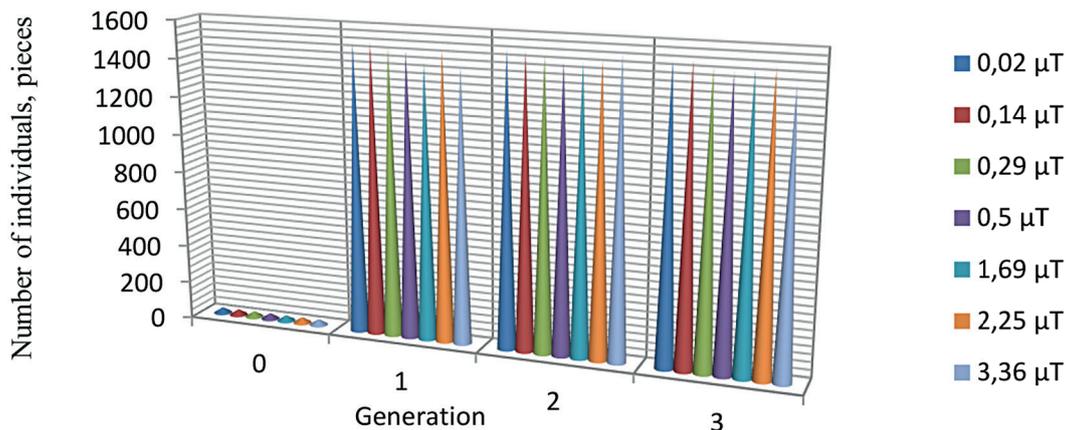


Figure 2. Reproductiveness of *Drosophila melanogaster* L. depending on the levels of magnetic induction

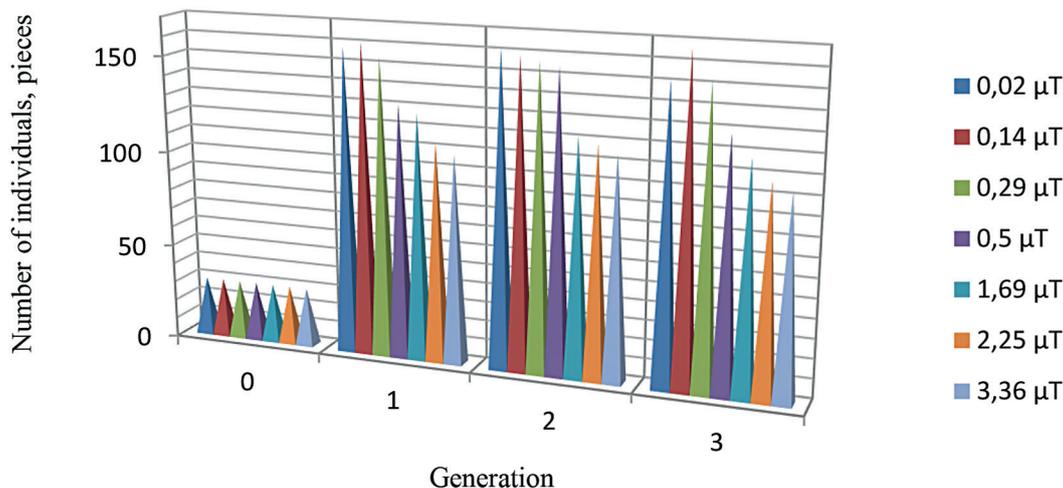


Figure 3. Reproductiveness of *Daphnia magna* Straus dependence on the levels of magnetic induction

0.02–3.36  $\mu\text{T}$  has almost no effect on the number of *Drosophila* offspring (Fig. 2), but there is an imbalance between different stages of metamorphosis (change in the duration of the larva and pupa stages). At the same time, the same levels of induction cause a marked decrease in *Daphnia*'s reproductive capacity (Fig. 3).

With a level of IMF = 3.36  $\mu\text{T}$ , the *Daphnia* reproductive level decreased in the third generation by 30% compared to the norm. There is a tendency to return to the birth rate in the second generation at an IMF of 0.02 to 0.5  $\mu\text{T}$ , but in the third generation again shows a difference in reproduction, characteristic of the first generation. At IMP = 0.02  $\mu\text{T}$  for 10 days, no cases of death were found among MO. The increase in mortality on the second day of the experiment was recorded, starting with an induction level of 1.69  $\mu\text{T}$  (Fig. 4, 5).

In fruit flies on the fourth day, cases of death were established already at the induction of 0.29  $\mu\text{T}$ . Crustaceans die at the same magnetic field values two days later (on the sixth day of research). The reaction of MO to the level of IMF = 0.14  $\mu\text{T}$  is similar. With prolonged exposure to IMF, the MO activates the mechanisms of active adaptation, which, at exorbitant values, cannot protect the body. The first increase in *Drosophila* mortality (up to 9% of deaths) was recorded at induction of 1.69  $\mu\text{T}$  on the sixth day of the experiment; at 2.25  $\mu\text{T}$ , mortality did not increase.

At levels of IMF = 2.25  $\mu\text{T}$ , there is an abrupt increase in the number of deaths (13%) on the eighth day of the experiment. At the same time, *Daphnia* responds to the changes in IMF levels more evenly: with an increase in induction, the percentage of deaths gradually increases. Pearson's correlation coefficient ranges from 0.90 to

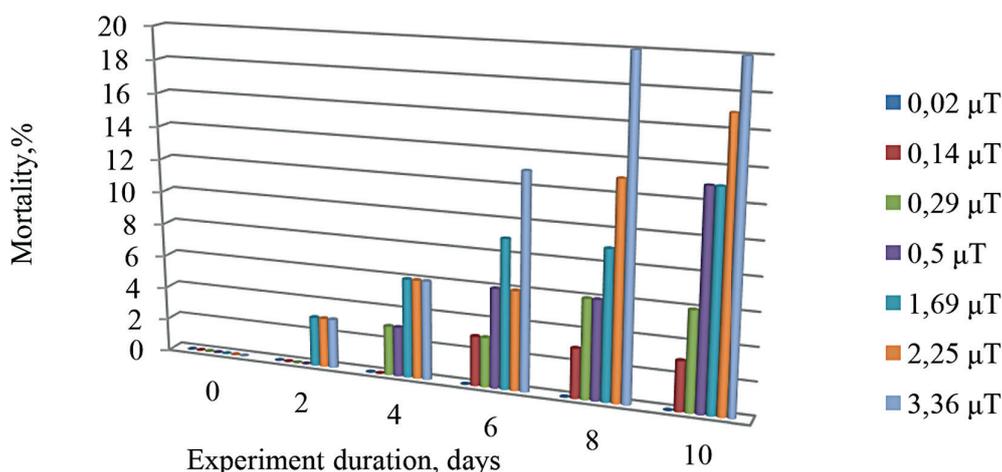


Figure 4. Mortality of *Drosophila melanogaster* L. depending on the levels of magnetic induction

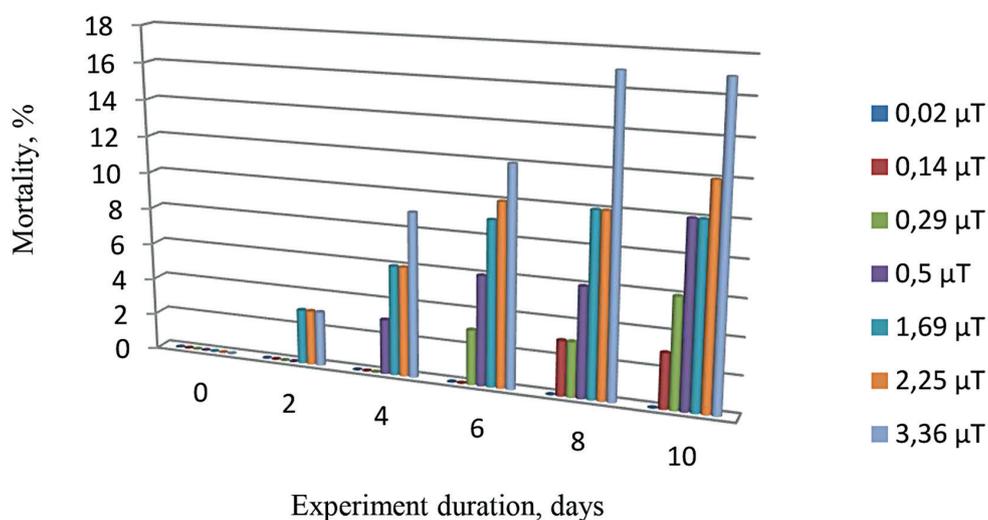


Figure 5. Mortality of *Daphnia magna* Straus depending on the levels of magnetic induction

0.95. During the experiment, organisms respond to a stress factor by increasing their activity. However, it should be noted that after the termination of exposure, restoration of the initial activity (return to normal) is observed (Fig. 6).

In the studies of the long-term effects of EMR on aerobionts, new forms of mutations associated with morphological deformations of organs were recorded. The phenotypic manifestation of the first mutations was recorded under constant exposure to electromagnetic radiation with a frequency of 50 Hz and  $IMF \geq 2.25 \mu T$ . With IMF indices of 2.25–5  $\mu T$ , the frequency of *Drosophila* mutations for three generations fluctuates within 0.2–1% (Fig. 7). Abdominal deformities and wing modifications

are more common than other teratologies. Under the action of  $IMF = 5–20 \mu T$ , mutations occur in 3% of individuals with high mortality (> 15%).

At the next stage of the research, the activity and reproduction of MO were analyzed depending on the intensity of the effect of magnetic induction, the percentage of mortality was established, and the conditionally permissible levels of hazard of exposure to IMF were determined. The results of the analysis make it possible to generalize different reactions of MO and compare them with the corresponding levels of IMF (Table 2). It has been experimentally proven that a high environmental hazard is represented by the  $IMF > 7.6 \mu T$ . During the constant action

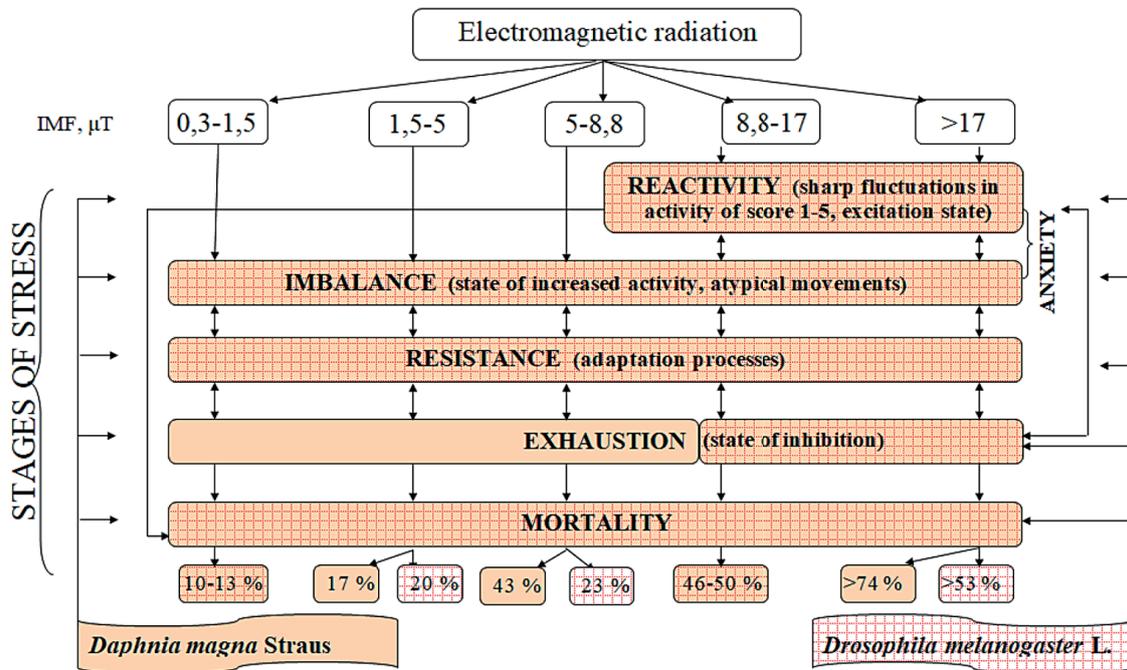


Figure 6. Diagram of the dependence of MO activity on the duration and intensity of the action of electromagnetic radiation

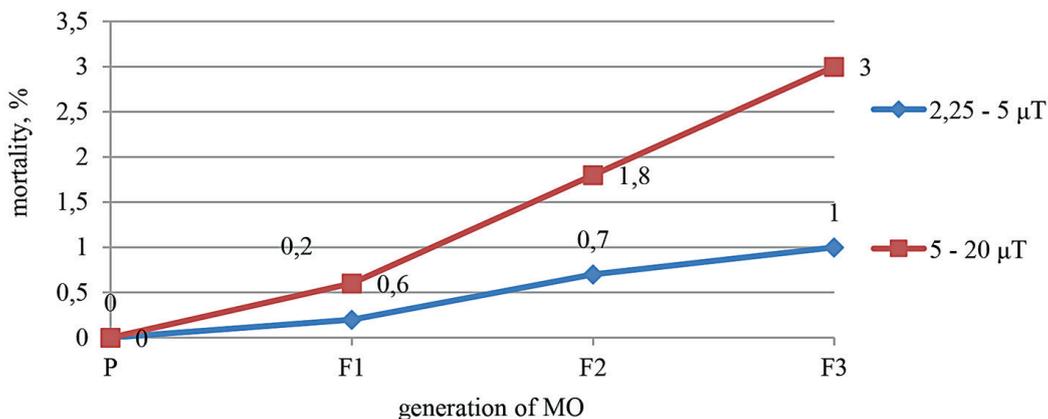


Figure 7. Frequency of mutations in *Drosophila melanogaster* L. induced by electromagnetic radiation

**Table 2.** Grading of risk levels caused by electromagnetic radiation

Level environmental hazard	Magnetic field induction, $\mu\text{T}$	MO response characteristic in water and air conditions	<i>Daphnia magna</i> Straus				<i>Drosophila melanogaster</i> L.			
			Activity, score		Reproductiveness, for 1 individual	Mortality, %	Activity, score		Reproductiveness, for 1 individual	Mortality, %
			short-term impact	Long-term impact			short-term impact	Long-term impact		
Sublethal	>34	Sharp changes in activity from complete lethargy to overexcitation. The lethality is high. A decrease in reproductive performance by >73%.	0–5	0–5	0–20	>85	0.5–5	0.4–5	32–58	>60
Unbearable	17.2–34	Strong excitement turns into lethargy. Reproduction of <i>Daphnia</i> decreased by an average of 70%, <i>Drosophila</i> – by 40–50%	0.7–4.9	0.6–4.8	5–24	74	0.5–4.9	0.7–4.6	92–121	53
Very high	8.8–17.2	Sharp changes in activity from excitement to inhibition. Reduced reproduction of <i>Daphnia</i> by 45–55 % <i>Drosophila</i> by 15–35%	1–4.9	0.7–4.7	2–47	50	1–4.8	1.1–4.5	121–180	46
High	5.2–8.8	Activity ranges from dull to agitated. Reproduction of <i>Daphnia</i> decreased by 32%, <i>Drosophila</i> increased by 2%	1.4–4.7	1–4.6	1–57	43	1.5–4.8	1.3–4	163–215	23.3
Elevated	1.5–5.2	Frequency and amplitude of fluctuations in activity and reproductive performance return to normal	2.9–4.8	1.5–4.3	3–65	17	1.8–4.6	1.5–3.7	191–207	20
Acceptably high	0.3–1.4	Insignificant differences in activity and reproductive performance	2.8–4.2	2.6–4	3–81	10	2.8–4.4	2.7–3.6	197–202	13
Normative	0.1–0.3	Stable condition	3.1–3.8	2.8–3.4	5–84	0–3	2.9–3.4	2.8–3.2	193–210	0–3

of a magnetic field with a strength of more than 17  $\mu\text{T}$ , the death of MO is observed, which is identical to the data recorded under short-term exposure to an IMF of  $\approx 250 \mu\text{T}$ .

## CONCLUSIONS

The universal technique developed by the authors of the article enables to quickly and accurately determine the degree of influence of abiotic stress factors of the environment on model organisms in vitro under the conditions of water (*Daphnia magna* Straus) and air (*Drosophila melanogaster* L.) habitats. Biotesting of the negative impact of electromagnetic radiation on living organisms, in comparison with instrumental research methods, is distinguished by a lower error in the results and is less expensive. It was found that the EMR level  $\geq 2.5 \mu\text{T}$  with prolonged exposure (20–30 days) causes not only changes in behavioral and adaptive reactions, and is also mutagenic. EMF can lead to teratologies (wing or body deformities), as well as changes in pigmentation or organ size. There are mutations with a recessive type of inheritance and defects in the “suppressed gene”. The spectrum of mutations ranges from neutral to lethal.

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