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Work Practices

Engineering Controls

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NEW RESULTS OF INVESTIGATIONS ON THE PROBLEMS OF WORK HYGIENE AND THE BIOLOGICAL EFFECTS OF RADIOFREQUENCY ELECTROMAGNETIC WAVES

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/Article by Z.V. Gordon/

/Text/ Results are presented of hygienic, clinical, and experimental investigation including biophysical studies conducted during the last five years on work hygiene and biological effects of radiowaves. Due consideration was given to investigations on the combined effects of SHF and soft x-rays, SHF and heat, intermittent irradiation, problems of scientific organization of labor, as well as to studies on the pathogenic effects of radiowaves.

Every four to five years we summarize the results of investigations carried out in this area and evaluate them from the point of view of theoretical significance and practical value, and formulate new tasks for the future.

One of the primary problems to which investigations of the last years were devoted consisted of providing an in-depth approach to hygienic investigations. This applied to studies on the combined effects SHF and x-rays, SHF and heat, intermittent regimes of irradiation, as well as scientific organization of work at radio and television stations.

Considerable attention was given to studies on the combined effects of SHF electromagnetic fields and soft x-rays. Since the possibility existed that individuals working with electrical vacuum instruments at SHF installations may have been exposed to x-rays, it was necessary to conduct studies on the biological effects of these factors whenever employed at low intensities (K.V. Nikonova, N.D. Khramova).

K.V. Nikonova and I.P. Sokolova have shown convincingly in animal experimentation that at high intensities of combined radiation synergism prevails, while in the case of long-term experiments with low intensities of the combined factors, the changes that resulted were no greater than when the factors were employed alone. It should be noted that at low levels of radiation the importance of the SHF factor is more pronounced in the combination. These findings guided our approach in setting the hygienic standards for combined effects of SHF and soft x-rays.

A combination of SHF and elevated air temperature is frequently encountered in the industrial situation, or it is related to climatic conditions, and appears as an important hygienic factor which required special studies for its resolution.

At the present time, on the basis of the experimental studies of K.V. Nikonova, as well as on the basis of the data of V.A. Zhuravleva /1972/, there are reasons for believing that synergism prevails when the effects of SHF and heat are combined, and that furthermore, only heat alone induces lesser changes in terms of a number of indices than the combination of heat and SHF of athermal intensity. This emphasizes the significant changes that occur within the organism, and which apparently are due to the important role of microwave irradiation. These investigations require further expansion particularly when dealing with low intensity levels of irradiation, since they will be highly significant in setting hygienic standards for cases in which combination of SHF and heat exist.

The fact that due consideration was given to sanitary regulations in planning and scientific organization of work, resulted in effective hygienic protection of the personnel of radio and television stations from irradiation, maintained their work capability, created favorable conditions for work at the industrial sites, and so forth. This entire set of measures significantly improved working conditions, and was largely due to the efforts of a group of scientific workers under the leadership of P.P. Fukalova.

A new trend in our investigations deals with determining the significance of conditions of irradiation to which personnel working with emitters of electromagnetic waves (EMW), including microwaves, are exposed. It is generally recognized that until recent years hygienic studies did not take into account the dynamics of irradiation of workers employed in handling microwave emitters.

Hygienic investigations on the industrial conditions, conducted by V.V. Markov, have shown that operators of SHF instrumentation are exposed to irradiation which is highly intermittent in nature; the use of the mathematical theory for chance processes in treating the resultant hygienic data demonstrated that the intermittent conditions of irradiation constitute a transient random process.

In view of the nature of irradiation of people under actual industrial conditions, we employed an experimental model consisting of a transient random process in which the major features of intermittency were represented to their fullest extent. Furthermore, we adhered strictly not only to the total incident energy of the microwaves, but also to the total duration of exposure, which were equal to analogous parameters in a state of constant irradiation. Experimental neurophysiological investigations (M.S. Bychkov, et al.), changes in weight of experimental animals, the state of vascular tone (V.V. Markov), certain biochemical changes, changes in the endocrine organs -- pituitary (N.K. Demokidova), as well as morphological changes (M.S. Tolgskaya, et al.), have shown that when the incident energy and the total time of exposure are equal, intermittent radiation shows much greater biological effects than does constant radiation.

This again supports our earlier contention that the factor of intermittency may be highly important for an organism since the biological effects are determined not only by the total amount of energy that is absorbed, but also by the manner in which the absorption is distributed in time.

In order to introduce the appropriate corrections into the hygienic standards, it is necessary to establish the relationship between duration and intensity in the case of intermittent irradiation which can elicit more pronounced biological effects than those obtained with constant low intensity irradiation. This presently is the object of our investigations.

Prolonged dynamic investigations conducted for a period of 20 years on the state of health of people working with sources of SHF irradiation (M.N. Sadchikova, and others), enables us at the present time to discuss three major groups of subjects that had been followed at the clinic of our institute.

The first group (from 1953) consisted of individuals who were subjected to significant intensities of radiation (up to 10 mW/sq cm and higher).

The second group consisted of subjects who commenced work at the installation after 1960, when the hygienic standards which we had formulated (1957) were already largely in force.

Finally, the third group consisted of individuals who first started work at that enterprise during the last five or more years, and were not subjected to irradiation exceeding 10 mW/sq cm.

The clinical picture of the first two groups has been described by specialists at our clinic and at other clinics (E.A. Drogochina, M.N. Sadchikova, et al., N.V. Tyagin, N.V. Uspenskaya); they are characterized by the degree of clinical manifestations and the presence or absence of restorative processes.

With respect to the third group, it can only be pointed out that some of these individuals showed limited changes which became evident during the clinical observation, but that they differed little from changes in the control group, and consequently, they cannot be related to the effects of SHF radiation.

On the basis of this we feel that our closest attention must be accorded to the second group. The clinical picture of this group continues to remain unfavorable despite the relatively favorable working conditions. This may either be due to inadequacies in the hygienic standards, or to intermittent radiation.

In order to understand the mechanism of action of radiofrequency electromagnetic fields (EMF) on the entire organism, it is necessary to investigate every level of its vital activities. In connection with this it is necessary to conduct in-depth experimental and theoretical studies on the mechanism of the athermal action of microwave radiation on the molecules, elucidate the direct effects of microwaves on the excitability of isolated cells, and in connection with this, study its effects on ion transport across cell membranes, and so forth.

Already at the present time, in some cases, we may speak of a correlation of results of biophysical investigations with clinical findings. Thus, the data of V.M. Shtemler on the direct effects of microwave irradiation on the membranes of isolated erythrocytes, which results in changes in the transmembrane transport of Na+ and K+, and consequently a change in the transmembrane gradient, are in agreement with the results of clinical investigations (G.G. Lysina, et al.)

on individuals working under conditions where they are exposed to low intensity microwave irradiation, and who evidence changes in the electrolyte composition of their erythrocytes and plasma, as well as significant changes in the trans-membrane gradients.

Studies on the effects of microwave radiation on the activity of certain enzymes in vitro and in vivo, which were conducted by V.M. Shtemler, demonstrated the possibility of a direct effect of the field on complex protein molecules which possess features of "supermolecular" structure (actomyosin).

However, analysis of the literature data in this field, as well as the results of investigation conducted by V.M. Shtemler with blood catalase and cholinesterase, suggest that the primary reason for changes in enzyme activities during irradiation of the entire organism are due to, apparently, disturbances in the neurohumoral regulation of metabolism.

Nevertheless, it must be pointed out that at the present time studies at the biophysical level are quite inadequate and require significant expansion.

Up to the present time a significant gap in our theoretical understanding of the biological effect of radiofrequency EMF, including the microwaves, was the absence of a detailed understanding of the genesis and the nature of the effects of athermal action of excitable systems, particularly the CNS, although concrete neurophysiological investigations of the individual aspects of this action have been rather numerous.

The present symposium contains a series of articles of theoretical nature (Ye. A. Lobanova, M.S. Bychkov, V.V. Markov, V.M. Rychkova) which on the basis of analysis with experimental data obtained in neurophysiological investigations, provide us with some clues as to the effects of microwaves with low and very low intensities (essentially from 5-100 μW/sq cm).

Ye. A. Lobanova employed pharmacological agents and came to the conclusion that the decreased susceptibility of animals to microwave irradiation, which is elicited by narcotics and analeptics, is related to increased tone of brain systems which bring about the inhibitory regulating function.

Obviously, even today the problems of pathogenesis at the level of the CNS cannot be regarded as having been entirely studied. Nevertheless, even at the present state of progress one may state that the feeling of the clinicians that the diencephalan

is involved in the genesis of the primary syndromes in subjects exposed to irradiation under commercial conditions have been confirmed in both acute and chronic experiments on animals.

In the view of M.S. Bychkov, the data which have been obtained on cortical and subcortical relationships in the mechanism of action of the microwaves, point to the rationale of attempting to strike a regulatory balance between stimulants and tranquilizers as part of the therapeutic measures taken to combat the pathogenetic effects. At the present time this aspect still remains a point of discussion. However, in view of its practical significance, it obviously deserves special experimental studies, as well as further clinical observations.

V.N. Dumkin and S.P. Korenevskaya have observed alterations in glucocorticoid function of the adrenal glands in patients with manifested forms of radiowave disease, and interpreted this as resulting from primary lesions in the deep structures of the brain which regulate the metabolism and synthesis of corticosteroids; dysfunction in the hypothalamus-hypophysis-adrenal cortex system is obviously responsible for the clinical syndromes of the disease.

According to experimental data, changes which arise in organisms under the influence of intermittent and constant low intensity radiation also clearly point to the susceptibility of the hypothalamus-hypophysis-adrenal cortex system to microwaves. This is supported by data on pathomorphological investigations of the hypothalamus which indicate changes in secretory activity of the supraoptic and paraventricular nuclei (M.S. Tolgskaya, et al.).

This is also indicated by eosinopenia in irradiated animals in response to a strong sound stimulus, and the absence of such a reaction in control animals (I.A. Kitsovskaya, E.I. Polukhina). Changes in the weight of endocrine glands (hypophysis, adrenal glands), also may indicate their altered functions (N.K. Demokidova). In addition, changes were also noted in the degree of diuresis and the excretion of Na and K in the urine (N.K. Demokidova). A tendency -- which frequently bordered on significance -- was seen in the increase of epinephrine in the adrenal glands in animals during exposure to low intensity irradiation (I.A. Kitsovskaya).

The problem of the effects of radiofrequency EMW on the reproductive function is quite timely. Experimental studies conducted on animals by A.N. Bereznitskaya and her collaborators, have shown quite convincingly that nonthermogenic

intensities elicit disturbances in spermatogenesis, degenerative changes in the ovaries, decreased reproductive capacity, decreased number of progeny, and damage to the feti. Data are accumulating which indicate that there is a genetic effect. A decrease in fertility and viability has been demonstrated for the second and third generation of progeny of irradiated mice, a decrease in the number of progeny, as well as an increase in the pre- and post-implantation deaths of feti in nonirradiated females mated with irradiated males. These investigations uncovered potential danger of the embryotropic effects of microwaves.

The changes which have been observed are obviously due to complex causes along with a direct effect of the microwaves on the gonads and the embryos. Indirect effects are also of the greatest importance which are to a certain extent mediated by the nervous and endocrine systems.

Thus, microwaves have been shown to exert an adverse effect on reproduction, and may be important in the development of delayed sequelae.

Studies on the nature of the biological effect of radiofrequency EMW requires the participation of specialists from various branches of science. Studies conducted by V.V. Sokolova, et al., have made it possible to elucidate in patients with radiowave disease various changes in the peripheral blood and bone marrow. These changes were not evident in the development of systemic damage to hemopoiesis, and the hematologic shifts appeared reactive in nature.

A significant contribution to the problem of biological effects of radiowaves, have been made by studies dealing with the defensive mechanisms of organisms. Thus, investigations conducted on people under conditions of possible exposure to short wave irradiations at radio stations (A.P. Volkova, P.P. Fukalova) have demonstrated that in those cases in which the intensity of irradiation exceeded the maximum permissible levels, phagocytic activity of the neutrophils was inhibited, and the mouth cavity was highly seeded with indigenous microbial flora.

Experimental studies conducted by these authors on animals have shown that the short waves and ultra-short waves of significant intensities -- but below the threshold for a thermal effect -- lead to changes in natural immunity.

Both clinical and experimental studies support the contention which we expressed earlier that to a large extent the biological effect of radiofrequencies is due to disturbances in regulatory processes.

Particularly pertinent data on the biological effects of microwaves have been obtained in recent years on the effects of very low intensity irradiation (up to 150 μW/sq cm ; Table 1).

Studies on the problems of biological effects of radiofrequency EMW were designed to provide hygienic standards for this factor. However, the problem of standardization still requires further detailed and complex investigations.

The criteria which are utilized by institutes of work hygiene and occupational diseases for setting standards represent complex investigations consisting of three major components;

1. Hygienic evaluation of the working conditions of persons working with sources of radiofrequency EMW, i.e. determination of the actual intensities of radiation.

2. Dynamic clinical observations on the state of health of people working with sources of radiofrequency EMW radiation over a period of several years (5 and more).

   Comparison of clinical and hygienic data permit more accurate determination of the work conditions and state of health of the individual.

3. Experimental studies on animals designed to yield threshold values for functional changes which appear largely during chronic exposure (from 4 - 10 months for the different biological indices).

It is of advantage to discuss this problem in somewhat more detail without, however, any pretention at complete coverage.

The problem lies in the fact that, unfortunately, the concept of "threshold reaction" from the point of view of medical evaluation of a biological effect and, all the more so, the setting of standards up to the present time remains indefinite due to the fact that there are as yet no clear-cut and widely applicable pathophysiological criteria for distinguishing between, for example, protective adaptive reactions and compensatory reactions, as well as between regulatory reactions in an emergency situation, and pathological reactions at the level of various systems, including the central nervous system, as well as the regulatory processes at other levels.

This results in significant difficulties in the analysis of homeostasis, as well as in the analysis of the differentiated threshold characteristics of biological reactions which are determined by the general level of excitability and reactivity, as well as in the analysis of pathological reactions which are determined by adaptional and compensatory capabilities of a system.

This indicates the complexity of establishing standards which is, for example, comparable with the problem of extrapolating to human beings data which are experimentally obtained on animals when the formal approach is based on, let us say, mathematical calculations and purely physical considerations, which does not guarantee that the true facts have been established.

In both cases we must adhere to the principle of reservation which is accepted in Soviet public health circles in the determination of the maximum permissible levels with the assistance of coefficients which naturally are not determined by these considerations alone.

In relation to the above-mentioned aims, experimental investigations, at least in part dealing with standardization, are largely directed toward establishing threshold intensities of EMF which elicit either known adverse biological effects, or a reaction which at any rate cannot be with complete certainty regarded as reflecting a disturbance in the homeostatic mechanisms.

It is in this sense that we must appreciate experimental data on biological effects of low intensity EMF, which deal with threshold effects that are considered while hygienic standards are being set.

This approach enabled us to recommend hygienic norms for the maximum permissible levels of irradiation, and in recent years, to reconsider some of the earlier maximum permissible levels which we had proposed; we have also developed and proposed hygienic standards for the population as a whole. The hygienic standards presently in force are presented in Table 2.

Our hygienic standards have been largely accepted in the Socialist bloc countries, but differ from the standards in the United States. This is understandable since the United States' standards are based on the heat effects of microwaves (other ranges have been largely unstandardized). Effective means of protection have been developed on the basis of these

Table 2. Soviet Hygienic Standards for Radiofrequency Electromagnetic Fields

Таблица 2

Отечественные гигиенические нормы
для электромагнитных полей радиочастот

	(1) Диапазон радиоволн	(2) ПДУ для профессиональных групп	(3) ПДУ для населения
(4)	Средние волны (СВ)	50 В/м	10 В/м
(5)	100 кгц—3 МГц	5 А/м	
(6)	Короткие волны 3—30 МГц	20 В/м	4 В/м
(7)	Ультракороткие 30—50 МГц	10 В/м	1 В/м
(8)	50—300 МГц	5 В/м	
(9)	Микроволны 300—300 000 МГц	10 мкВт/см^2	1 мкВт/см^2

Key:
1. Radiowave band
2. Maximum permissible level for occupational groups
   50 V/m, 5 A/m, 20 V/m, 10 V/m, 5 V/m, 10 μW/sq cm
3. Maximum permissible level for the population
   10 V/m, 4 V/m, 1 V/m, 1 μW/sq cm
4. Medium waves (MW)
5. 100 KHz-3 MHz
6. Short waves 3-30 MHz
7. Ultrashort 30-50 MHz
8. 50-300 MHz
9. Microwaves 300-300,000 MHz

Table 1. Continued

10. Hypothalamus-hypophysis-adrenal cortex system
11. Metabolism
12. Immunology
13. Lag in weight (chronic experiment)
14. Biphasic course with marked hypotension (chronic experiment)
15. Decreased fertility, decreased litter size, increased number of defective progeny, increased embryonal mortality etc. (chronic experiment)
16. 1. EEG changes with predominant synchronization (acute experiment)
17. 2. Bivariant shifts with predominance of activation (acute experiment)
18. 3. Bivariant shifts in the subcortical-basal structures (chronic experiment)

9b. Increased electrical activity of active unit

19. 1. Weight change of endocrine glands (hypophysis, adrenals)
20. 2. Change in the neurosecretory function of the hypothalamus
21. 3. Tendency for increased levels of norepinephrine in the adrenals
22. Changes in water and electrolyte metabolism (Na, K, water, and total nitrogen excretion)
23. Inhibition of neutrophils phagocytic activity
24. 10-20 and more
25. V.V. Markov
26. A.N. Bereznitskaya et al.
27. Z.V. Gvozdikova et al.
28. M.S. Bychkov, V.V. Markov, V.M. Rychkova
29. V.V. Markov
30. N.K. Demokidova
31. M.S. Tolgskaya et al.
32. I.A. Kitsovskaya, E.I. Polukhina
33. N.K. Demokidova
34. A.P. Volkova, V.V. Markov

Table 1. Some Results of Experimental Studies on the Biological Effects of Very Low Intensity Microwaves (Up to 150 μW/sq cm)

Таблица 1

Сводка некоторых результатов экспериментальных исследований биоэффектов микроволновых воздействий весьма малых интенсивностей (до 150 мкВт/см²)

(1) Исследованные функции	(2) Характер изменений	(3) ППМ, мкВт/см²	(4) По данным исследователей	
(5) Вес тела	(13) Отставание в весе (хронический опыт)	150	В. В. Марков	(25)
(6) Артериальное давление	(14) 2-фазное течение с выраженным гипотензивным эффектом (хронический опыт)	150	В. В. Марков	(25)
(7) Воспроизводительная функция	(15) Снижение способности к оплодотворению, уменьшение численности потомства, увеличение количества неполноценных потомков, увеличение эмбриональной смертности и т. д. (хронический опыт)	150	А. Н. Березницкая и соавторы	(26)
(8) Центральная нервная система	1. Изменение ЭЭГ с преимущественной (16) синхронизацией (острый опыт)	(24) 10—20 и более	З. В. Гвоздикова и др., Ч. Асабаев	(27)
	2. Бивариантные сдвиги с преобладанием (17) активаций (хронический опыт)	150	М. С. Бычков В. В. Марков В. М. Рычкова	(28)
	(18) 3. Бивариантные сдвиги в подкорково-стволовых структурах (хронический опыт)			
(9) Электромиография	(19) Изменение электрической активности ДЕ	150	В. В. Марков	(29)
(10) Система гипоталамус—гипофиз—кора надпочечников	1. Изменение веса желез внутренней (19) секреции (гипофиза, надпочечников)	150	Н. К. Демокидова	(30)
	2. Изменение нейросекреторной функции (20) гипоталамуса	150	М. С. Толгская и соавторы	(31)
	3. Тенденция к увеличению содержания (21) норадреналина в надпочечниках	150	И. А. Кишовская Э. И. Полухина	(32)
(11) Обмен веществ	Сдвиги в водно-солевом обмене (выведение (22) воды, Na и K, общего азота)	150	Н. К. Демокидова	(33)
(12) Иммунология	Угнетение фагоцитарной реакции нейтро- (23) филов	150	А. П. Волкова В. В. Марков	(34)

Key:
1. Function
2. Change
3. Power flux density, μW/sq cm
4. Investigator
5. Body weight
6. Arterial pressure
7. Reproductive function
8. Central nervous system
9. Electromyography

standards which are adhered to by TU /technical administration/ in the manufacture of the equipment, and have been successfully put into effect in the installation and the utilization of radio transmitters.

Subsequent investigations in this area should proceed along the following lines:

--Hygienic evaluation of new technological processes related to the use of radiofrequency EMW;

--Timely protection of individuals from irradiation during the development and manufacture of new equipment;

--Provision of measuring equipment which will cover every region of the radiofrequency spectrum and provide graphic recordings;

--Studies on the combined effects of radiowaves of different regions with other factors of the industrial environment;

--Biological evaluation of the different regimes of intermittent microwave irradiation;

--Studies on delayed sequelae and restorative processes.

Such have been the major results of investigations conducted during the past several years, and our future plans for investigations to be conducted on the problems of work hygiene and the biological effects of radiofrequencies.