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BIOLOGICAL EFFECTS OF HIGH-FREQUENCY ELECTROMAGNETIC WAVES

Translation

(ATD Work Assignment No. 78)
Task 11

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Foreword

This translation was prepared in response to Work Assignment No. 78, Task 11. The article was originally published as follows: Marha, K. Biologicke ucinky elektromagnetickych vln o vysoke frekvenci. Pracovni lekarstvi, v. 15, no. 9, 1963, 387-393.

BIOLOGICAL EFFECTS OF HIGH-FREQUENCY ELECTROMAGNETIC WAVES

Radio waves are of interest to physicists, chemists, biologists, and doctors. They all are interested in finding out whether electromagnetic waves cause chemical and biological changes similar to those brought about by ionic radiation. The first experimental work on the influence of high-frequency electromagnetic waves on organic and inorganic matter was done at the end of the last century.

The number of studies grew constantly until a first peak was reached between 1930 and 1940. During that time valuable studies were conducted, especially in physical chemistry and biology. Less interest was focused on medical problems and the effects of high-frequency waves on man.

World War II interrupted this research, and at many places it was forgotten or was re-discovered only in the past few years. This is particularly true of the influence of high-frequency waves on the colloidal system.

After 1945, attention was given almost exclusively to the influence of ionic radiation, i.e., waves (x-ray, gamma radiation) and corpuscular (alpha and beta) [9]. Interest in high-frequency electromagnetic waves has been renewed only recently. The interest developed when it was recognized that animals and plants die in a high-frequency field of a certain minimum effective density in the cm wave band and when workers at radar stations began to complain about certain physical difficulties. Thus, the situation had changed from that which had existed before the war.

The greatest number of workers engaged in this research are in the USSR and the USA, where there are specialized facilities for such investigations. In addition to these countries, Poland, Italy, and, lately, England should be mentioned as places where studies are being made of the effects of high-frequency fields on the biological system. Czechoslovakia has also seen an increase in studies concerned with this subject. The Institute of Industrial Hygiene and Occupational Diseases houses a special high-frequency department which since early 1961 has dealt exclusively with questions relating to the influence of electromagnetic waves on living matter and especially with the protection of men from these waves.

Although there have been regular international conferences on this subject, the exchange of information and the publication of results has been limited. The reason for this is clear from one fact. In the United States, the research on the influence of high-frequency waves, especially microwaves, has been carried out on a broad scale since 1957, and this has been done under the auspices of the Department of Defense and coordinated with the medical research laboratory created as a part of the experimental rocket base at Cape Canaveral. Therefore, one cannot expect that all results would be published in detail. It is also understandable that information on new results from other countries would be equally hard to come by. In spite of this, about one thousand studies have been published on this subject up to the present time [1963]. [8]

The following is a short discussion of the influence of high-frequency electromagnetic waves on living matter, especially in the field of microwaves. (For greater detail, see references 5, 7-10, 12-14, 17, 19, 21, 28, 29).

The first question deals with the penetration of high-frequency energy into the organism. Let us observe the behavior of the body in the electromagnetic field. It should be stated that the body, by its very presence, changes the field, because the electrical properties of the body are considerably different from the properties of the air in which the waves spread. This is particularly true of electrical constants. The magnetic permeability is the same for the body as it is for the air.

When the electromagnetic wave hits the surface of the body, it means a transition from one medium to another [10]. At the transition boundary, part of the energy is reflected. The rest penetrates the tissue, changing speed; if it enters at an angle it also changes direction. As it penetrates the tissue, high-frequency energy is absorbed under the influence of dielectric losses, and is transformed into heat. The amount of high-frequency energy which is absorbed depends on the kind and size of the tissue and on the environment.

Fig. 1 shows the dependence of high-frequency absorption on frequency in the case of a human subject. The figure shows three layers: skin, fat, and muscle. This presentation is very appropriate in the area of microwaves, because there we can disregard the influence of bone on the absorption properties of the body, and the blood system in the skin can be substituted by changing the thickness. Thus, we can visualize the influence of some parameters on absorption. This dependence has the character of dampened oscillations. According to our calculations, however, the location and absolute maximum value or minimum value depend on the so-called constitutional parameters; the example shown in Fig. 1 represents the absorption in the body, which can be visualized as three layers, with an equivalent thickness for the skin (0.35 cm), the fat (1.14 cm), and a semi-infinite layer of muscles. In this system the first highest maximum absorption is at [illegible] MHz, the second around 9000 MHz. Minimum absorption is around [illegible] MHz. With the change of frequency the percentage of absorbed energy changes, as does its percentile distribution in single tissues, especially in the skin and muscles.

A direct result of high-frequency energy absorption in tissue is an increase in temperature. This correlates with the electrical parameters of the tissue, especially its conductivity and dielectric constant, and naturally is also connected with thermal conductivity. Apart from this, the thermo-regulating system of the organism also plays an important role; which explains the fact that to a certain degree the thermal balance of the organism is stabilized regardless of the intensity of the field. The body temperature first rises and then, as a result of increased flow of blood, it sinks, as is shown in Fig. 2 [6].

In addition to high-frequency energy absorption, the possibility for electromagnetic induction of the body also exists. There are electrical transmission lines in the organism, especially the nerve system and the blood circulation. In the presence of an alternating electromagnetic field, induced tension results, which, however, is distributed through these systems into the organism. Losses are small, and thus high-frequency reaches areas which had received only very weak doses through primary absorption. This means for the entry of high frequency into the organism can be extremely significant, especially in damaging the central nervous system and the blood vessels. In this connection it is interesting to observe that nerve fiber changes its electrical resistance in a high-frequency field.

Low-intensity electromagnetic waves cause difficulties which are primarily of a neurotic nature [14]. These include headaches, pain in the eyes, tiredness and general weakness, dizziness after standing for a period of time, fitful sleep at night, sleepiness in the daytime, changing moods, irritability, hypochondriacal attitudes, fear, depressions, reduced intellectual capacity, and reduced memory. With longer exposure, laziness and an inability to make decisions result. Complaints are voiced regarding sensations of tension in the skin, head, and forehead, loss of hair, muscle aches, and pain around the heart. Complaints of sexual difficulties are not uncommon. Such people experience slight eyelid, tongue, and finger tremors accompanied by increased perspiration. During work in a higher field a marked reduction in blood pressure has been observed which lead to collapse.

As to any connection between a high-frequency field and sexual function, it was found that no special changes occurred in the female organism, but that women in general are more susceptible to such influence than men. Interrupted menstrual periods and a reduction in the milk supply of nursing mothers are a sign of damage.

A few weeks after the end of exposure (sometimes several weeks or longer) the body returns to its former physiological state and all subjective and objective difficulties vanish. This is called regeneration and is proof of the reversibility of the effects of a high-frequency field.

On the other hand, the chronic influence of a high-frequency field results in cumulative biological effects, which can be explained by the lowered resistance of the organism to outside influences. This effect was described in detail in a study of damaged eyes subjected to repeated radiation of sub-threshold intensities. This was a case of the non-thermal effect of the high-frequency field.

It should be pointed out that the possibility of the existence of the non-thermal effect of electromagnetic waves is generally accepted today, and because substantial experimental documentation exists, it can be considered proven. It has been demonstrated that non-thermal effects also occur with fields of greater intensity, where the rise in temperature is the first reaction of the organism. Non-thermal effects brought about changes in inter-neuron connections, the inactivation of certain viruses, and changes in the growth and infection properties of bacteria. Undoubtedly the most important non-thermal effects are the changes in the course of the division of cells, especially of chromosomes. Fig. 3 shows the process. It depicts the dependence of the mitotic index on the intensity of the field at different radiation times [11]. Also, actual changes in the shape of the chromosomes have been encountered. These changes are directly connected with the development of the individual and the changes in the properties of the descendants.

In view of these and other effect of the electromagnetic field [18, 25] it is natural that interest in these problems is increasing and that attention must be devoted to them [8].

Let us investigate the mechanism of the biological effect of microwaves [10]. When electromagnetic waves enter the organism they cause primarily the polarization of the molecules which have a dipole.

The ions, which are not electrically neutral, begin to move under the influence of the field. Since the sign of the field changes constantly in the rhythm of the frequency, the orientation of the dipole and the direction of the ions also change. Many authors ascribe to this oscillation of the ions and dipoles a considerable part of the biological activity of the high-frequency waves. Friction of the particles results, energy is absorbed and converted into heat, and the organism's temperature rises. The amount of liberated heat depends on the frequency and intensity of the field, because the faster and more frequent the change of orientation of the dipoles and ions, the larger the number of collisions [2]. The heating, however, also depends on the dielectric constant of the medium. This can be different for various materials, and therefore zones of higher temperature can be created. Nonuniform absorption of high-frequency energy results in nonuniform heating of various cells or of parts of them. Thus, the coordination of the biochemical reaction might be disturbed, the speed of which may change, depending on the temperature of the medium in which it occurs. Since under normal conditions all these reactions take place under nearly equal temperature, some researchers believe that this disturbance of coordination may lead to the formation of certain materials which are alien to the cells, thus leading to the possibility of blood poisoning during high-frequency irradiation. The correctness of these considerations is open to question. At greater densities the liberated heat is so great that damage to proteins may result. This is particularly true of tissue with few blood vessels, for example, the eyes. Certain processes are decided by enzymes, which are thermo-labile. Therefore, disturbances in the metabolism may be a direct result of heat influences. This helps to explain eye and nerve damage, and as was pointed out previously, non-thermal phenomena also enter the picture [5].

It is known that electromagnetic waves bounce back from the boundary surface of two media. If a homogeneous part inside an organism has the proper dimensions, so-called "dead waves" may result at a certain frequency and may cause locally significant rises in temperature. Dimensional resonance dominates the thermal effect and occurs mainly in the microwave band.

As was pointed out previously, the organism can accomodate a certain amount of heat released in a specific range. If, however, the output density and the time of radiation is greater than a certain critical value, the thermoregulation breaks down and the organism, or a part of it, perishes. Therefore, we may say that in a field of greater intensity the thermal phenomena are responsible for the damage to the organism. The existence of non-thermal phenomena has also been proved. Although not much is known about their origin, it is certain that the mechanism of the non-thermal effects of high-frequency waves is of a physical nature. There are various interpretations for the partial effect of the high-frequency field. There is the possibility of resonance of some organic molecules at a certain frequency. At this resonance the load on the molecules is at a maximum, and a change in their structure may result. This possibility is under consideration in the case of albumin, peptides, and amino acids [23]. Recently, such resonance phenomena were observed in gamma globulin [1]. It will be difficult to interpret this discovery because it was found that under certain conditions this is a strictly selective process whose basic frequency lies in the 7 MHz band and that it can also be induced by harmonic oscillations. At an appropriatefrequency, a change in the electrophoretic homogeneity of the gamma globulin can occur at a relatively low intensity. An even lower intensity is required for a considerable change of its antigen reactivity. We can further imagine that the oscillating ions and dipoles exert primary influence in the hf field. As a result of this oscillation, a change of the ion processes may occur, and thus also a change in the conditions for the polarization and depolarization of the membranes, especially in the case of nerve cells. Simultaneously, a breakdown of the diffusing process may take place by affecting the cell's permeability. It seems certain that the biological effects of the alternate field in the entire frequency band, from the lowest to the highest, are caused by influences on the cellular substance. Lately, certain considerations have come to the foreground regarding the orientation and chaining of components of the intracellular fluids, which have a colloidal character [4, 24, 27]. None of these speculations, however, completely explains all of the observed biological effects of high-frequency; on the contrary some are contradictory. No complex theory for the mechanism of the effect of electromagnetic waves on the living organism has been available which would satisfactorily explain all known phenomena. We have tried to develop such a theory, and will present some of the main ideas here.

When entering an organism, electromagnetic waves cause heating of the tissue through dielectric losses and induction of high-frequency voltage through the blood and nervous system. In cell protein, they create an alternating field with regard to their own charge. Such a field may result in chaining and bunching of the protein. Similarly, the induced dipoles may create amphoteric compounds, such as amino acids and pseudo-macromolecular compounds. Many parts of the organism have electrical characteristics which qualify them as semiconductors. The asymmetrical nonlinear volt-ampere characteristics of those elements are mainly responsible for creating the distortion of the alternating signal and a dc component. Thus, a change occurs in some of the electrical properties of the cell, especially in the electrical load. Many living cells, such as nerve cells, have a certain load characteristic for their function. It is important to remember that certain molecules with dipoles are present in the cell fluid whose biological characteristics, such as oscillation and position, depend on the electrical characteristics of the environment. As the charge of the cell changes, the normal physiological state of the cell also changes. If it is a controlling cell, e.g., a nerve cell, other parts of the organism are also secondarily affected. The higher the field intensity and the higher the amplitude of the induced voltage, the more intensive the response of various parts of the body. The result is altered cellular balance and subsequent readjustment. When a certain limit is reached, an irreversible collapse occurs in the case of the whole organism or parts of it. If the limit is not reached, the electrical and physical characteristics of the cell return to normal when the high-frequency field is withdrawn, leaving no marked effects [20]. These changes cannot be sudden, and are not equal in every person. It will depend on the type of high-frequency signal, the amplitude, and the character of the electromagnetic field. It also was found that the simultaneous action of high-frequency and x-ray radiation can cause greater harm to the organism than one or the other can alone. While the effects of the high-frequency waves on the organism are to a certain degree reversible, repeated exposure, even of small intensity, increases the organism's sensitivity. Polyfrequent radiation is biologically more effective than monofrequent radiation.

From what has been said so far, it follows that we have to consider the high-frequency field under certain circumstances as a biologically active part of the environment which can have an unfavorable effect on the organism [22].

Equipment which produces high-frequency energy is being used in increasing amounts and soon there won't be a field in human activity where high-frequency generators will not be used. A classical example is its use in telecommunications. Its use is varied, and high-frequency heat is used, for example, in the production of pure germanium and in semiconductor technology, etc. Because of the hazards to the workers, it was necessary to establish a maximum permissible field intensity [16]. Because there are thermal and nonthermal effects, different values for the maximum permissible intensity were established, depending on the criteria used. In the USA there is still indecision regarding these values. As the basis the thermal effect of electromagnetic waves was established, and as this is more pronounced at very high frequencies, directives were worked out only for microwaves. It was established that for heating of the body a maximum output density of 10 mW/cm2 can be endured, and therefore this was accepted as the maximum permissible intensity. Some called this amount the "tolerance value," and as the maximum permissible intensity 1 mW/cm2 was proposed. This was accepted by the General Electric Co. and was also used at the Bell Telephone Laboratories. However, a biological effect can be expected at 0.1 mW/cm2, which is the third value used in the USA. At this output density, we already consider long-time repeated irradiation with the participation of non-thermal effects. And this is the only correct point of view. This was also adopted in the USSR and they also selected the safety factor 10, thus obtaining 10 W/cm2 as the maximum permissible field intensity for the whole working day in the cm wave band. The same value was also adopted in Czecho-slovakia for pulse operation. For permanent operation a maximum output density of 25 W/cm2 was suggested. Because the biological effects are dependent not only on the intensity of the field, but are a function of intensity and time, it was possible to permit great output density for shorter exposure. In Czechoslovakia this question was resolved by introducing a maximum coefficient which states that the product of the time (in hours) multiplied by the output density in W/cm2 must not be above 200. This is shown in Fig. 4.

The quoted values are for microwaves, which is the area of frequencies above 300 MHz.

As far as we know today, however, it must be said that the biological efficiency of electromagnetic waves has no frequency dependence which can be generally expressed. The biological effect is always forthcoming if a certain value of high-frequency energy is reached in the organism. The efficiency of transmission during interaction between the field and the organism depends on the frequency, and for absorption it is depicted in Fig. 1. The true result is complicated by the existence of induction. Therefore, we can find even in the case of relatively low frequencies a field intensity in which the effective energy in the organ-ism exceeds the critical value.

For frequencies below 300 MHz, the maximum permissible intensity was established in the USSR at 5 V m, and in exceptional cases at 10 V m. The latter value was also adopted in Czechoslovakia for the 10 KHz to 300 MhZ band. A number of organizational precautions were taken for the protection of workers, including periodic checkups, and prohibition of work to those under 18 years of age, pregnant women, and nursing mothers. The USSR in some cases grants an additional 14 days of vacation to workers; those who work in the cm waveband have a 6-hour work day. Similar arrangements have been adopted in Poland.

The best protection is prevention [13, 26]. Shading methods can be used to prevent unwanted reflections in the rooms [7].

Metal objects should be avoided. Where it is impossible to avoid the field, personal preventive measures must be taken. Glasses with metal netting or gold coating have been suggested for safeguarding the eyes. A cloth cover interwoven with a metal thread is recommended for the rest of the body, including the head. For proper protection, the field intensity in the room must be known. Computation without measurement is possible only if the parameters of the generators and antennas are known, and this is only possible in the so-called distant zone, which roughly speaking is at a distance greater than 10 wavelengths. This is practically possible in the case of radar. These are only for orientational calculations. Therefore, it is always necessary to measure the field intensity. However, the method of measurement is not simple, and for hygienic reasons will have to be developed [15]. Only the USSR has proper measuring equipment for the lower wave band. Under certain circumstances, however, properly adjusted and calibrated absorbing ondometers can be used.

In the operation of high-frequency generators, sources of high voltage are used to feed the terminals. At approximately 20 kV we must count on the occurrence of x-ray radiation. Peak doses of 50 r min can occur. Measurement of this x-ray radiation is complicated by the fact that it appears mostly in pulsating equipment. In this case ion chambers must be used.

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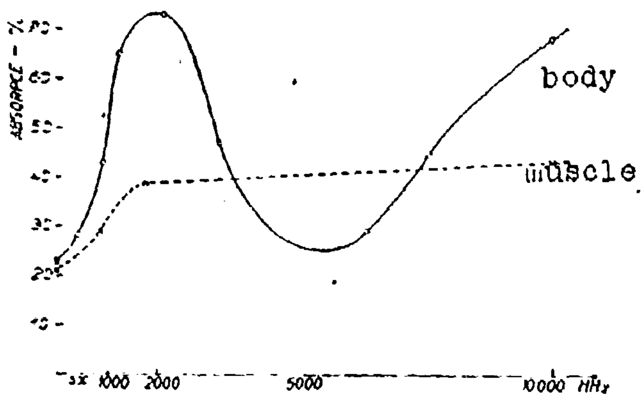

Fig. 1.

Frequency dependence of the absorption of high-frequency energy in muscle and in the model of a body composed of three layers: skin, fat, and muscle

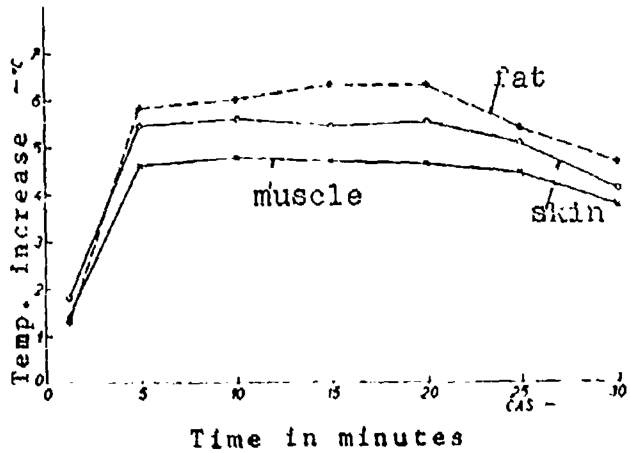

Fig. 2.

Temperature increase on the various parts of the human body depending on the duration of radiation with electromagnetic waves at a frequency of 2450 MHz (Gersten J.W. and Co. 1949)

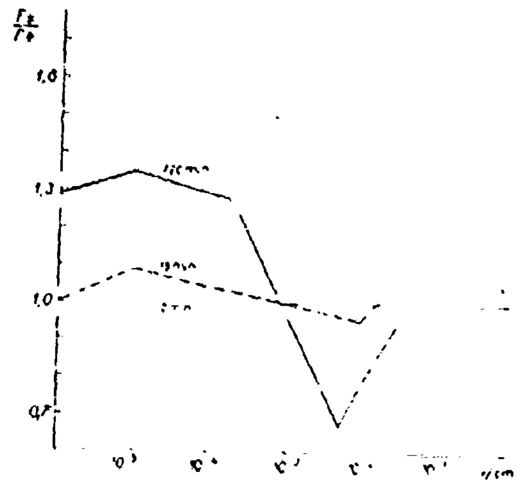

Fig. 3.

Dependence of the relative speed of the isolation of Vicia Faba cells of the field intensity for different periods of radiation (Klepenhauer and Co. 1949)

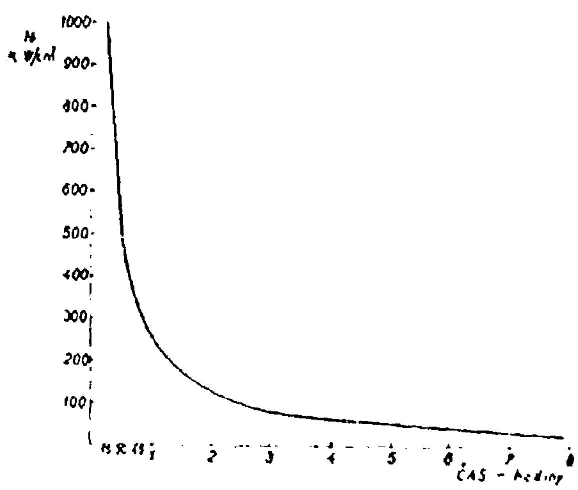

Fig. 4.

Dependence of the maximum permissible uniterrupted time of stay in an electromagnetic field of a given operational density of non-pulsating operation (CW)