Influence of Microwave Radiation on the Organism of Man and Animals.
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CONCLUSION

This monograph has been devoted to an important problem of contemporary medicine and occupational pathology: the effects of microwaves, which are used widely in radio communications, television, radar, radiospectroscopy, and elsewhere, on the organism. This problem is becoming more urgent with each passing year, since the powers of microwave generators are being increased and more and more people are subject to microwave exposure.

As we know, radio wavelengths are found among the cosmic rays, i.e., they are an ecological factor; for this reason, the problem acquires general biological significance. Consequently, human radio exposure does not admit of comparison with any other artificial form of radiation; at the present time, practically the entire population of the globe is subjected to the effects of this energy to a greater or lesser degree.

Although research on this problem was begun even before the war, the lack of dosimetry during that period calls for thorough verification of the data obtained. Only after the end of the Second World War did study of the various aspects of the effects of microwaves on the organism move to a new, higher methodological level. Scientists were then confronted with rather complex and difficult problems.

The complexity of elaboration of this problem consisted in the fact that the range of wavelengths involved is extremely broad. It encompasses the millimetric, centimetric, decimetric, and metric bands, which have been found to differ greatly in biological effectiveness. Moreover, almost all radioelectronic equipment emits modulated electromagnetic oscillations (frequency- and amplitude modulation 'are encountered most frequently); it was also necessary to ascertain the peculiarities of their effects on the organism.

Finally, with the transition to the ultra shortwave band, which borders directly on the microwave band, it was necessary to investigate separately the biological effects of the electric and magnetic fields, again with consideration of modulation. When we remember that neither measuring apparatus nor methods of measuring radiant intensity existed during the first few years of work on the problem, we understand not only the complexity of the problems that arose, but also the large volume of preliminary research that was needed.

The reader who familiarizes himself with the material given in the monograph will be impressed with the enormous amount of work that has been done over the last 20 years on various problems of the influence of microwaves on the organism and with the great theoretical and practical importance of the data acquired. At the same time, a great deal of important work remains before scientific workers and representatives of the various specialties who are engaged in the development of this problem.

Along with the major achievements, the book emphasizes the contradictions in the data obtained on a number of questions involving microwave effects, and the occasional differences in the explanations offered for the observed results as a result of the great difficulties encountered in the development of the problem. The difficulties are primarily methodological. Firstly, it is not always possible to use generally accepted electrophysiological methods in studying the influence of the microwave field on the organism, since the sensors (electrodes, thermocouples, etc.) act as receiving antennas of a sort, so that substantial high frequency voltages are induced in them during irradiation. These voltages may give rise the secondary but sometimes very strong stimuli, ranging up to thermal coagulation of protein in tissues. Unfortunately, investigators have at times overlooked this fact.

Secondly, animals to be exposed to microwaves must be immobilized in radiotransparent cages and beakers with no metallic fasteners (nails, clamps, etc.), since the electromagnetic field may be sharply distorted when they are present.

Thirdly, the generators used must be powerful enough to permit placing the animal at a substantial distance from the radiator (in the zone of the shaped wave), since otherwise measurement of the radiant intensity will be inaccurate and, moreover, one of the components may predominate in the action on the organism. Again, investigators have not always taken this into account.

Fourthly, it is desirable that the walls of the irradiation chamber be given absorbing coatings, since reflection of electromagnetic energy makes it impossible to measure the amount of incident energy accurately.

If these coatings are not provided, the chamber must be large enough so that the irradiated animal can be placed several meters from the walls; this is possible only in well-equipped specialized problem laboratories.

Fifthly, systematic measurements of the radiant intensity should be made by qualified electronics engineers at the position of the biological object.

The experience of the team of authors responsible for developing the present monograph has convinced them that coordinated research with participation of various specialties is necessary for successful elaboration of this important problem. Only then will it be possible to cover all of its basic aspects. Working from these considerations, representatives of medicobiological (a physiologist, a biochemist, a pathophysiologist, an immunologist), clinical (a therapist, a neuropathologist, an oculist, a physiotherapist), and engineering-technical (an electronics engineer and a physicist) specialties who had had substantial experience in work on this problem and could evaluate literature data critically were called upon to prepare the monograph.

In study of the various problems of microwave effects on the organism, a great deal of attention was devoted to experimental research on animals and to clinical observations. There is no doubt that the experiment is highly important in ascertaining the mechanism by which microwaves affect the human organism.

This is, in fact, the only method of solving this problem, since observations made on humans are of limited value in this respect. Experimentation also yields comparative data for the effects of different microwave wavelengths, different intensities, different irradiation conditions, etc.

Naturally, the results of experimental studies must be extended to man with great caution. They require subsequent verification and comparison with data on the influence of microwaves on man. The latter can be obtained on the basis of observations made under practical conditions while radio equipment is being operated at various installations.

In the performance of experimental studies on animals, it must be remembered that the changes in the organism depend to a major degree on the geometrical dimensions of the animals, owing to the depth of penetration of microwave energy (which is roughly 1/10). It is known that at a given wavelength (for example, wavelength = 10 cm), vitally important organs are acted upon by the electromagnetic energy in white mice and rats, while in dogs almost all of this energy is absorbed by the soft tissues of the head, thorax, and abdominal wall. The brain, heart, etc., escape direct irradiation almost totally.

This effect of microwaves is brought out especially clearly in study of lethal effects; for example, centimetric waves (wavelength = 10 cm) are lethal to white mice and rats after a few minutes of continuous exposure at a PFD of 100 mW/cm^2, while dogs survive as much as 6 hours of irradiation under the same conditions. Experiments will remain important in the future when new aspects of this problem are being solved, although the studies should be done on large animals, and on dogs in particular, when the most important problems are being investigated.

The results of numerous experimental studies have shown that when the organism is subjected to high microwave intensities, the fundamental and decisive changes are explained by the rise in body temperature. Some investigators have even concluded that the influence of microwaves on the human and animal organism is determined at all intensities solely by the thermal energy into which the electromagnetic energy is converted in the organism. However, as has been pointed out in the book, this one-sided view cannot be accepted.

The results of comparative studies of the effect of the microwave field and infrared light at intensities that cause the same body-temperature increase have shown that there are substantial differences between them. These differences are associated both with the manner in which the organs and tissues are heated and with the presence of the so-called nonthermal (specific) action of microwaves. The thermal effects under microwave exposure were determined chiefly by wavelength. Thus, 2-3-cm waves cause heating for the most part in superficial tissues, and therefore have a thermal action more closely similar to that of infrared rays. As we know, they and the millimetric waves border on the infrared range of the electromagnetic spectrum. When we come to the decimetric and metric waves, the penetration into the organism is so deep that vitally important organs may be heated.

Since different tissues have different dielectric constants and conductivities, the absorption of microwave energy is different at different frequencies, and different tissues are also heated unequally. The rate of blood circulation is important in this respect. Nonvascular organs, such as the lens of the eye, heat up especially quickly, as do the contents of certain cavitary organs (stomach, intestine, gall bladder, etc.). The hypothesis has therefore been advanced that the damage to some of these organs is due to features of their vascularization. In fact, the problem has been found to be much more complex.

It has been established experimentally that either death from overheating or deep burns are extreme manifestations of the microwave thermal effect. This property of the thermal effect of microwaves has even been put to practical use in the microwave oven.

High-intensity microwaves present a serious hazard to the lens of the eye, the testicles, and the mucosa of the stomach (intestine). Possibilities are irreversible changes in the form of cataracts, degenerative changes in the germinal epithelium and in the form of ulceration of the gastrointestinal mucosa (as established in rabbit experiments). It is noted that the damage to these organs cannot always be explained by a temperature increase in them.

Selectivity of the damage to these three organs has not yet been established. However, we may advance the hypothesis that it is related to two factors: firstly, the rate of blood supply, and, secondly, the rate and nature of physiological regeneration.

This hypothesis is supported by data obtained on chick embryos, in which undifferentiated cells were found to be most sensitive.

Quite possibly, the familiar law of Bergonie-Tribondeau can be applied to the action of microwaves: the sensitivity of tissues is directly proportional to the rate of cell division in them and inversely proportional to the degree of differentiation. It is known that the rate of cell division is very high in the testicles and gastrointestinal mucosa.

At the present time, there are few practical data that might confirm the applicability of this law in respect to other organs and tissues with high physiological regeneration, although this must be borne in mind in future research.

As for the lack of a relation between the damage observed and temperature rise in the irradiated organs: this indicates the presence of a nonthermal (specific) microwave effect. It appears that this specific effect is encountered along with the thermal effect just asunder exposure to electromagnetic radiation in other bands: visible, ultraviolet, x-ray, etc. There is, of course, the difference that the nonthermal effect is determined in those cases by the quantum energy (E = hV). In the microwave band, the quantum energy is, as we know, negligibly small (averaging 10-6 eV), so that the mechanism of the nonthermal microwave effect is totally different and still not understood.

Since the quantum energy is too small in the microwave band to cause rupture of even the weakest chemical bonds in any of the biological structures, several theories of a molecular mechanism /206 of microwave action have been suggested. The theory of the specifically thermal effect, the theory of nonthermal protein coagulation (resulting from resonant vibrations of the side chains in the protein molecules), the "string of pearls" theory (which involves cohesion of suspended particles), the theory of disturbance to electromagnetic function regulation (it is assumed that the organs are controlled by means of electromagnetic waves), and others have been advanced. None of these hypotheses has yet been proven.

It may be assumed that the microwave field intensifies or suppresses metabolic processes (for example, tissue respiration) by influencing enzymatic activities. This hypothesis is supported by certain observations of the amount of absorbed oxygen in tissues, certain biochemical and histochemical studies in vivo and in vitro, and observations made on microorganisms.

It has been demonstrated experimentally in recent years that metabolic changes are sensed by chemoreceptors. Consequently, information should then proceed to the CNS, and. specifically to the opposite hemisphere in the case of surface microwave absorption (wavelength less than 10 cm). This has actually been detected in animal (dog) experiments.

Direct changes in metabolic processes in the CNS are also possible under exposure to longer microwaves (wavelength greater than 10 cm). This may be accompanied by distinct changes in reflex activity.

Since both mechanisms may be involved under real conditions, the final result of the nonthermal microwave effect is probably still more complex.

Experimental studies have shown that microwaves have certain inherent general attributes similar to those of other stimuli. In fact, an increase in the effect of the microwaves, i.e., a cumulative effect, has been observed in certain animals subjected to repeated irradiations, while in other animals, or under different irradiation conditions, the functional changes became less conspicuous and eventually disappeared as the radiation exposures were repeated. In these cases, it was impossible to detect any abnormalities in the behavior of the irradiated animals. This indicated that their organism had adapted to some degree even to such an extraordinary factor.

It is important to note that the nontherrnal effects of microwaves have definitely been detected in organisms previously conditioned to other adequate and nonadequate stimuli. Thus, for example, in a rabbit that had developed cardiovascular-system stability (its arterial pressure ceased to change) to the thermal effects of infrared rays and even to a microwave field of another wavelength, a microwave exposure with a PFD of 1 mW/cm^2 destroyed this acquired stability within two days. The same exposure taken alone caused no changes in arterial pressure.

Consequently the effect of the microwave field depends to a major degree on the stressing of adaptive mechanisms that counter various environmental factors. And since, under real conditions, the organism is practically always adapted to a variety of conditions, including unfavorable ones (high temperature in summer, low temperature in winter, etc.), breakdown of stability in the organism may be one of the symptoms of the development of clinical changes. It is important to recognize this in examining persons who work with microwave generators.

We have devoted much attention in the book to the influence of microwaves on the human organism as seen in the results of clinical and polyclinical observations of individuals who have worked with microwave apparatus for extended times.

We have also examined certain cases of acute injury that occurred when safety rules were violated. Clinical observations showed that asthenic phenomena appear most frequently in chronically irradiated subjects. The picture is usually that of the asthenovegetative syndrome with neurocirculatory disturbances. As a rule, the onset of the sickness in man is associated with complaints of headache, rapid fatiguing, and disturbed sleep, i.e., we are dealing with functional changes of the CNS. Later, these complaints become more severe, but when irradiation is terminated soon enough, for example, during a furlough, they may vanish comparatively quickly.

The objective signs of the sickness are characterized by early changes in arterial pressure (usually hypotonia), the electrocardiogram, the composition of the peripheral blood, etc.

While specialists concerned with the problem generally agree regarding the clinical changes, the same cannot be said in respect to nomenclature. An attempt has recently been underway to gain recognition for radio-wave sickness as an independent neurological entity.

As concerns injuries to the organ of vision (cataract) in humans, they are fact identical with those of animals. For this reason, problems of cataract prevention are discussed in greater detail in the monograph.

Presentation of the experimental and clinical material was followed by an attempt to shed light on the little-studied problems of the etiology and pathogenesis of microwave affections. Attention is drawn to the importance not only of the etiological factor itself, but also that of the specific working conditions, which must be taken into account in the development of the pathological process, since microwaves frequently act in combination with other harmful factors. In such cases, the medical specialist must be able to determine which of the etiological factors acting on the human organism is of decisive importance. This is necessary for organization of rational protection and prevention. However, if the pathological process has already made its appearance, clarification of this question is important from the standpoint of treating the patient.

The book has presented material on the combined effects of microwaves and other factors on the organism (elevated ambient temperature, thin atmosphere, soft x-rays). However, this important question requires further study.

Finally, the importance of the organism's reactivity for the appearance of pathological changes under microwave exposure was demonstrated. The typological peculiarities of the nervous system and the functional state of the pituitary-adrenal system may either raise or lower the stability of the animal or human organism to microwave radiation. This problem also requires further study.

At the same time, the book examined the complex problem of the general pathogenesis of the pathological processes that arise under microwave exposure. Here an attempt was made to characterize not only the role of the actual etiological factor, but also the importance of the organism's functional state and that of functional changes of the CNS, anterior pituitary, and adrenal cortex; the role of heating of organs and tissues was noted, and the features of disturbances in the organism related to the specific action of microwaves were pointed out. The primary CNS changes and the associated neurosis, which are accompanied by disturbances to the activity of internal organs, were described. At the same time, neuroreflex and neuroendocrine adaptation mechanisms (hypothalamus-pituitary-adrenal cortex system) and the mechanisms leading to pathological changes were placed in the pathogenetic scheme.

The important problem of the pathogenesis of microwave injury also requires further research.

Since microwaves may cause "deep heating," attempts have been made for some time to use them to treat certain diseases. These problems are set forth in a separate chapter, which points out the rather extensive use of microwaves to treat sick people. Microwaves have been used successfully to treat disorders of the supporting and motor apparatus with various etiologies. In a number of diseases, however, the therapeutic indications require refinement and study. Thus, it would be premature to use microwaves extensively to treat persons with diseases of the stomach and intestine (gastric and duodenal ulcer) and diseases of the eye, since gastric ulcer and cataract have been observed to appear under microwave exposure in rabbit experiments. It must be stressed that microwave therapy is one of the methods of a complex therapeutic approach.

Finally, questions of prophylaxis and the prevention of humans from the detrimental effects of microwaves were considered. Although preventive medication has been attempted, the literature still offers nothing on the subject.

As the book points out, our country's microwave-exposure standards are based on the occurrence of functional disturbances in experimental animals and in humans subject to irradiation at work and from other sources. Here it was taken into account that the lowest intensity at which quite stable functional shifts are possible occurs at PFD's above 1 mW/cm^2 and exposure times longer than 1 hour (for wavelength = 10 cm). This was manifested in the form of an experimental neurosis in dogs and by increased tremor of the hands during performance of certain coordinated movements and by other shifts in humans; in persons subject to chronic microwave irradiation, it took the form of an asthenovegetative syndrome.

On the basis of this figure, one-tenth of the radiant intensity, i.e., 0.1 mW/cm^2, was recommended as the safe level for exposure throughout the working day (rounded off to 10 hours). For a tenfold hygienic safety margin, arrived at in view of the varying ages, individual sensitivities, etc., a still lower (by a factor of 10) intensity, i.e., 0.01 mW/cm^2 (10 $microW/cm^2$) has been recommended as the maximum permissible level. It is this level that is regarded as the maximum permissible in our country for the irradiation of specialists working with the electronic equipment throughout their working day (Provisional Sanitary Rules).

However, differentiated standards should be introduced in view of the biological-effectiveness differences of microwaves of different lengths. Further, the time-and-dose patterns of the irradiation, the type of modulation, and other parameters should also be taken into account.

The intensities that cause irreversible changes in the organism (for example, cataract) have been adopted abroad as a basis for the maximum permissible irradiation levels for humans. According to data submitted for the most part by American investigators, this intensity was 100 mW/cm^2. On the basis of this figure, and applying a tenfold hygienic margin, an intensity of 10 mW/cm^2 was adopted as the permissible maximum. However, certain companies have adopted even lower levels (1 mW/cm^2).

While dealing with progress made in elaborating the problem of the biological effects of microwaves, the monograph presents certain information on prospects for its further development. Apart from study of the problems noted previously, these are determined by the fact that we now know the features of the microwave effect on the organism only for certain discrete points in the electromagnetic spectrum. The literature offers reports of microwave effects on the organism for wavelength = 8 mm, 1.25 cm, 2 cm, 3 cm, 10 cm, 12.25 cm, 12.6 cm, 21 cm, 40 cm, 1 m, etc. Only one or two reports are available for some bands. As a result, there are vast expanses of the spectrum whose influence on the organism has not been investigated at all.

Even at those points at which such observations have been made, almost nothing is known concerning the molecular-cellular changes; our information on the mechanism of the nonthermal effects on various organs and systems is inadequate, and little study has been given to the peculiarities of the microwave effect on the permeability of cell membranes, tissue respiration, etc.

Thus, solution of all the practical problems with a bearing on the diagnosis and treatment of patients who have been subject to microwave exposure over the long term and the elaboration of therapeutic and prophylactic measures constitutes a highly complex task. The difficulties to be dealt with in the course of study of the biological effects of longer radio waves (USW, SW, and other bands) are particularly formidable, since they will require a totally different methodological approach, namely, separate investigation of the influence of the electric and magnetic fields on the organism. Studies of this nature made during the prewar years also require review.

No less important is establishment of the ecological significance of radio waves incoming from outer space. As we know, these radiations are variable in frequency and intensity, and significant increases in the incidence of certain diseases have long been associated with periods of maximum solar activity.

It may be that the rather frequent variations of the solar radio emission (for example, those associated with the appearance of sunspots) are an ordinary stimulus - one for which the organism has been prepared to a certain degree in the course of evolution. During chromospheric flares (eleven-year solar-activity maxima), the organism enters external conditions and its adaptive mechanisms may be inadequate. This is accompanied by various functional disturbances and a lowering of the organism's resistance.

As a rule, operation of the electronic facilities subjects the organism to monochromatic radiation exposure, and the radiation is almost always frequency- or amplitude-modulated. A pulse modulated field is most often used in the microwave band. The biological importance of all these aspects of artificial radio emissions has thus far been almost totally neglected, although there are isolated reports dealing with the specifics of modulated radio-wave effects. Very little attention has been given to the combined influence of various environmental factors (microwaves and high temperature, microwaves and oxygen deficiency, microwaves and ionizing radiation). Certain general problems of the biological action of radio waves have not been clarified adequately (problems of adaptation and cumulation, general pathogenesis, and others).

A serious problem arises in the attempt to establish norms for this factor. There are very few data available for derivation of sound maximum permissible irradiation levels. We know absolutely nothing concerning the influence of radio waves on heredity, and very few facts concerning their influence on pregnancy and the offspring. Thus, we are still very far from definitive standards, and the provisional maximum permissible irradiation levels will probably be in use for a long time to come.

The clinician is faced with major complex problems. He must not only catalogue additional specific signs of illness in persons who have been acutely or chronically radio-irradiated, but must also identify peculiarities related to wavelength, modulation, irradiation regime, etc. It is important to identify early signs of the disease, study its pathogenesis, etc. Particular interest attaches to investigation of the effects of very low ("everyday") radio-irradiation levels, those to which the entire population is exposed from day to day in the form of radio emission from communications and television apparatus. According to some sources, the world's largest cities are even now irradiated by television antennas at intensities in excess of the maximum permissible levels.

Nor has much study been given to the therapeutic use of radio waves, especially in regard to the optimum parameters of the radiation and indications and contraindications for the therapeutic use of this new factor. Problems of radiometric measurement are still quite complex. This is due firstly to the fact that the existing apparatus of the P-01 type, though accurate enough, can be used for measurements only in the zone of the shaped wave and with a fixed radiation source. However, it cannot determine the true radiation level in the near zone, which is especially dangerous for humans, or on the "sweep” of a radiation pattern. Secondly, it is not always convenient to measure radiant intensities in W/cm^2. In many studies it is necessary to determine the amount of incident energy.

Thirdly, there are as yet no sufficiently convenient and portable measuring instruments (the P-01 consists of several cabinets and weighs about 80 kg). All of these factors confront the electronics industry with the task of improving the measuring apparatus and developing new equipment for the purpose.

Although it has a comparatively simple fundamental solution - the development and use of various shielding devices - the protection problem still gives rise to various difficulties in practice. For example, it is necessary to develop special fabrics, glasses, and screens that could be used to make protective suits, headgear, coats, etc.

All of these problems can be solved only in the process of coordinated research in which various specialists participate.