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INFLUENCE OF MICROWAVE RADIATION ON THE ORGANISM OF MAN AND ANIMALS

Edited by I. R. Petrov

"Meditsina" Press, Leningrad, 1970

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INFLUENCE OF MICROWAVE RADIATION ON THE ORGANISM OF MAN AND ANIMALS /2*

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ABSTRACT: The book deals with problems of the effect of the microwave field on the organism, which are becoming more pressing with each passing year, since the power outputs of microwave generators are being increased and more and more persons are being exposed to this factor. The monograph consists of three parts. The Introduction deals with the biological bases of the action of microwave electromagnetic radiation on the organism. Parts I and II set forth experimental material on the influence of high and low microwave intensities on the animal organism, characterizing the functional changes of the organism's basic systems and its metabolism. Also considered is the question of damage due to microwaves combined with other factors and changes in the organism's immunological reactivity, the properties of bacteria, viruses, and simple animals. Part III of the book is devoted to the influence of microwaves on the human organism and sets forth data acquired as a result of observations on volunteers as to the influence of low microwave intensities on the healthy human organism; it sets forth the symptomatology, stages, reversibility of changes, and a classification for the pathological processes that arise under the influence of microwaves in persons working with microwave generators. The book examines problems in the etiology and pathogenesis of sequelae to exposure to microwave radiation, characterizing the significance of microwaves and factors operating concurrently with them in the appearance of pathological changes, and indicating the basic pathogenic mechanisms of the pathological changes that arise under the influence of microwaves. It also presents material characterizing the application of microwaves to treat patients. The last chapter is devoted to protection from and prevention of detrimental effects of microwaves on the

*Numbers in the margin indicate pagination in the foreign text.

human organism. It cites the maximum permissible microwave radiation levels, characterizes means for individual and collective protection from the harmful effects of microwaves, and presents experimental material on the use of drugs to prevent detrimental aftereffects of microwave exposure. The Conclusion sets forth concisely the basic premises of the problem of microwave effects on the organism as reflected in the monograph and takes note of problems that require further study. The book contains 24 illustrations, 36 tables, and a bibliography of 521 citations.

FOREWORD

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The widespread use of radioelectronic equipment in the national economy and the development of the radioelectronic industry have led to a situation in which large groups of persons are even now being exposed to radio waves in the microwave band.

Present-day space research, aviation, the high promise of spaceflight, the development of automation and communications, and the use of radioelectronic gear in various branches of science and engineering have opened extraordinary possibilities for the use of radioelectronics.

As a result, the number of persons coming into contact with microwave radiation is increasing with each passing year.

At this time, a great volume of scientific research data has been accumulated on the problem of microwave radiation both in the USSR and abroad; their study has led to the conviction that radio waves in the microwave band may have both pathogenic effects and, under certain conditions, a therapeutic action on the human organism. Even now, the microwave field is in use in the treatment of a number of human illnesses.

However, many aspects of this pressing problem remain almost totally neglected; in particular, our information on the mechanism by which microwaves affect the human organism is inadequate, and without it it is difficult in cases of need to develop protective and preventive measures against the harmful effects of microwave exposure and to design effective therapy.

The literature offers only occasional monographs, each of them written by a representative of only one specialty, although the problem of the effects of microwave radiation on the organism can be dealt with successfully (and the literature material critically generalized) in its present state only by a team of scientists representing various specialties. /4

Thus, the present volume constitutes a brief generalization of published foreign and Soviet scientific research and the experience of the authors in study of this pressing problem.

Representatives of the following specialties participated in compilation of the monograph: physics, radioelectronics, physiology, biochemistry, pathophysiology, immunology, neuropathology, therapy, ophthalmology, and physiotherapy.

The book examines a variety of problems related to the effects of microwaves on the organism, namely: 1) the biophysical bases for their biological action; 2) the influence of high intensities that cause a general rise in body temperature on the organism of animals; 3) the influence of low intensities on the organism of animals; 4) changes in immunological reactivity; 5) clinical medicine and treatment of the pathological processes that arise in humans under the action of microwaves; 6) changes in the functions of the organ of sight; 7) treatment of pathological processes caused by microwaves; 8) therapeutic use of microwaves; 9) standardization and problems of protection from and prevention of the detrimental effects of microwaves.

It is hoped that this structuring of the monograph will convey a more complete idea of the present state of this urgent problem and future research trends.

It is also our hope that the monograph will aid in solving the public-health problems stated by the Program of the Communist Party of the Soviet Union.

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INTRODUCTION /5

The explosive development of radioelectronics and its widespread penetration into various branches of the economy and the military (radio communications, television, radar, radio navigation, radiospectroscopy, radio astronomy, etc.) have led to a situation in which practically the entire population of the earth has come under exposure to radio waves to a greater or lesser degree. The influence of electromagnetic radiation in the radiofrequency band on specialists who operate the radioelectronic equipment and on individuals in the radiating zones of the antenna systems is particularly strong.

In this connection, industrial-hygiene problems of prime importance have arisen, involving determination of the amount of harm done by the radio waves to the human organism, establishment of maximum permissible human exposure levels, and development of preventive and protective measures.

However, it has been found impossible to solve these problems without thorough study of the mechanism by which radio waves act on biological objects. It was also necessary to investigate the changes in the organism as they depend on wavelength (the frequency of the oscillations), time of exposure, and other conditions.

It was very important that sufficiently reliable dosimetry of the radio emissions be provided, that the necessary measuring apparatus be developed, and that the protection problems be solved.

Taken together, all of these questions composed the new and independent problem of the biological effects of radio waves, which came under most circumstantial scrutiny in the 1930's.

Since radio waves (including microwaves) represent a part of the broad electromagnetic spectrum, it is obvious that study of their influence on the organism cannot be separated entirely from problems in the biological action of other wavelength bands. This applies particularly to those segments of the spectrum directly bordering on the radio frequency range (the infrared).

Electromagnetic radiation is one of the forms in which matter exists. There is no rigid boundary between matter and radiation. It has been proven experimentally that certain elementary particles, on interacting with one another (for example, an electron and a positron) are transformed into electromagnetic radiation of /6
a certain wavelength and, conversely, that elementary particles can be produced from an electromagnetic field.

Electromagnetic radiation is composed of alternating electric and magnetic fields that propagate in space at a finite velocity and cannot exist without one another. From the gamma-rays to the long and ultralong radio waves, they exhibit wave and quantum properties. It is these properties that determine the aspects of their biological action.

The wave properties include the velocity of propagation of electromagnetic radiation in space (c), the frequency of the field oscillations (f), and the wavelength (λ).

The propagation velocity is the same for all forms of electromagnetic radiation, equalling approximately 300,000 km per second in the atmosphere. The frequencies of the oscillations (f), which attest to the alternating nature of the radiation as it propagates in space, may vary. It is measured in hertz (Hz). A hertz is one oscillation per second. Derived units are the kilohertz (KHz), 1 thousand Hz; the megahertz (MHz), 1 million Hz; and the gigahertz (GHz), 1 billion Hz.

Wavelength (λ) is a quantity derived from the propagation velocity of the electromagnetic field (c) and the frequency of its oscillations (f):

$$\lambda = \frac{c}{f}.$$

Wavelength is measured in kilometers (km), meters (m), decimeters (dm), centimeters (cm), millimeters (mm), microns (μ), millimicrons (mμ), and angstroms (Å).

Since the propagation velocities (c) of the various types of electromagnetic radiation are the same, the frequency of the oscillations can be determined if we know their wavelength:

$$f = \frac{c}{\lambda}.$$

The biological effectiveness of electromagnetic rediations in various bands is determined, apart from the frequency (f) and wavelength (λ), also by the irradiance. The irradiance of electromagnetic waves, also known as their power flux density (PFD), indicates the amount of energy transferred by the radiation per unit time across a surface with an area of 1 cm^2 placed perpendicular to the propagation direction of the wave. Power flux density is measured in W/cm^2, mW/cm^2, and $\mu W/cm^2$. This quantity is the basic parameter used for the irradiance of electromagnetic waves in the microwave band.

The biological effects observed under exposure to microwaves are compared with the PFD of the radio waves. An electronic measuring apparatus (designated PO-1) has been developed and placed in production for measurement of the PFD in the microwave band; its basic components are a receiving antenna and a received-power meter. By dividing the power received by the device by the area of the antenna receiving surface, we obtain the PFD at the location of the antenna.

The following properties of electromagnetic radiation are also among the wave properties of major biological importance: reflection, refraction, interference, and diffraction. The degree of absorption of the fields by the tissues of the organism, the depth of penetration, the distribution of the electromagnetic energy at interfaces, etc. depend on the wave properties of the electromagnetic fields. /7

In addition to the above wave properties, we also distinguish quantum parameters of electromagnetic radiation; here the radiation is regarded not as a continuous process, but as an intermittent one in the form of separate elementary portions known as quanta.

The quantum (photon) is the minimal, indivisible portion of electromagnetic radiation and propagates in space with the finite velocity (c) mentioned above. An electromagnetic quantum (photon) possesses a certain energy whose magnitude depends on frequency:

$$E = hf,$$

where h is Planck's constant, which equals $6.6 \cdot 10^{-34}$ W/sec^2, and f is the frequency of the electromagnetic radiation. The energy of a quantum (E) is usually expressed in electron-volts (eV). It is seen from the formula that the energy of a quantum is larger the higher the frequency of the electromagnetic-field oscillations.

The biological effect of electromagnetic radiations, especially in the ultraviolet, x-ray, and gamma-ray frequency bands, is determined chiefly by the quantum energy (E). Thus, for example, it is known that an energy of approximately 13.5 eV must be expended to detach the electron from a hydrogen atom. Quantum energies sufficient to produce this effect are encountered only at frequencies corresponding to electromagnetic oscillations in the ultraviolet or at still higher frequencies.

The quantum energy is negligibly small in the radio-frequency band: it averages about 10^{-6} eV. Thus, electromagnetic radiations in the VHF, UHF, and microwave bands are low-energy radiations, and the quantum effects are less significant for them. On the whole, three basic bands (Table 1) are distinguished in the broad electromagnetic spectrum. Some of them have even acquired names based on their biological criteria. For example, the optical band covers the region of the electromagnetic spectrum that is perceived by the eye as visible light.

The biological role of electromagnetic radiations was most comprehensively defined by Academician V.I. Vernadskiy (1926). He was the first to point out that the earth's biosphere was "built" with the aid of electromagnetic radiation incoming from the cosmos. In his conception of the biosphere, he included not only the entire organic world of our planet, but also the products of their metabolism, and oxygen in particular. V.I. Vernadskiy was the first to submit the notion that it is difficult to conceive of the biological importance of only 4.5 octaves of electromagnetic radiation (3 octaves in the infrared, one octave in the visible, and 0.5 octave in the ultraviolet). He argued that among the 40 known octaves, there should be other bands of the electromagnetic spec- /8
trum that participate in the shaping of the earth's biosphere. The radio-astronomical, biological, and other research of recent years has confirmed his point of view.

TABLE 1. CLASSIFICATION OF THE ELECTROMAGNETIC SPECTRUM

Region of spectrum	In conventional units	Average frequency in Hz	Average quantum energy in eV
Radio waves:			
long, short (SW), ultrashort (USW)	1 km-1 m	$3 \cdot 10^5 - 3 \cdot 10^8$	10^{-6}
microwaves: (decimetric, centimetric, millimetric)	1 m-1 mm	$3 \cdot 10^8 - 3 \cdot 10^{11}$	
Optical band:			
infrared	500 μ-15 μ		
	15 μ-7600 Å	$3 \cdot 10^{12} - 3 \cdot 10^{13}$	
visible	7600 Å-3800 Å	$3 \cdot 10^{14}$	1
ultraviolet	3800 Å-1000 Å	$3 \cdot 10^{15}$	
Ionizing radiation:			
x-rays	100 Å-0.1 Å	$3 \cdot 10^{18}$	
gamma-rays	0.1 Å-0.0001 Å	$3 \cdot 10^{20}$	10^6

It has actually been established that the sun emits electromagnetic waves not only in the infrared, visible, and ultraviolet, but also at longer, radio wavelengths. Needless to say, not all of its radiation reaches the earth's surface: radio waves reach our planet only at wavelengths from 1 cm to 50 m. The rest are stopped in the sun's chromosphere and in the upper layers of the atmosphere (by reflection or absorption).

The intensity of the sun's radio emission at wavelengths from 1 cm to 50 m (in contrast to the infrared, visible, and ultraviolet rays) is subject to very wide fluctuations. Thus, the level of radio emission may increase by a factor of 1000 on the appearance of a sunspot. The radio intensity rises especially sharply during chromospheric flares on the sun (A. Smit, 1961). Radio emissions arrive at the earth not only from the sun, but also from other cosmic radio sources. Thus, the planet Jupiter emits strong radio bursts at frequencies around 20 MHz (λ = about 15 m). Radio emissions arrive at the earth from the Milky Way, nebulae, and colliding galaxies, and also from the interstellar gas hydrogen (at a wavelength of 21 cm). Radio emissions also appear at the time of lightning discharges in the earth's atmosphere. /9

Thus, radio waves in the metric, decimetric, and centimetric bands are nothing altogether new and unusual for the earth's biosphere. To the contrary, radio emissions would appear to be a parameter of the environment on a level with the gravitational field, the oxygen partial pressure, and others. A basic attribute of this parameter is its variability.

Up to the present time, almost no study was devoted to the biological role of the natural radio emissions. This has been principally because quantitative estimates of these radiations have been made only during the last few years, and discoveries of new radio sources continue to be reported.

The biological action of radio waves from artificial sources came under study only after radio engineering had reached a certain level in its development. The first experimental investigations of the biological effects of radio waves were performed five years after A. S. Popov invented radio, by our compatriot V.Ya. Danilevskiy (1900).

Systematic study of the influence of these waves was begun much later, and then the selection of the frequency ranges was determined chiefly by the level of radioengineering development. In the first stage, the effects of short, and then ultrashort waves (SW and USW bands) were the principal objects of study. As a rule, the biological objects were placed between the plates of a capacitor, so that what was actually determined was the effect not of the electromagnetic field, but that of its electric component on the organism (G.L. Frenkel', 1937, 1940; V.V. Tatarinov, 1937; K.P. Golysheva, 1940; A.V. Lebedinskiy, 1940; A.V. Tonkikh, 1940; Pätzold, 1930; and others). Later, when radioengineering began to master still higher (superhigh) frequencies, experimenters also began to study their biological effects. At first, the biological objects were again placed between capacitor plates in analogy with the method used to subject the organism to the UHF electric field (V.Ya. Batunina and Ye.V. Gernet, 1938; F.M. Suponitskaya, 1938, 1940, and others).

However, no measurements of the radiation intensity were made during those years when these studies were performed. In spite of these shortcomings, the factual material from prewar research is of definite interest. At that time, the biological effects of microwave radiation were usually studied simultaneously with determination of the effects of the UHF electric field. The research took three directions: 1) the thermal effects of the radio waves; 2) the nonthermal (specific) action of these waves on the organism; 3) the radio emission of the human brain. /10

Attempts were made in each of these trends to ascertain the features of the influence of the microwave field on biological objects or models thereof. One of the first experimental studies in which the microwave band was included in a study of the thermal effect of the UHF electric field was that of Pätzold (1930), who established that different electrolytes taken in the same concentrations and amounts are, other conditions equal (wavelength, field strength), heated differently. The thermal effect depended on the conductivity (σ) of the solutions. Pätzold derived a formula that can be used to find the conductivity at which maximum heating is obtained and plotted a diagram of the wavelengths that produce the most distinct thermal effect in the rabbit. Thus, Pätzold indicated a wavelength of 79 cm for heating of cerebrospinal fluid, 93 cm for bile, 177 cm for blood, 7 m 87 cm for the brain, and so forth. These data were confirmed by Schliephake et al. (1932) and expanded by V.V. Tatarinov (1937).

Later, I.V. Zherdin (1938) used one of the first magnetron microwave generators (by changing magnetrons) for similar studies in even shorter-wavelength bands: λ = 8, 23, 25, 31, 42, 62, 84 cm and 1 m 4 cm.

It was found that the absorption maxima characteristic for the UHF that were established by Pätzold are not observed in the microwave band. Thus, substantial differences between the thermal effects of UHF and microwave electric fields were identified even in the first biophysical studies of the problem.

The experiment of Esaux (1933) is regarded as most interesting in that it demonstrates the role of conductivity in the thermal effects of UHF and microwave electric fields. Briefly, this experiment consists in an unusual increase in the temperature of an emulsion of water in paraffin oil. When placed in a UHF capacitor field, such an emulsion boiled at 50-60°C. This was because of peculiarities in the heating of the different phases of the emulsion, which had different electrical parameters ε and σ. The water was heated, as usual, to 100°C, but the paraffin oil remained relatively cold, with the result that the thermometer registered an average temperature of 50-60°C.

The results of the experiment formed the basis of one of the first theories of selective heating of individual tissues and even subcellular formations (the specific-thermal action of radio waves). The microwave electric field was also studied from the same aspects (F.M. Suponitskaya, 1938, 1940; Denier, 1932, 1937).

It was established from study of the nonthermal (specific) action of radio waves that the changes that appear in the organism cannot be explained solely in terms of the amount of heat formed in it. /11

P. Libezni (1936) stated flatly that the nonthermal effect of the radio waves is basic, and that the temperature rise in the tissues merely masks the specific shifts in the organism. F.M. Suponitskaya (1938) also linked the influence of decimetric (λ = = 40 cm) waves on the organism with basically nonthermal tissue changes (the vibrator effect).

At the same time, A.V. Lebedinskiy (1940) suggested that practically all changes in the organism under the influence of radio waves can be explained from the standpoint of generation of heat in the biological object. He did, however, stress that molecular resonance is also possible on transition to another frequency range. The nonthermal action of radio waves, including microwaves, was also acknowledged by I.M. Khazen (1940), N.N. Livshits (1957), I.A. Abrikosov (1958), and others.

A third (and singular) direction in this research was initiated by Cazzamalli (1928), who reported that he had discovered radio waves emitted by the human brain. These radio emissions depended on the psychic state of the subject. Arguments for the existence of biological radio communications were subsequently advanced (B.B. Kazhinskiy, 1962; Amadou, 1954, etc.). However, these researches were not supported convincingly in later studies (L.L. Vasil'ev, 1964, and others).

Thus, significant steps were taken during the prewar years toward establishing how the organism is affected not only by the HF and UHF electric fields, but also by shorter wavelengths — the microwaves.

Systematic research on the biological effects of microwave electromagnetic radiation was begun immediately after the end of the Second World War. By this time, as we know, radar had come into widespread use and its development was continuing at a rapid pace. The power outputs of radar installations were being increased steadily, and the operating frequency ranges were also being broadened. Almost all forms of radio emission had come into practical use, especially those in the metric, decimetric, centimetric, and millimetric bands.

Research was being pursued in several directions. Simultaneously, the mechanism of microwave action was being investigated in experiments on higher and simple animals and plants. Much attention was devoted to study of the most obvious, thermal effects of microwaves on the organism. Attention was also given to the state of health and morbidity of individuals working with microwave apparatus.

Much attention was devoted to biophysical research on the biological action of microwaves. The studies of Pätzold (1930), /12
Esaux (1933), V.V. Tatarinov (1937), and I.V. Zherdin (1938), whose object was to ascertain tissue heating as a function of tissue conductivity (σ) and dielectric constant (ε), were unable to explain the diversity of the biological effects in heterogeneous structures, especially under exposure to microwave radiation.

For this reason, broad-gauge research on the electrical parameters of tissues was extended into this frequency range during the 1950's (Schwan, Li, 1956; Schwan, Piersol, 1954, 1955, and others). It was found that all tissues of animals and man can be classified into two groups on the basis of ε and σ: 1) tissues with a high water content (muscle, skin) and 2) tissues with a high fat content (subcutaneous fatty tissue, etc.).

The tissues of the first group have large ε and σ, with ε decreasing with increasing frequency, while σ increases; this corresponds to the characteristic behavior of water.

Tissues of the second group have small ε and σ.

When electromagnetic waves act upon tissues of the first group (a homogeneous model was adopted), the amount of absorbed energy reaching the interior increases, but remains relatively constant at about 40% in the range from 600 to 10,000 MHz. The remaining 60% is reflected. Inhomogeneous models were also used, with simulation of the skin layer, the subcutaneous fatty tissue, and muscle. Substantial variations of the absorbed microwave energy were established here at frequencies of 1000-3000 MHz (from 20 to 100%). It was also shown that the amount of absorbed energy may vary substantially as a function of the geometrical dimensions of the biological object. Thus, the body of an adult human can absorb 50 to 125% of the energy incident upon its cross section in the 400-10,000-MHz range (Salati et al., 1962).

As it is absorbed, the electromagnetic field penetrating into a biological object declines in strength. This attenuation is determined by the conductivity of the medium (σ). The rate of attenuation of microwaves in a homogeneous medium is characterized by their depth of penetration, i.e., the distance from the surface during passage through which the intensity of the radiation is reduced by a factor of 2.7. The depth of penetration of the microwave field into tissues of the first group (the water-containing tissues) is much smaller than that in tissues of the second group. The customary rough approximation is that the depth of penetration into the animal organism is 1/40 of the wavelength.

Thus, the depth of penetration of microwave radiation into a biological object depends on its wavelength. As a result, longer-wave radiations (decimetric waves) penetrate deeper and may have a direct influence on internal organs, while shorter wavelengths (centimetric and millimetric waves) are absorbed almost entirely /13
by the skin because of their very small depth of penetration and have their basic influence in the surface regions of the biological object. Almost all of the energy absorbed in this process is transformed into heat. The best-known effect of microwave on the organism, and the first to come under study, is that in which the irradiated tissues are heated.

Since different tissues absorb microwave energy to different degrees, they are also heated differently. This was the result of experiments on models of biological objects and animals.

It was observed that the temperature distribution established in the biological object under the action of microwaves depends not only on wavelength, but also on a number of other factors, chief among which are heat exchange at the surface of the heated object (natural or forced cooling), the tissue structure of the object (homogeneity or a layered structure), the rate of blood supply to the heated area, etc.

In addition, the degree to which biological objects are heated under microwave exposure also depends on the PFD. At small PFD, the thermal energy liberated in the biological object may be dissipated into the surrounding space without any appreciable rise in the temperature of the biological object as a result of functioning of its temperature-control mechanisms. Local microwave exposure of a biological object that can be regarded as homogeneous results in the strongest heating of the object's outer layers under conditions of natural cooling of its surface. The internal regions of the object are less strongly heated under these conditions.

The decrease in temperature toward the interior of the biological object is the more rapid the shorter the wavelength of the radiation. If the surface is subject to forced cooling (for example, by blowing air over it), the maximum temperature rise occurs inside the object, at a certain distance from its surface; this distance is larger the longer the wavelength of the radiation and the stronger the cooling of the object's surface.

When microwaves act on a zone of the biological object that has an inhomogeneous structure (for example, when there is a layer of fat covering a layer of muscle), the temperature distribution becomes more complex. Owing to the weaker absorption of microwave energy by the fatty tissue, less heat is liberated in the fatty layer than in the muscle layer. When the layered system is irradiated, therefore, the temperature rise in the layer of muscle is larger than in the fatty layer, even though the latter is nearer the source of the radiation. This phenomenon is particularly conspicuous at decimetric wavelengths.

As we have noted, a marked temperature reaction of the organism to microwave exposure is observed when the PFD is not too small (more than 10 mW/cm^2). However, organisms are also observed /14 to react to the electromagnetic field at smaller microwave power flux densities, even though the temperature rise is not observed in this case. These phenomena belong in the category of nonthermal or specific effects of microwaves.

The physical nature of the nonthermal effect is not as clear as in the case of the thermal effect. One of the earliest theories advanced to explain the nonthermal action on the organism is the theory of "point" heating (of the type in the Esaux experiment). It has been shown in recent years that certain microstructures may indeed be heated much more rapidly than nearby elements with lower conductivity (for example, the lipoid cell membrane). In the final analysis, extraordinary temperature gradients form between subcellular formations, cells, and even tissues. Thus, when suspended solid isolated particles no less than 80 μm in diameter were irradiated with a PFD of 10 mW/cm^2, the temperature gradient reached 10°C. If it were ever shown that a similar picture prevails in the living organism, the specific-thermal mechanism would be accepted.

The "chain of pearls" theory has also attracted considerable attention. Droplets of a liquid (milk, lymph) or solid particles (polystyrene beads) suspended in another liquid arrange themselves into chains in the radio-frequency field. These chains are oriented along lines of force.

The orientation of the suspended particles is explained by the fact that charges are induced in them under exposure to the field. Electrostatic attraction is what causes the stringing of the particles. It is believed that the "chain of pearls" phenomenon is of nonthermal nature, since it is weakened by increasing the field strength, whereupon the temperature rises (Kalant, 1959). This phenomenon has not been observed in the living organism. Saito (1961) takes the view that this effect has no biological importance at all.

The theory of nonthermal denaturation of protein also has numerous adherents. It was first advanced by V.I. Romanov (1940). He suggested that polar molecules are not rigid dipoles, as was assumed by P. Debye, but elastic ones. This makes it possible for parts of the molecules to shift in an electromagnetic field. In his opinion, molecular deformation is also possible even in nonpolar molecules. A medium composed of such elastic molecules would be a medium composed of resonators. Electromagnetic waves could be absorbed in this medium if their periods coincided with the natural vibration period of the dipoles.

V.I. Romanov reasoned that such effects might also occur at superhigh frequencies and that transition of molecules to excited states was quite possible. Much later (A.S. Presman, 1963; Kalant, 1959, 1965, 1968) proposed that such phenomena are also possible in certain parts of protein molecules. Here, hydrocarbon and other bonds might be ruptured as a result of the forced orientational vibrations of the protein molecules. The hydration zone, which, as we know, determines the solubility of the molecules, might also change. Either rupturing of intramolecular bonds (due to resonance forces) or changes in hydration zones could ultimately lead to nonthermal denaturation of the protein. However, the importance of this mechanism has not yet been confirmed experimentally. /15

A.S. Presman assumes that the following also occur: a) a change in the "potassium-sodium gradient" owing to different effects of microwaves on the degrees of hydration of Na and K; b) a change in the permeability of the cell membrane owing to effects of microwaves on the water molecules that hydrate the protein molecules in the surface layers of the cell membranes; c) disruption of electromagnetic functional regulation.

In his view, electromagnetic fields give rise to a regulatory process in the living organism (alongside the nervous-reflex and humoral processes), i.e., that intracellular processes are controlled, along with the interactions of organs and systems. Proceeding from these considerations, it is possible that this regulatory mechanism might be disturbed under microwave irradiation.

However, since there is no proof of the electromagnetic-wave functional regulatory mechanism in the organism, we find it difficult to concur with this view. In addition to this one, many other hypotheses have been advanced to account for the nonthermal effect. In one, for example, the microwave field may influence the molecular structure responsible for the specific activities of proteins and enzymes (Bach et al., 1961; Bach, 1965). It is proposed further that the nonthermal effect may be related to resonance-absorption effects of microwaves at certain frequencies by complex biopolymer molecules or their components. There are also the supramolecular hypotheses of the thermal-effect mechanism, according to which elements of the cellular structures (membranes) detect microwave signals.

It is also possible that the action of weak microwave fields (nonthermal action) is brought about with water molecules as an intermediary; vibrating under exposure to the electromagnetic fields, these molecules can produce changes in the strictly regulated rhythm of metabolic processes in the cell, which take place in the aqueous phase. This hypothesis is favored, for example, /16 by the fact that the nonthermal effect of electromagnetic fields is observed not only in the microwave band, but also at lower frequencies, and the corresponding phenomenological manifestations of this effect (physiological and other reactions) have much in common.

Summarizing the above, we can state that electromagnetic microwaves may affect biological objects in two ways: thermally and nonthermally. At high microwave intensities, this effect is related to liberation of heat in the biological object with all of its consequences (heating of organs and tissues, thermal damage, etc.).

The physical mechanism behind the biological effect of lower-intensity (nonthermogenic) microwave fields is still unclear, although there is no doubt that the nonthermal microwave effect exists.

Part I /17

INFLUENCE OF MICROWAVE RADIATION AT HIGH (THERMAL) INTENSITIES

Chapter 1 /18

GENERAL CHARACTERISTICS OF THE INFLUENCE OF THERMAL INTENSITIES ON THE ORGANISM

The first experimental studies of the effect of microwave radiation on the organism were, as a rule, made at high (thermal) intensities. Even in the prewar years, attempts were made to compare the heating effects in organs and tissues in UHF and microwave (λ = 40 cm) electric fields (F.M. Suponitskaya, 1938, 1940).

However, the intensity of the radiation was not measured at that time, and the animals were not even subjected to electromagnetic waves, but only to the electric component; the data obtained therefore required verification and refinement.

Systematic research on the thermal effects of microwaves was begun in the postwar years, with the advent of improved microwave generating and measuring equipment. Most experimentors reported that the body temperatures of warm-blooded animals rose under exposure to microwaves only at PFD values above 10 mW/cm^2 (N.V. Tyagin, 1957; Z.V. Gordon, 1960; Schwan, Piersol, 1954, 1955, and others).

Later, however, V.I. Mirutenko (1963, 1964) showed that heating of certain tissues is also observed at PFD around 10 mW/cm^2. Tomberg (1961) established that at this intensity (10 mW/cm^2), the temperature gradients may reach 10° in certain structures (suspension of solid particles in water).

In the opinion of Deichmann (1961), the amount of excess heat formed in the organism as a result of absorption of electromagnetic energy at a PFD of 10 mW/cm^2 (λ = 12.4 cm) is considerably in excess of the normal rate of heat dissipation; from this he concludes that the maximum permissible levels adopted in the USA (10 mW/cm^2 with no limit on time of exposure), which are based only on consideration of the thermal microwave effect, are too high.

Considerable attention was devoted in animal experiments to features of the temperature rise in various organs and tissues as functions of wavelength, the thickness of the subcutaneous fatty layer, blood-circulation rate, and other factors. The results of biophysiological studies, which had indicated a dependence of tissue heating on the conductivity σ and dielectric constant ε, were in large part confirmed (I.V. Zherdin, 1938; Schwan, Piersol, 1954, 1955; Saito, Schwan, 1961; and others). Thus, when the thigh region was exposed to a 12.2-cm microwave field, the temperature rose to a greater degree in the muscles than in the skin and subcutaneous fatty layer (Seguin, 1948; Rae et al., 1949; Cook, 1952; Herrik et al., 1953; Krusen, 1956, and others). However, Osborne et al. (1948) failed to observe this negative temperature gradient. Worden (1948) reported that the thermal effect depends on time of exposure and that deep-lying muscles are more strongly heated only during the first 20 minutes of exposure. It was established at about the same time that the blood supply to the extremity increases (Gersten et al., 1949). It was subsequently shown that the distribution of temperature among the various tissues depends very strongly on the rate of blood circulation. Thus, when a tourniquet was applied to the thigh, exposure to a microwave field caused extremely rapid heating of all tissues (A.I. Semenov, 1963, 1965; Krusen, 1956), and volunteers irradiated under similar conditions (λ = 12.4 cm and λ = 33 cm) even showed stronger heating of the surface tissues than of the muscles in some cases (Lehmann, 1964). /19

Hendler (1960) also noted that the sensation of heat appears in man later under exposure to microwaves (λ = 3 cm) at rather high (thermal) intensities than under infrared light, although the skin temperature rose more rapidly at the locations of the temperature sensors (at depths of 150-200 μm).

According to the studies of Schliephake (1960), the most pronounced heating of deep-lying tissues occurs when metric wavelengths are used. According to this author, the temperature rise in the thigh muscles was 4 times greater than that in the subcutaneous fatty layer. The results of the study showed that in dogs whose forelegs were irradiated (λ = 12.2 cm), the temperature rose by 4.3°C in the subcutaneous fatty layer, 4.6° in the surrounding muscles, 3.8°C in the humerus, and 3.0°C in the bone marrow (Engel et al., 1950).

In rabbits, local irradiation of the paws with microwaves (PFD about 200 mW/cm^2) caused necrosis and sloughing of the soft tissues (A.G. Subbota, 1957). The temperature rise in the deep tissues of the leg could vary substantially in repeated local irradiations. Thus, while the temperature in the upper-leg muscles rose 4°C (rounded value) after the first treatment with the microwave field (PFD about 120-150 mW/cm^2, λ = 12.6 cm, exposure ten minutes), the rise was smaller by almost half (about 2°C) after the sixth or seventh treatment; this indicated that adaptive reactions had come into play. Adaptive reactions are also noted on the opposite (unirradiated) leg after daily conditioning exposures to microwaves. After denervation of the rear extremity, the temperature rise in the thigh muscles remained the same irrespective of the number of irradiations (A.I. Semenov, 1963, 1965). Similar conditioning effects of the temperature-regulating mechanisms have also been reported for whole-body microwave irradiation treatments (A.G. Subbota, 1966). /20

Temperature changes more pronounced than those in other tissues were noted in the transparent parts of the eye. This is because they do not have blood vessels, i.e., one of the basic temperature-regulatory mechanisms is absent. Thus, according to Daily et al. (1956), the temperature rose by 1.9°C in the soft tissues around the eyeball, by 3.2°C in the vitreous humor, and 2.8°C in the aqueous humor after a microwave treatment (λ = 12.2 cm). The temperature rise was even greater in the crystalline lens, leading to the development of cataract (I.P. Gapeyev, 1957; Clark, 1950; Richardson, 1950; Carpenter, 1957, 1960, 1961).

Experiments were performed on embryos to solve the problem of the mechanism of thermal damage to certain organs. For this purpose, chicken eggs that had been incubated for 48 hours were exposed to a 12.4-cm microwave field with a PFD of 400 mW/cm^2. The temperature rose to 55°C at the position of the embryo. After irradiation, the eggs were returned to the incubator for another 48 hours. Then the 96-hour embryos were examined under the microscope, and it was found that the foreparts of the irradiated embryos were practically normal, while the hindparts were totally absent. This effect was linked to the fact that the rear part of the body (tail, rear extremities) was still in an undifferentiated state at the time at which the embryos were irradiated. Consequently, the microwave field inhibited differentiation of tissues.

On the basis of these experiments, it was suggested that high-intensity microwave fields may, in addition to heating, produce nonthermal changes in young (differentiating) cells, such as those in the process of physiological regeneration in the lens of the eye (Van Ummersen, 1961).

When the abdominal region is exposed to thermal microwave intensities at high enough microwave-field powers in the 12.6-cm band, the temperature rises in the hollow organs of the abdominal cavity; the effect is most pronounced in the contents of the stomach, intestine and bladder, and less so in the rectum (Hines, Randall, 1952). These data were confirmed in a study of the temperature of the water in a thin rubber balloon introduced into the stomach of a rabbit through its esophagus (Table 2). Damage to the mucous membrane of the stomach was noted at a PFD of 100-120 mW/cm^2. In dogs, subjection of the anterior celiac region to microwaves (λ = 12.6 cm) of the same PFD caused a smaller increase in the temperature of water in the stomach (Fig. 1), and no damage was observed (I.V. Pitenin and A.G. Subbota, 1965). /21

TABLE 2. CHANGES IN WATER TEMPERATURE IN A RUBBER BALLOON INTRODUCED INTO THE STOMACH OF A RABBIT UNDER MICROWAVE IRRADIATION OF THE ANTERIOR CELIAC REGION

Number of animals	Intensity of radiation, mW/cm²	Exposure in minutes	Water temperature in balloon		Rectal temperature	
			Before irradiation	After irradiation	Before irradiation	After irradiation
10	70–80	10	36,9 (36,6—37,1)	37,9 (37,6—38,7)	37,0 (36,5—37,3)	37,3 (37,0—37,6)
10	110–120	10	37,0 (36,6—37,2)	38,2 (37,6—38,8)	36,9 (36,4—37,5)	37,0 (36,3—37,8)

Deichmann et al. (1961) compared the survival times of rabbits subjected to local microwave exposure (λ = 1.25 cm, PFD = 300 mW/cm^2) with the same irradiated body area. It was found that the survival time was 18.5 minutes for irradiation of the head, 15.5 minutes for the lumbar region, and 12.3 minutes for the abdomen.

The authors suggested that the animals died quickly under local irradiation of the abdominal region because of overheating of the contents of the hollow organs, which, like the transparent media of the eye, cannot be cooled by the bloodstream.

Local thermal microwave-field effects on the parietal region of the head in dogs (λ = 12.4 cm, PFD = 0.5 W/cm^2) indicated that the brain is most severely heated at the point nearest the radiator (directly under the parietal bone). In this experiment, the dogs perished after 75-137 minutes, although their rectal temperatures showed almost no increase (Searle et al., 1961). At a somewhat lower intensity (PFD = 165 mW/cm^2), irradiation of the heads of dogs was accompanied by swelling of the tongue and formation of numerous blisters filled with a serous fluid on the oral mucosa (Michaelson, 1961, 1962).

Besides local irradiation, whole-body irradiation was also used, usually involving unilateral exposure to high (thermal) microwave intensities; here it was found that body temperature rises with increasing PFD and that the animal dies of hyperthermia when it reaches 44-45°C. The nature of the increases in rectal, /22
subcutaneous, and muscle temperatures were different for different animals. Usually, the subcutaneous temperature was the first

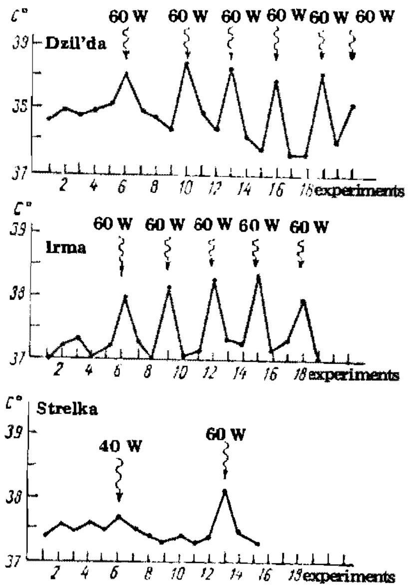

Figure 1. Water-Temperature Changes in Balloons Introduced into Isolated Dog Stomachs on Irradiation of the Anterior Celiac Region. Wavy arrows indicate microwave treatments; the numerals above them indicate the power output of the Luch-58 generator in watts (at 60 W and a distance of 10 cm from the radiator, this represents about 110-120 mW/cm^2).

to begin rising (N.V. Tyagin, 1957; Z.V. Gordon, 1960; S.F. Gorodetskaya, 1962, 1964). Since microwaves also heat deep-lying tissues (if the wavelength is longer than 10 cm), hyperthermia develops much more rapidly than under exposure to infrared rays. Thus, on microwave (λ = 12.6 cm) irradiation of the spinal region in rabbits, a 1-1.5°C rectal-temperature rise was observed at a PFD of 50 mW/cm^2 (exposure 30 minutes), while a PFD of 350 mW/cm^2 was necessary to produce the same effect with infrared (IR) rays. Consequently, the thermal effectiveness of the microwave field is approximately 7 times that of infrared rays.

In spite of certain peculiarities of the heat effect of microwaves (development of heat in deep-lying organs and tissues, nonuniform heating of various structures), and the presence of the specific effect on the organism, adaptive reactions are also brought into play in microwave hyperthermia. This has been demonstrated on dogs that were irradiated in a 12.4-cm microwave field with a PFD of 165 mW/cm^2 (Michaelson, 1962, 1963, 1965) for 4-6 hours; the rectal temperatures of the animals rose to about 40°C within 1/2-1 hour and then, despite the continuing irradiation, remained at the same level, probably as a result of increased heat rejection.

As irradiation continued, body temperature began to rise again after a certain time and the animal would perish. However, if the exposure was terminated or the dogs were irradiated in a microwave field of lower intensity, they developed deep and slow-healing burns, especially where the tension on the soft tissues is greatest (over bony protuberances). /23

The nonuniform heating of different tissues is also confirmed by a nonuniform temperature increase in the blood in the inferior vena cava of the rabbit. Thus, when this temperature was measured at its confluence with the portal veins, the increase was 0.69 ± 0.29°C; it was 0.68 ± 0.28°C 5 cm below this point, and

0.63 ± 0.26°C still farther upstream (below the discharge of the renal veins). There was a slight decrease in blood temperature at these points in control experiments (R.I. Kovach et al., 1966).

The survival times of different species of animals differ under identical irradiation conditions. Thus, continuous irradiation of dogs with microwaves in the 12.2-cm band at a PFD of 165 mW/cm^2 is lethal after only 4-6 hours of exposure. A microwave field with PFD = 100 mW/cm is not lethal in these animals (Michaelson et al., 1960, 1961). However, white rats and white mice perish under almost the same irradiation conditions (λ = 10.0 cm, PFD = 100 mW/cm) (Z.V. Gordon et al., 1955, 1960; N.V. Tyagin, 1957). This is due to different effects of microwaves on vitally important organs in large and amall animals. When dogs are exposed to a 10-12-cm microwave field, almost all of the electromagnetic energy is absorbed in their skin, the subcutaneous fatty layer, and muscles, while the vital organs are protected to a certain degree, since the depth of microwave penetration is roughly equal to 1/10 wave.

In small animals, on the other hand, the brain, heart, and other organs are easily reached under the same microwave irradiation conditions, since the distances to them from the body surface are shorter than $\lambda/10$. The temperature of their cerebrospinal fluid (including that in the ventricles of the brain) also rises rapidly, since the bloodstream provides limited cooling. In dogs, on the other hand, the dominant picture is one of general overheating. Obviously, the mechanisms leading to the death of large and small animals are also different. Thus, it has been established that heating of the brain causes convulsions in rats (Austin, 1954). The lowest microwave intensity in the 3-cm band that is lethal to mice is 38 mW/cm^2 (Jacobson et al., 1959), and, according to certain sources, as low as 8.6 mW/cm^2 (Baranski, 1963). The results of intermittent-irradiation experiments and experiments in which the animals were fan-cooled during irradiation also indicate that temperature changes in the organs and tissues are prominent in the mechanism leading to the death of the animals. Thus, white rats survived for 15 minutes under continuous irradiation with microwaves (λ = 1.25 cm, PFD = 300 mW/cm^2). When the same microwave field was applied intermittently (one second on /24 and two seconds off), death occurred only at the 95th minute of actual radiation exposure (not counting the pauses). Clearly, the dose required with periodic irradiation was 6 times larger than that in continuous exposure (Deichmann, 1959, 1961).

Similar changes were noted under exposure to 10-cm waves (Table 3). We see from Table 3 that approximately the same effect is obtained in intermittent irradiation (1:4) and continuous radiation, although the amount of absorbed energy is substantially (almost twice) as large in the former case (R.I. Kovach et al., 1966). This indicates that the adaptive mechanisms provide for offtake of a substantial amount of heat during the pauses, so that

TABLE 3. SURVIVAL TIMES OF WHITE MICE UNDER INTERMITTENT AND CONTINUOUS IRRADIATION WITH MICROWAVES IN THE 10- cm BAND

Series No.	Number of mice	PFD in mW/cm^2	off and on times, sec		Ratio of on to off time	Survival time, min
First	10	600	6,5	3,5	1 : 2	$10,8 \pm 1,2$
Second	10	600	7,5	2,5	1 : 3	$16,3 \pm 2,5$
Third	10	400	2,0	2,0	1 : 4	$28,5 \pm 3,7$
Fourth	10	68,5	Continuous		—	$30,2 \pm 1,5$

hyperthermia develops more slowly. In addition, it appears that this leaves time for other adaptive mechanisms to come into play.

Fan cooling of the animals during irradiation also increased their survival times considerably.

The data given above indicate that application of the conventional concept of dose to microwaves is incorrect. This applies, at least, to those levels that cause pronounced hyperthermia. The survival times of the animals in intense microwave fields also depended on polarization. Dogs whose bodies were placed along the lines of force of the electric field perished at lower PFD than dogs oriented across the lines (Addington et al., 1961).

Sensitivity to microwave fields of thermal intensity also depends to a major degree on the functional state of the central nervous system. The survival times of white rats with inadequate internal inhibition (I.R. Petrov and V.A. Pukhov, 1966) and those of mice that had been dosed with adrenalin were shorter than those /25
of animals irradiated after administration of cholinomimetic substances such as acetylcholine (M.I. Yakovleva, 1966).

Circulatory changes predominated in the pathomorphological picture of animals that perished under exposure to high- (thermal-) intensity microwave fields. They took the form of paralytic dilatation of blood vessels, stases, and extravasation. Perivascular and pericellular edemas were also observed frequently in the brain (V.Yu. Pervushin and A.V. Triumfov, 1957; I.V. Pitenin, 1962, 1966).

Dystrophic changes in organs and tissues were not pronounced. However, after multiple exposures to microwaves at somewhat lower levels (or shorter exposure times), the dystrophic processes began to predominate. They were manifested in swelling and homogenization of the cytoplasm, changes in tinctorial properties, shrivelling and pycnosis of nuclei, changes in the contents of oxidative enzymes and nucleic acids (I.V. Pitenin, 1966). This morphological picture resembles that observed after subjection to other physical factors, such as infrared rays. However, the tissue changes begin at smaller temperature rises than in experiments with natural heat sources.

It was established even earlier in experiments on animals that were irradiated with a 10-cm microwave field with PFD's up to 100 mW/cm^2 that a picture of receptor irritation appears against the background of hyperthermia, along with substantial dystrophic changes in the receptors, sometimes to the point at which they disintegrate into fragments (M.S. Tolgskaya, Z.V. Gordon, 1959, 1960, 1964; M.S. Tolgskaya et al., 1959).

Pathological changes of the dry-necrosis type appeared in the skin of rabbits and rats under local exposure to 3-cm waves of very high intensity (500 mW/cm^2), during which the skin temperature increased to 55 ± 3°C (A.A. Slabospitskiy, 1964).

Chapter 2

CHANGES IN FUNCTIONS OF VARIOUS SYSTEMS OF THE ORGANISM UNDER EXPOSURE TO HIGH-INTENSITY MICROWAVE FIELDS

In this chapter, we shall discuss changes in the functions of the central nervous system, the endocrine glands, respiration, the cardiovascular system, the blood, and the stomach as observed in animal experiments under the influence of thermal microwave intensities.

THE CENTRAL NERVOUS SYSTEM /26

The central nervous system of animals irradiated at high (thermal) intensities is apparently the first to undergo functional changes. They are manifested in abrupt suppression of conditioned-reflex activity (decline and disappearance of positive conditioned reflexes, disinhibition of differentiations, etc.) in white mice (S.F. Gorodetskaya, 1963, 1964). These data have been confirmed in large part in rabbits in which feeding conditioned reflexes had been developed. When their heads were irradiated ($\lambda = 12.6$ cm, PFD = 35-40 mW/cm^2, exposure 20 minutes), the conditioned reflexes were observed to vanish in the absence of disinhibition of differentiations. The offspring of rats irradiated during gestation developed conditioned reflexes with great difficulty and modification of acquired responses was slow (R.I. Kruglikov, 1968).

In dogs with elaborated motor conditioned reflexes and electrodes implanted in the thalamus, caudate nucleus, frenulum, inner geniculate body, and sciatic nerve, still higher radiation levels (0.4-0.5 W/cm^2) produced a variety of dissociated changes in the electrical activity of these formations, as well as disturbances to conditioned-reflex activity (V.S. Belokrinitskiy, 1966). Since a high-frequency voltage was induced on the implanted electrodes in these experiments, artifacts cannot be excluded in the observed picture.

Salivary conditioned reflexes were also investigated in dogs subject to unilateral microwave irradiation at about 20-30 mW/cm^2; a decrease in the strength of the conditioned reactions and an increase in their latent times were noted. In the case of functional weakening of the cortex, when the animal fell asleep in the chamber and even refused food, such microwave treatments restored considerable conditioned-reflex activity over 1-2 days (A. G. Subbota, 1958; Z.P. Svetlova, 1963).

Rabbits subjected to the same irradiation intensity show abrupt suppression of the basic rhythm of cerebral-cortex electrical activity and their responses to exteroceptor stimulation. Since the hemisphere on the radiator side was heated much more strongly than the opposite one in the rabbit, in contrast to the case of the dog, interhemispherical asymmetry was observed as a result of the earlier and more pronounced changes on the irradiated side.

Often, depending on the intensity of the microwave field and the exposure time, an exaltation phase preceded the development of central inhibition in one of the hemispheres. On this basis, the hypothesis was advanced that inhibition of parabiotic nature occurs in the CNS under microwave heating (M.S. Bychkov, 1957). /27

Some time later, Yu.A. Kholodov (1962, 1966) carried out electrophysiological studies of the CNS under exposure to high-intensity electromagnetic fields. He regards the generalized nonspecific synchronization reaction (an increase in the number of "spindles" and slow waves) that appeared 20-40 seconds after the generator was switched on as the most characteristic aspect of the effect of these fields (λ = 12.6 cm with PFD from about 40 mW/cm^2 to 1 W/cm^2). This reaction was also observed at the instant at which the generator was switched on. Similar results were obtained by R.A. Chizhenkova (1967).

The synchronization reaction was most distinct from the hypothalamus and least distinct from the reticular formation when the activities of various divisions of the brain were registered (Yu.A. Kholodov, 1967). However, as the author himself correctly notes, high-frequency induction on the electrodes cannot be excluded from these versions of the experiment, so that there was a possibility of secondary stimulation of the brain formations under study.

A neuronally isolated strip of cortex responded to the microwave field with a shorter latent period than intact cortex. These and other facts prompted Yu.A. Kholodov (1966, 1967) to argue for the direct action of electromagnetic fields on the CNS. This action is manifested in the appearance of trans-limit inhibition.

When rabbits were irradiated with microwaves of various lengths (λ = 12 cm, λ = 52 cm, λ = 1 m, with PFD from 0.2 to 50 mW/cm^2), a variety of changes in the fundamental rhythm of electrical activity were observed. The curve of the sensitivity of the CNS to a microwave field of λ = 52 cm was similar to that of Weiss-Lapicque. Analysis of the latent-period distribution of all cases in which the ECoG showed changes indicated that the CNS is most sensitive to metric waves and least sensitive to centimetric waves (λ = 12.6 cm; Z.M. Gvozdikova et al., 1964).

N.F. Smorodin, T.A. Gribanova, and A.G. Subbota compared the effects of single and repeated exposures to microwaves (λ = 12.6 cm, PFD = 50 mW/cm^2, exposure 30 minutes) on the bioelectric activity of the right frontal lobes of rabbits that had been thoroughly acclimatized to the experimental conditions. It was established that in once-irradiated animals, the amplitude of the slow waves (Δ) was lower, while those of the other waves (Θ, α, and β) were higher 10-30 minutes after the end of the microwave treatment. The respiratory frequency was 2-2½ times higher against the background of moderate hyperthermia (body-temperature rise about 1°C). The ECoG of repeatedly irradiated rabbits showed phased changes in the slow-wave amplitudes when a similar time had elapsed after the end of the 30th treatment: an increase on Δ_2, /28
a decrease on Δ_1, and an increase on Θ. On the other hand, the activity remained the same as in the control group in the fast ECoG rhythms. Respiration was also unchanged. The absence of ECoG changes at the fast rhythms (β) and the rapid normalization of respiration in the repeatedly irradiated rabbits would also appear to indicate the development of adaptive reactions to the microwave field in the organism.

CHOLINERGIC ACTIVITY

As we noted above, microwave irradiation gives rise to pronounced functional changes in the nervous system; for this reason, research on cholinesterase activity during microwave irradiation is of interest for understanding of the mechanism by which electromagnetic energy acts.

TABLE 4. CHANGES IN CHOLINESTERASE (ce) ACTIVITY IN CERTAIN DIVISIONS OF THE RABBIT BRAIN FOLLOWING IRRADIATION IN A DECIMETRIC MICROWAVE FIELD (PFD 50 mW/cm^2, exposure 20 min)

Division of brain	ce activity, μmole of acetic acid		Percentage change in ce activity	ce activity in μmole of acetic acid with introduction of proserine		Percentage change in ce activity	
	Control	Experiment		Control	Experiment	without proserine	with proserine
Cortex	5,1±0,23	3,8±0,17	−26	4,0±0,09	4,2±0,16	−22	No changes
Subcortex	5,8±0,20	4,1±0,13	−29	4,3±0,13	4,4±0,10	−28	Same
Cerebellum	5,3±0,28	4,6±0,16	−13	4,5±0,11	4,6±0,15	−15	» »
Stem (oblongata, corpora quadrigemina, hypothalamus)	6,8±0,24	5,7±0,19	−18	5,2±0,14	5,5±0,11	−24	» »

A decrease in cholinesterase activity in the internal organs and blood of irradiated rabbits (irradiation at thermal intensities of the microwave field) was observed in the studies of S.V. Nikogosyan (1960). V.A. Syngayevskaya, T.P. Pliskina, and O.S. Ignat'yeva (1963) irradiated rabbits at nonthermal intensities (PFD = 500 $\mu W/cm^2$) of the microwaves and observed a decrease in cholinesterase activity in the cortex, subcortical divisions, cerebellum, brainstem, and medulla oblongata by 13-29% (Table 4); at times, it was accompanied by accumulation of acetylcholine. Injection of 0.1 mg/kg of proserine without irradiation of the rabbits lowered the /29 activity of the enzyme in the same divisions of the brain, while irradiation of the animals in weak microwave fields after preliminary injection of proserine was accompanied by no marked changes in cholinesterase activity and the effects were not additive, indicating a more complex mechanism in the action of microwave energy on cholinergic activity.

After a single 10-minute microwave irradiation at thermal intensity (PFD = 100 mW/cm^2), all rabbits showed a 40-70% increase in cholinesterase activity (averaging 50%); it remained high in some of the rabbits for 15-20 minutes after the end of irradiation (Table 5), and the rectal temperatures were observed to rise to 40°C. Five 10-minute radiation treatments daily also resulted in an increase in blood cholinesterase activity, but a less significant one than after the single microwave dose (V.A. Syngayevskaya, 1966).

A 20-minute irradiation at the same PFD resulted in a depression of cholinesterase activity in all rabbits (by an average of 40%), and their rectal temperatures rose to 42-42.5°C; the rabbits behaved restlessly and salivated. Five radiation treatments of 20 minutes each on a daily basis also produced a depression of blood cholinesterase activity (averaging 19%), but it was not as large as after the single-shot irradiation.

After a single 10-minute radiation treatment (PFD = 100 mW/cm^2), acetylcholine was detected in the blood of 70% of the 20 rabbits studied; this was indicated by the contraction of isolated eserinized frog abdominal muscle. The force of the muscle contraction was equal to that at a $1:10^8$ acetylcholine concentration. After a single 20-minute irradiation, no acetylcholine was detected in the blood of the rabbits (in this concentration). Irradiation under the same conditions produced a reliable decrease in blood calcium and sodium (Table 6), together with a substantial rise in the potassium-calcium coefficient.

The work of V.A. Syngayevskaya (1968) established a substantial decrease in ATP and accumulation of ADP and inorganic phosphorus in the liver, heart, skeletal muscles, and brain of rabbits after 10 minutes of irradiation with microwaves in the centimetric band (PFD = 100 mW/cm^2) as compared with control rabbits (Table 7). This indicated increased decay of macroergic phosphorus compounds disturbed the functioning of the nervous system and neurohumoral regulation (D.Ye. Al'pern, 1963).

In contrast, blood cholinesterase activity increased at lower radiation intensities, along with enhancement of the tissue phosphorylation processes; acetylcholine was detected in the blood, a factor that could have been important in maintaining neurohumoral regulation of organs and systems.

Microwave-irradiation research on isolated frog abdominal muscle (V.A. Syngayevskaya, 1968) has made it possible to trace the changes in cholinergic activity in a biological object that is simpler than the intact animal organism.

Isolated frog abdominal muscle was placed in a plexiglas vessel with thoroughly aerated physiological solution and irradiated with microwaves; acetylcholine was then added (with a final concentration of $1:10^6$) and the force with which the muscle contracted was observed and compared with the contractile force at the same acetylcholine concentration in the solution before irradiation. It was noted that after the muscle was irradiated with centimetric microwaves for 5 minutes (PFD = 100 mW/cm^2) or for 30 minutes (PFD = 20 mW/cm^2) and exposed to acetylcholine, its contractions were weaker (by 14-30%) than at the same concentration without irradiation. A similar effect can be observed on an increase in cholinesterase activity, with the associated more rapid breakdown of the acetylcholine.

The temperature of the solution in the plexiglas vessel rose from 19°C to 22-25°C during irradiation. The same solution-temperature increase under ordinary heating did not change the force of the muscle contraction when acetylcholine was added to the solution containing the muscle, either before or after heating. Thus, these studies indicated a nonthermal effect of electromagnetic waves on the cholinergic properties of isolated muscle.

Changes in the cholinergic link were established in these experiments on animals and on isolated muscle with microwave irradiation. Apparently, microwaves may act as a stimulus that works through interoceptive links to change the cell-membrane electrical potential or cause de- or hyperpolarization.

It is possible that, entering the blood, the acetylcholine formed in the synapses under microwave exposure acts upon the chemoreceptors and pressoreceptors of the carotid sinus and on the skin mechano- and thermoreceptors (Brown, Gray, 1948), and, /33
by exciting the carotid chemoreceptors, causes reflex changes in the functions of the hypophysis and adrenal glands.

Depending on the intensity of the microwave exposure, they cause either an enhancement and activation of cholinergic transfer in the irradiated biological object or a weakening of this process owing to disturbances in the formation of the attendant biochemical components, with disturbance of the associated metabolism (Kh.S. Koshtoyants, 1938; Ye.B. Babskiy, 1947; D.Ye. Al'pern, 1963; V.A. Syngayevskaya, 1968, and others).

ENDOCRINE GLANDS

According to presently available data, changes occur in the functions of the anterior pituitary and adrenal cortex, the thyroid gland, and the sex glands under the influence of thermal microwave intensities.

Changes in the functions of the anterior pituitary and adrenal cortex. In dogs exposed for 2-6 hours to microwave radiation (λ = 12.5 cm and 1.5 m, PFD = 165 and 100 mW/cm^2), distinct leucocytosis, lymphocytopenia, and eosinopenia were observed 24 hours after irradiation (Howland et al., 1961); this is an indirect indication of intensified functioning of the anterior pituitary and adrenal cortex. Similar changes in anterior pituitary and adrenal cortex function were reported by Fukui (1959), Cooper et al. (1962), and others under the influence of microwave radiation.

In the opinion of Schliephake (1960), changes in pituitary and pancreatic function are highly important in man and animals in the development of the effects that appear after exposure to microwaves. In humans exposed to microwaves in the centimetric band (PFD = 50 W/cm^2, time of exposure 10 minutes), he observed an increase in the content of 17-ketosteroids in the urine, and in white rats a marked increase in the ascorbic-acid content of the adrenal cortex, indicating increased secretion of the hormones.

The results obtained by F.L. Leytes and L.A. Skurikhina (1961) indicated increased hormone production in the adrenal cortex under exposure to microwaves as soon as 1-2 hours after the beginning of irradiation.

According to the research of V.A. Syngayevskaya et al. (1962), different changes in pituitary and adrenal-cortex function are observed in animals under the influence of different microwave intensities. Indeed, one hour after exposure to thermal intensities (70 mW/cm^2, irradiation for 30 minutes), increased contents of ascorbic acid were found in the adrenal glands of dogs and rabbits. But after exposure to nonthermal microwave intensities (PFD = 5 mW/cm^2, irradiation for 30 minutes), the same animals showed lower ascorbic-acid contents in the adrenals. /34

Thus, it may be concluded on the basis of these studies that thermal intensities suppress the hormone-producing functions of the anterior pituitary and adrenals, while nonthermal intensities enhance them.

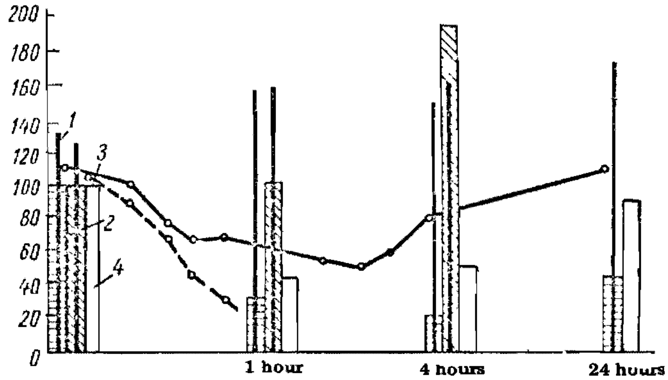

Figure 2. Changes in Respiration, Oxygen Demand, and Blood Leucocyte and Eosinophil Counts After Microwave Irradiation in Rats. 1) Leucocytes; 2) eosinophils in rats with inhibitory bell reaction; 3) same, with convulsive reaction; 4) oxygen demand. Solid curve: respiratory frequency in rats with inhibitory bell reaction; dashed: in rats with convulsive reaction to bell.

I.R. Petrov and V. A. Pukhov (1966) found pronounced eosinopenia in the large majority of white rats that survived after microwave irradiation (λ = 12.6, PFD = 116 mW/cm^2), an indirect indication of increases in the adrenocorticotropic function of the anterior pituitary and the level of glucocorticoid hormones in the blood (Thorn, 1953, Sel'ye, 1960). Eosinophil count continued to decline in most of the surviving rats after 4 hours, but rose slightly after a few days, although it remained at half its original level. The changes noted in the eosinophil counts in the blood of the rats that died during irradiation were the opposite (eosinophilia).

In most of the surviving animals, oxygen demand declined over the first few hours after irradiation, but rose sharply after 4 hours and reached its initial level after 1 day. Breathing slowed /35 at first, rose abruptly at 4 hours, and had reached the original rate within 24 hours (Fig. 2). The research results of I.R. Petrov and V.A. Pukhov indicated that the resistance of white rats to microwaves was sharply lower 1 week after bilateral adrenectomy. The blood eosinophil count increased by an average of 118% after removal of the adrenals, and either did not change or continued to rise after irradiation. As a result, acute adrenal insufficiency has a detrimental influence on the course of the pathological process initiated by exposure to radio waves in the microwave band.

To ascertain the role of the gluco- and mineral-corticoid function of the adrenal cortex, experiments were designed with autotransplantation of adrenal glads, a technique that can be used to study these functions in isolation, since only their mineral-corticoid function recovers within the first two weeks after autotransplantation of the glands, and glucocorticoid activity resumes only after 1-1.5 months.

TABLE 8. RESISTANCE OF RATS TO THE ACTION OF THE MICROWAVE ELECTROMAGNETIC FIELD (PFD 60 mW/cm^2, exposure 45 minutes)

Experimental series	Number of rats	Survived	Perished
Control	15	10	5
After adrenectomy	14	4	10
1-2 weeks after adrenal autotransplantation	9	—	9
1 month after adrenal autotransplantation	10	8	2

The results of these experiments showed that 1-2 weeks after adrenal autotransplantation, when there is an acute insufficiency of their glucocorticoid function, all nine of the experimental rats perished, while only 5 of 15 white rats in the control group expired as a result of microwave irradiation (λ = 12.6 cm, PFD = = 60 mW/cm^2, exposure time 45 minutes) (Table 8). Irradiation of adrenectomized rats under the same conditions also produced high mortality (10 rats out of 14 perished). Thus, the adrenectomized animals and animals exposed 1-2 weeks after adrenal autotransplantation, at a time when glucocorticoid activity was nonexistent but mineral-corticoid activity was in force, were more sensitive to microwaves than intact animals.

In contrast, one month after autotransplantation, when glucocorticoid activity had recovered in the animals, the resistance of the white rats to microwave radiation was substantially higher. Indeed, 8 out of 10 of these white rats survived irradiation under the same conditions (see Table 8), i.e., they had the same microwave resistance as intact animals. /36

Comparison of the results of these studies indicates convincingly that the sensitivity of animals to microwave radiation depends on adrenal functional state and, in particular, that insufficient glucocorticoid activity of the adrenal cortex is accompanied by lowered resistance of the animals to microwaves.

The enhancement of glucocorticoid activity observed in most of the rats during and after irradiation is an adaptive reaction. A few of the white rats developed inhibition of the adrenal-cortex function (glucocorticoid activity), attended by a decline in resistance to microwaves.

The latter can also be explained in terms of insufficient ACTH supply. The increase in resistance may be related, in turn, to an increase in the secretion of ACTH, which would also be an adaptive reaction of the organism. This is supported by the fact that the resistance of white rats to microwaves shows a slight increase when ACTH is administered.

It is known that the CNS is highly sensitive to microwave irradiation and that changes in its functions may be adaptive in nature, with a regulatory influence on the endocrine glands.

According to present-day notions, the functions of the anterior pituitary and adrenal cortex are regulated by the central nervous system. From this viewpoint, it is interesting to compare the functional changes in the CNS, hypophysis, and adrenal cortex that take place under the influence of microwave irradiation. The results of experimentation have brought out very clearly differences in the microwave sensitivities of rats in which inhibition and excitation of the central nervous system predominates.

Under the effects of irradiation at a PFD of 60 mW/cm^2, only two out of 12 rats with an inhibited reaction to an acoustic stimulus perished, and the other 10 survived. On the other hand, only one of seven rats with a convulsive response to the bell survived while the other six perished during irradiation (Table 9). Thus, animals with predominant excitation of the CNS, i.e., with insufficient internal inhibition were found to be more sensitive to irradiation in a microwave field.

/37

TABLE 9. RESISTANCE OF WHITE RATS TO MICROWAVES (λ = 12.6 cm, PFD 60 mW/cm^2, exposure 45 minutes)

Experimental series	Number of rats	Perished during irradiation	Survived	X^2	P
Rats with inhibitory reaction to bell	12	2	10	—	—
"Excitable" rats (convulsive reaction to bell)	7	6	1	6,1	0,01
"Inhibited" rats with caffeine (30 mg/kg)	7	5	2	3,6	0,05
"Excitable" rats with sodium barbital (100 mg/kg)	8	2	6	6,1	0,01

It is interesting to note that the rats with the convulsive response to the acoustic stimulus were found to be eosinophilic, while a decrease in eosinophil count was observed in the rats with the inhibitory reaction (see Fig. 2). Starting 7-10 minutes after the beginning of irradiation, rats in which excitation predominated suffered convulsive attacks that generally followed one another at intervals of 1-2 minutes. During one of these attacks of motor excitation and convulsions, the animals would suffer respiratory stoppage and perish. The rectal-temperature increase (immediately after irradiation) was 1.7°C greater in rats of this group than in rats with the inhibitory response to a strong acoustic stimulus ($P = 0.05$).

Experiments in which the central nervous system was artificially stimulated with caffeine showed that the stability of rats with the inhibitory reaction to the acoustic stimulus dropped sharply on administration of the drug and was the same as that observed in animals with insufficient internal inhibition on application of a strong acoustic stimulus. In contrast, the microwave resistance of rats with an excitation response to the bell was higher 30 minutes after administration of a soporific dose of sodium barbital, i.e., artificial inhibition of the central nervous system (see Table 9); here, six of eight rats survived, as against only four in an 11-animal control group ($\chi^2 = 6.1$, $P = 0.01$).

It is interesting to note that when the rats are placed in two groups based on their response to a strong acoustic stimulus, eosinophilia was observed in rats with the convulsive reaction to the bell and eosinopenia in animals with the inhibitory reaction, i.e., a pronounced adaptive response of the hypophysis-adrenal- /38
cortex system was observed on irradiation of the latter group with microwaves, while this reaction was insufficient in the animals of the first group.

The question as to the state of glucocorticoid and mineralcorticoid activity in the adrenal cortex and the participation of the hypothalamus in these processes cannot be solved simply by studying blood eosinophils and adrenal ascorbic acid, since eosinopenia and decreased ascorbic acid indicate general ("summary") stimulation of the hypophyseal and adrenal-cortex hormone-producing functions.

The studies of V.A. Syngayevskaya et al. (1966) established a significant enhancement of the hormone-producing functions of the hypophysis and adrenal cortex in dogs. Three and 24 hours after the dogs were irradiated with 10-cm microwaves at a PFD of 10 mW/cm^2, the glucocorticoid content in their blood had increased by 100 and 150% above the original level, while blood potassium was down 5-10% and blood sodium up by percentages in the same range.

V.A. Syngayevskaya et al. (1962) and the previously cited data of I.R. Petrov and V.A. Pukhov (1966) indicated that the changes in the glucocorticoid activity of the adrenal cortex under the influence of microwaves depend on the functional state of the CNS. Indeed, the increase in blood glucocorticoids under the influence of microwaves was more pronounced in intact animals than in animals that had been given chlorpromazine, which blocks the reticular formation, before irradiation.

In a study of the influence of pulsed microwave irradiation (decimetric band, PFD = 1 and 10 mW/cm^2, exposure 1 hour), we also established an increase in the blood glucocorticoid level in dogs and smaller changes in blood potassium and sodium (Fig. 3); here the blood glucocorticoid content was 95% higher 3 hours after a single radiation dose (PFD = 1 mW/cm^2).

When ACTH (3.5 units/kg) was administered to irradiated dogs, the response of the adrenal cortex differed from that observed when the same ACTH dose was given to unirradiated dogs. Thus, the glucocorticoid content had risen by 200-280% within 3-4 hours after administration of the ACTH to the unirradiated dogs. When the same ACTH dose was given dogs 48 hours after the end of a single radiation treatment and 48 hours after repeated treatments (1 hour daily), the glucocorticoid content increased by 60-80% over its initial level.

Only when 3 days had elapsed after the single treatment and 14-21 days after the repeated irradiations did the response reaction of the adrenals to administration of ACTH return to the same /39 level as in the controls (Fig. 4). As a result, the stimulation of hormone production observed in unirradiated dogs was not observed in dogs irradiated 48 hours earlier, although the glucocorticoid content had recovered to its initial level in the latter after the single microwave dose.

Changes in sex-gland function. Although the literature makes frequent reference to complaints of impotence from persons who have been exposed to microwaves, little experimental study has been devoted to this question.

Dystrophic changes were observed in the sex glands of animals exposed to high microwave intensities in the centimetric band (Imig, Tomson, 1948). In males, brief exposures (15, 10, and 5 seconds) to microwave radiation (λ = 12.5 cm, PFD = 250 mW/cm^2) caused burns on the skin of the scrotum and hemorrhaging in the testicles (Gunn, 1961); microscopic examination revealed coagulation necrosis of the epithelium of the seminiferous tubules and necrosis of the interstitial tissue and vessel walls, although /40 only a small temperature rise (to 35°C) had been observed in the testes.

A reduction in the size of the testicles as compared with those of intact animals of the same age was observed 29 days after irradiation. The seminiferous tubules lacked the germinative epithelium, and the interstitial tissue contained large numbers of fibroblasts and few Leidig's cells. The degree of the morphological changes in the testicles depended on the duration of exposure; for example, the changes were less pronounced in experiments with 5 seconds of irradiation as compared with 15 seconds.

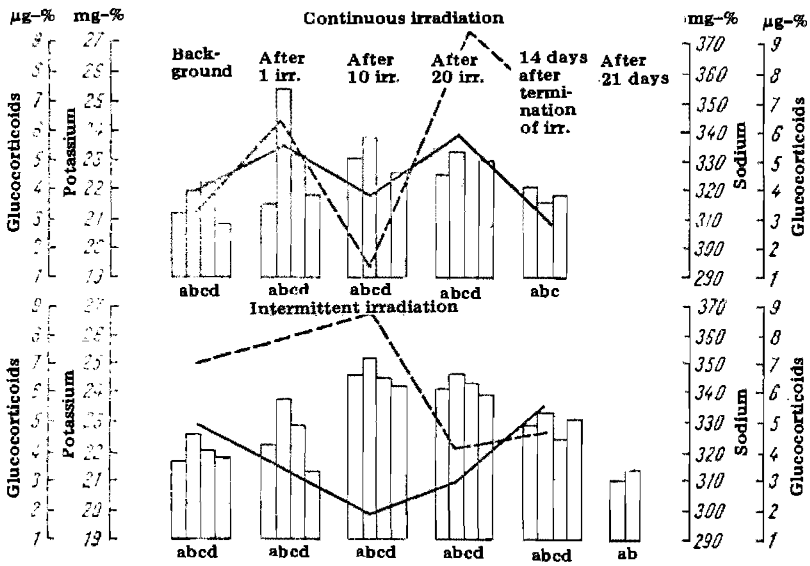

Figure 3. Contents of Glucocorticoid, Potassium, and Sodium in the Blood of Dogs (Decimetric Band, PFD of 1 and 10 mW/cm^2, Respectively, Exposure 1 Hour). Symbols: a) on awakening; b) 3 hours later; c) 24 hours later; d) 48 hours later; solid lines represent K contents and dashed lines Na.

S.F. Gorodetskaya (1962) reported more pronounced changes in the ovaries than in the testicles of mice under the influence of centimetric wavelengths (PFD = 370 mW/cm^2, exposure 5 minutes). The experimental results of I.V. Pitenin (1962) indicated that repeated exposure to microwaves (λ = 10 cm, 20 treatments lasting 60 minutes each), which are accompanied by an increase in rectal temperature, cause serious changes in the testicles of mice and rats (suppression of spermatogenesis, dystrophy of the epithelium, death of cells). In some animals, significant necrotic foci were observed in the tissue of the testicles (deposition of calcium salts). /41

G.V. Timeskova (1966) studied the influence of the microwave field on testicular function, impregnation, the course of pregnancy, and the offspring of sexually mature rabbits. They were subjected to whole-body irradiation with centimetric microwaves at a PFD of 100 mW/cm^2 with an exposure time of 15 minutes. Their rectal temperatures rose by 3-4°C. It was found in these experiments that the granulosa cells in the mature and maturing follicles of the rabbits dystrophy and decompose.

The irradiated female animals were hard to mate and were impregnated only after six or even 10 days with the male. It is

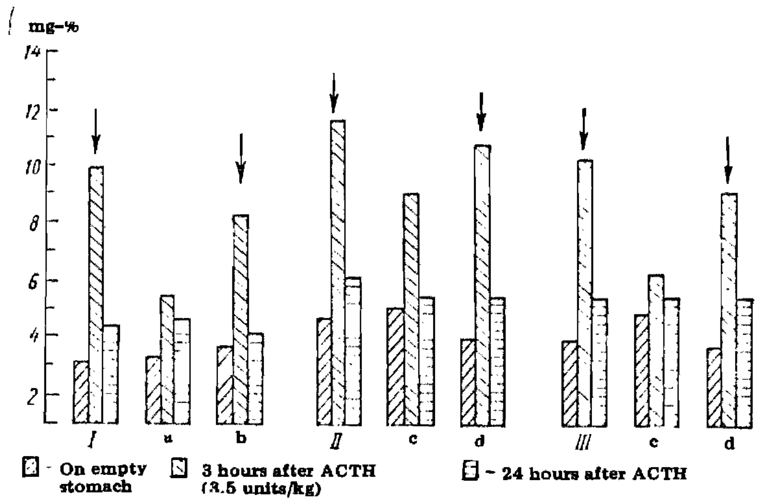

Figure 4. Glucocorticoid Contents in Blood Serum of Dogs Given ACTH After Microwave Irradiation (PFD = 1 mW/cm^2, Decimetric Band, Exposure 1 Hour). Symbols: I, II, III) background (without irradiation) but with ACTH (arrow above bar); a) after 48 hours; b) 3 days after single irradiation with subsequent ACTH administration; c) after 48 hours; d) 14-21 days after repeated irradiation with subsequent ACTH administration.

possible that the microwave energy damages not only the granulosa cells, but also the ova. The offspring of the irradiated females were born small and many of them perished during the first two days. The response of repeatedly (15 minutes on each of 14 successive days) irradiated female rabbits to choriogonadotropine (Friedmann's reaction) was more pronounced than that of rabbits given one and three doses of radiation. According to S.F. Gorodetskaya (1964), irradiated males (PFD = 400 mW/cm^2) produced almost no offspring when mated with unirradiated females.

R.I. Kruglikov (1968) reported lower viability of the offspring and abnormalities in their development (dwarfism, deformed teeth, low birth weight, abnormal growth of coat) when animals were irradiated during pregnancy with thermal-intensity microwaves (λ = 12.6 cm, PFD = 50-55 mW/cm^2). Antenatal exposure of the animals to microwaves affected the development and reinforcement of conditioned reflexes, which were found to be very difficult.

Changes in thyroid function. The literature offers comparatively few experimental studies of this question. The results obtained by V.A. Syngayevskaya and O.S. Ignat'yeva (1966) showed

TABLE 10. CHANGES IN IODINE CONTENT IN 1 ml OF SALIVA (IN μg) AFTER ADMINISTRATION OF POTASSIUM IODIDE WITHOUT IRRADIATION AND AFTER A SINGLE MICROWAVE IRRADIATION (30 minutes)

Name of dog and date of examination	After administration of potassium iodide			
	After 1 h 30 m	After 2 h	After 24 h	After 48 h
Martyn	**No irradiation**			
7/V	188	214	97	Traces
14/V	165	229	121	
27/VIII	182	202	82	
10/IX	148	252	91	
	After irradiation			
22/V	128	162	79	
28/V	127	156	91	
17/IX	104	123	102	
24/IX	117	127	95	
1/X	98	153	118	
15/X	111	128	94	
Boy	**No irradiation**			
27/V	194	237	80	
4/VI	185	220	142	
	After irradiation			
11/VI	166	189	126	
18/VI	168	186	80	
24/VI	180	197	115	

Note. Iodine could not be detected in the saliva after 72 hours.

enhanced thyroid function in dogs after brief (30-minute) irradiation with metric microwaves (PFD = 3 mW/cm^2). Dogs with Steno's ducts diverted to the outside were given potassium iodide perorally (0.5 g with sugar coating). It was found that the administered iodine was used more rapidly by the thyroid gland in the irradiated dogs than in unirradiated animals.

The saliva iodine content was down by an average of 37% in one of the irradiated dogs 1.5 hours after the end of irradiation and down by 18% in the other as compared with unirradiated figures for the same dogs (Table 10).

Similar changes in thyroid function were also observed after repeated irradiation (eight 30-minute treatments daily).

Seven days after termination of the repeated radiation doses, /42
the increased functional level still persisted, and only after 14

TABLE 11. CHANGES IN IODINE CONTENT IN 1 ml OF SALIVA (in μg) WITHOUT IRRADIATION AND AFTER REPEATED IRRADIATIONS (8 30-minute treatments daily)

Dog and date of examination	After administration of potassium iodide: After 1 h 30 m	After 2 h	After 24 h	After 48 h
Without irradiation (Average of control determinations)				
Martyn	157	234	96	Traces
Boy	190	229	111	
After 8 irradiations				
Martyn 12/VI	121	115	106	
7/VII	143	168	94	
Boy 12/VIII	169	178	145	
11/IX	172	190	101	
7 days after end of multiple irradiations				
Martyn 19/VI	125	155	84	
Boy 19/VIII	170	208	109	
14 days after end of multiple irradiations				
Martyn 25/VI	182	195	99	
Boy 26/VIII	183	210	115	

days had it returned to normal (Table 11); at the same time, the administered iodine was detected in the saliva in the same quantities after single irradiations as in the unirradiated dogs.

Using a combination of centimetric waves (PFD = 165 mW/cm^2) and x-rays, Howland and Michaelson (1959) also observed increased uptake of radioactive iodine I^{131}; they observed no pronounced functional or morphological changes in the thyroid gland 2-4 hours after administration of the I^{131} and irradiation.

K.N. Klyachina et al. (1963) observed increased thyroid function in animals irradiated with microwaves (PFD = 33 mW/cm^2) and small doses of x-rays generated by microwave equipment. /43

Increases in oxygen demand observed in dogs under the influence of metric- and microwave exposure (PFD = 2-3 mW/cm^2) were linked by N.M. Listova (1963) to a change in thyroid function, since thyroidectomized dogs did not exhibit these changes in oxygen demand after irradiation.

We cannot exclude the possibility that the effect of microwaves on thyroid function comes about with participation of the nervous system, since the dogs in the experiments of V.A.

Syngayevskaya and O.S. Ignat'yeva (1966) were subjected to whole-body irradiation (right side of torso and head), rather than radiation aimed at the gland. The animals were observed to become excited and restless. It is possible that the microwaves acted primarily on the nervous system and that the thyroid-function changes were secondary in nature.

Thus, disturbances to neurohumoral regulation appear under irradiation with high-intensity microwaves that cause an increase in body temperature, owing to changes in the functions of the CNS and certain endocrine glands. /44

EXTERNAL RESPIRATORY SYSTEM, CARDIOVASCULAR SYSTEM AND BLOOD

Simultaneously with the rise in body temperature, exposure to microwaves at more than 10 mW/cm^2 causes various systemic reactions. Respiratory changes are first to appear. Usually, pronounced shortness of breath develops within the first few minutes after the start of irradiation at PFD around 100 mW/cm^2, and is practically indistinguishable from the thermoregulatory polypnea that appears under conditions of ordinary overheating (in a temperature chamber, under exposure to infrared rays, etc.).

Salivation, motor restlessness, and other reactions are observed along with the sharp quickening and shallowness of respiration (A.G. Subbota, 1957; Michaelson, 1961, 1962). As the irradiation continues (at 100 mW/cm^2), the respiration of rabbits becomes arryhthmic; then signs of terminal respiration appear and respiration stops 20-30 minutes after the beginning of irradiation (most frequently during inspiration).

There are also rather distinct changes in the functioning of the cardiovascular system at these thermal microwave levels. Most typical are tachycardia and increased arterial pressure, especially during convulsions, and there are other signs of disturbance to the work of the circulatory apparatus. Later, when terminal respiration has set in, the heart rate slows and extrasystole appears; cardiac arrest occurs 1-2 minutes after stoppage of respiration.

Bilateral cervical vagotomy, bilateral adrenectomy (Cooper, 1962), and pharmacological blockade of sympathetic ganglia (Cooper, 1962; Pinakett, 1963) partially or completely eliminated such reactions as the tachycardia.

Electrocardiographic studies showed that an increase in the intensity of irradiation is also accompanied by phase shifts in the work of the heart. Frequently, changes in the intervals, amplitudes, and shapes of the ECG deflections have been related to irradiation of excitation from the respiratory center to the extracardial regulatory center of the heart. Profound changes in atrioventricular conductivity were observed, with the development of arryhthmia.

When the region of the heart was irradiated locally (PFD = = 100-200 mW/cm^2), a change in the amplitude of the deflections in the ventricular complex of the ECG (R, S, and T) and changes in the rhythm of the contractions (bradycardia) were linked to /45 shifts in blood potassium content (N.R. Chepikova, 1963, 1965). However, in chick embryos exposed simultaneously to microwaves and a stream of air (the temperature was held at around 38°C), inversion of the S and T deflections was observed after as little as 3 minutes, together with quickening of the heart rate (Paff et al., 1963).

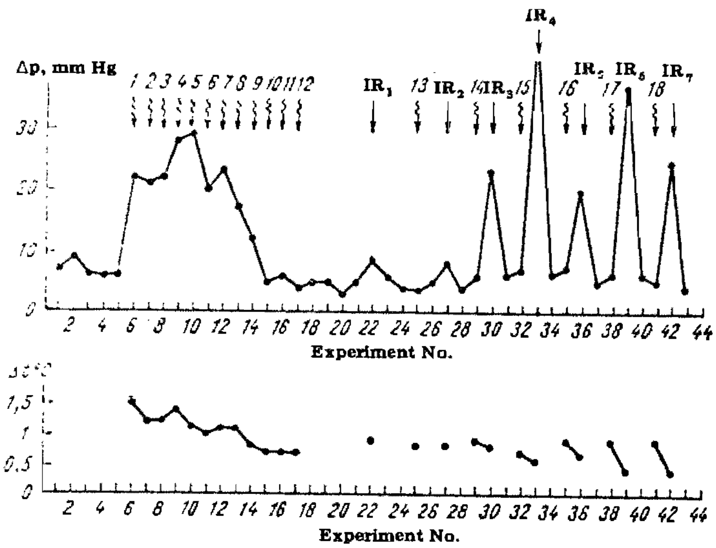

Figure 5. Arithmetic Mean Values of Arterial-Pressure Drop (Upper Curve) and Rectal-Temperature Increase (Lower Curve) in 6 Rabbits Irradiated with Microwaves (Wavy Arrows) and Infrared Light (IR, Straight Arrows).

In a study of arterial pressure under chronic-experiment conditions (exposure to a microwave field in the 12.6-cm band, PFD = = 50 mW/cm^2), it was found that the arterial pressure dropped and then recovered to its initial level after 1-2 hours. Characteristically, these effects were registered only after the first few microwave treatments, and later, as the treatments were repeated (once every 1-3 days), the arterial-pressure change became smaller in degree, to disappear altogether from the 9th or 10th treatment. The rectal-temperature rise was less conspicuous: instead of the 1-1.7°C increase after the first exposure, it showed 0.7-0.9°C after 9 to 10 treatments (Fig. 5). We see from Fig. 5 that the arterial-pressure drops were largest after treatments 1-5, and had returned almost to the preirradiation levels after 9-10 treatments.

Acquisition of the ability to maintain constant arterial pressure with a simultaneous decrease in the body-temperature rise may be interpreted as an index to the organism's adaptation to microwave exposure, which takes place with participation of the nervous system, since hemodynamic stability was not developed in rabbits with denervated sinocarotid reflexogenic zones. Moreover, the depressor reactions were more conspicuous in these rabbits, and the general stability of the organism was lowered (some of the animals perished from general overheating). /46

Since deep-lying tissues and blood are heated preferentially under microwave exposure, it is probable that the vascular thermoreceptors and, in particular, the thermoreceptors at the branching of the carotid artery (demonstrated by I.D. Boyenko, 1950) are decisive in the organism's adaptation to this extraordinary stimulus.

Many papers have been devoted to study of the morphological picture of the blood of animals subjected to high-intensity microwave irradiation. Thus, leucopenia, erythropenia, a 6-10% decrease in the percentage hemoglobin content, and shorter blood coagulation times were observed in rabbits after irradiation with 10-cm waves at a PFD of 100-300 mW/cm^2, against a background of manifest hyperthermia. The blood picture showed signs of a return to normal 2 hours after exposure.

Repeated irradiations of these animals at a PFD of 10-20 mW/cm^2 caused only a small decrease in leucocyte count and an insignificant shortening of blood-coagulation time (N.V. Tyagin, 1958). In dogs irradiated at high intensities (165 mW/cm^2), signs of thinning of the blood were observed (in the hematocrit) even before the rectal temperature had started to rise (during the first 30 minutes of exposure). It is assumed that this thinning of the blood results from an influx of tissue fluid into the dilated vessels.

Decreases in leucocyte, lymphocyte, and eosinophil counts were also observed and taken to indicate enhanced functioning of the pituitary-adrenal cortex system (Michaelson, 1961). After dogs had been irradiated for 2 hours and longer and begun to show manifest hyperthermia, concentration of the blood (on the basis of hematocrit readings), probably owing to a certain amount of dehydration, and leucocytosis were observed. The animals also showed more than a 5% loss of weight (Michaelson, 1961, 1962).

The appearance of leucopenia under exposure to low thermal microwave intensities has been reported on several occasions (V.V. Sokolov et al., 1960, 1963; I.A. Kitsovskaya, 1964; S.F. Gordetskaya, 1953, 1964; Deichmann, 1959, 1961; Fukui, 1959).

Interesting data were obtained on mice that were enclosed in a slowly rotating polystyrene cabin and irradiated daily for 16-19 months (λ = 3 cm, PFD = 100 mW/cm^2, exposure 4.5 minutes). The /47 rectal temperature rose by an average of 3.3°C after each radiation treatment. The blood of 30% of the experimental mice showed the picture of leucosis on examination after 16 months of irradiation. Among the controls, leucosis was reported for 10% of the animals.

After 19 months of irradiation, leucosis was found in 35% of the animals, and in the same 10% of the control-series mice (Prausnitz, Süsskind, 1961, 1962).

The coagulability of the blood was also studied under local irradiation of the liver region in dogs (λ = 12.25 cm, PRD = 158-197 mW/cm^2). It was found that the Bürker blood-coagulation time increased from 6.4 to 8.1 minutes after 10 minutes of irradiation but had shortened to 4.4 minutes after a second identical treatment given 5 minutes later. Shorter blood-coagulation times were also observed after subsequent treatments (Richardson, 1959).

Blood flowing through a polyethylene tube from the femoral vein of a dog was studied to ascertain the mechanism of the changes in blood composition in vivo. It was found that absolute neutrophilic leucocytosis developed much more slowly and that the eosinopenia was less pronounced in the experimental dogs while their blood was being irradiated in the tube as compared with control animals; absolute lymphocytosis arose during the first hour of irradiation at a PFD of 50 mW/cm^2. The results of these studies led to the hypothesis that the electromagnetic field has a direct influence on the formed blood elements or an indirect influence operating through changes in blood chemical composition (A.Ya. Kholodnyy, A.I. Ivanov, B.A. Chukhlovin, 1968).

ORGANS OF THE DIGESTIVE SYSTEM

Although it was long ago assumed that damage might occur to the hollow organs as a result of overheating of their contents (Hines, Randall, 1952), there had been no experimental confirmation of such microwave-field effects. McLaughlin (1957) was the first to attempt to prove this thesis by reference to a case of perforated ulcer in the small intestine of one radio technician who died after standing too close to a radiating antenna. However, Knauf (1958) considers this to be a doubtful case. Later, Linke (1962) observed that profound morphological changes may occur in the liver, stomach, etc., but only after organs have been irradiated with the abdominal cavity opened.

It was established only comparatively recently that local /48
irradiation of the anterior celiac region in the rabbit (which corresponds to the epigastric region in man) causes selective injury to the mucosa of the stomach. Thus, after exposure to a 12.6-cm microwave field at a PFD of about 110-120 mW/cm^2 and a 10-minute exposure time, half of the animals had gastric ulcers on the anterior wall of the stomach, i.e., on the wall nearest

the radiator (Fig. 6).

All of the other tissues through which the microwave energy had penetrated before reaching this membrane remained practically undamaged. The temperature of the stomach contents, and that of water introduced into the cavity of the stomach with a rubber balloon did not rise above 40-42°C. At still higher radiation intensities (150 mW/cm^2 and more), ulcers were found in practically all of the animals. Under microscopic examination on the 2nd day after irradiation of the rabbits, the ulcers took the form of circumscribed necroses of the mucous membrane extending to the submucosal layer and occasionally to the muscular layer (I.V. Pitenin and A.G. Subbota, 1965).

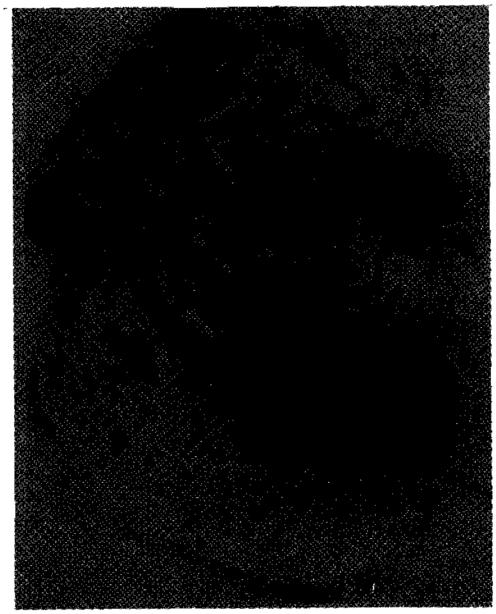

Figure 6. Ulcer in Lower Wall of Rabbit Stomach One Day After Irradiation of the Anterior Celiac Region (PFD = 150-160 mW/cm^2, exposure time 10 minutes).

Irradiation of the posterior celiac region (which corresponds to the hypogastrium in man) caused ulceration of the mucosa in the small and large intestines. To ascertain the causes of the damage to the gastric mucosa, experiments were designed in which the anterior celiac region was irradiated in rabbits into whose stomachs air had been introduced. This excluded contact between the irradiated wall of the stomach and the bolus of food, which was confirmed by x-rays and opening the stomachs. However, the ulcers were the same as in cases in which the stomach had its normal food content (Table 12).

It is quite possible that the mechanism of selective injury to the mucosa was governed by the same circumstances as were noted in the case of chick embryos (Van-Ummersen, 1961), i.e., by the higher sensitivity of young cells to the microwave field. /49

This hypothesis is favored by the generally recognized high physiological-regeneration level of the mucosa, whose epithelial cells are replaced by new ones practically every day (L.D. Liozner, 1962). Nor can we exclude the possibility of disturbance to certain physiological properties of the membrane, such as loss of stability to digestion by its own gastric juices, since the manifest ulcers did not appear until a day had elapsed since the microwave treatment. Autopsy of the rabbit on the 10-20th day after irradiation revealed ulcers resembling typical human callous ulcers.

TABLE 12. SUMMARY OF RESULTS OF RABBIT EXPERIMENTS IN WHICH THE ANTERIOR CELIAC REGION WAS IRRADIATED
(PFD = 150-160 mW/cm^2, exposure 10 minutes, λ = 12.6 cm)

Experimental conditions	Number of animals	Rectal-temperature rise, °C	Autopsy results
Anterior celiac region irradiated with animal supine. Stomach filled with usual food (control)	10	1.0° (0.9-1.3°)	In 8 rabbits, ulcers of the lower stomach wall, 1 × × 2 to 3 × 5 cm in size (2 also had intestinal ulcers)
Same region irradiated, but with air (50 ml) injected into stomach of unfed rabbits	10	1.3° (1-1.8°)	In 9 rabbits, gastric ulcers at typical position, sizes from 2 × 3 cm to 3.5 × 5 cm. In 2, intestinal ulcers (cecum and small intestine)

When the anterior celiac region was irradiated under similar conditions (λ = 12.6 cm, Luch-58 generator putting out 70 W and more, distance from radiator 7-8 cm), glucose induction in a Pavlov isolated stomach and in a Thiry isolated intestine increased against a background of heating of the stomach contents by 1.5-2°C. Glucose induction was also stimulated by irradiation of the cervical region and the rear extremities. Novocaine anesthesia of the skin of the epigastric area of the anterior celiac region, novocaine injected into the gastric mucosa, denervation of a loop of intestine, bilateral splanchnicotomy, or removal of the solar plexus usually eliminated or inverted the effect of the thermal-microwave treatment. On the basis of these data, V.R. Faytel'- /50
berg-Blank (1964, 1965) concludes that changes in absorption processes are basically of reflex nature.

Working with A.M. Grebeshechnikova, we showed that the secretory function of the stomach also changed substantially under local irradiation (λ = 12.6 cm) of the anterior celiac region in dogs with both Pavlov and Heidenheim stomachs (Fig. 7). Attention is drawn here to the effect of smaller shifts as the radiation treatments are repeated, although the water-temperature rise in a balloon introduced into the cavity of the Pavlov stomach remained practically the same.

Thus, the above-noted functional and morphological changes in the organism on irradiation with (thermal) microwaves can be explained in far from all cases by the temperature increase in

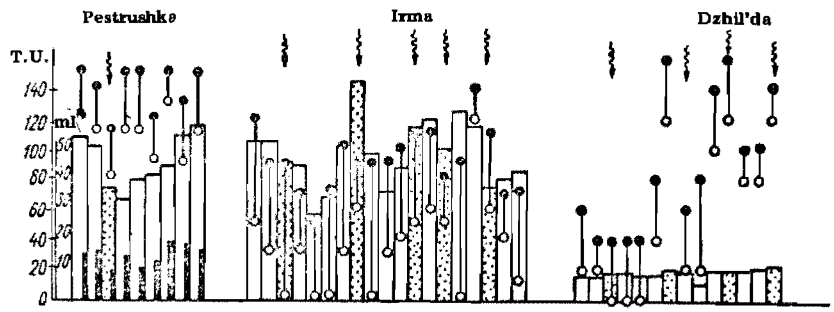

Figure 7. Changes in Secretory Function of Pavlov (Dogs Pestrushka and Irma) and Heidenheim (Dzhil'-da) Stomachs. Symbols: open bars, total amount of gastric juice after 5 hours; dark bars after 1 hour. Circles indicate acidity of first portion of juice (open circles free, dark circles total). Arrows indicate microwave irradiation (λ = 12.6 cm, PFD = 160 mW/cm^2 for Pestrushka and 110 mW/cm^2 for Irma and Dzhil'da).

the organs and tissues. Some of these changes are definitely specific in nature (ulceration of the gastric mucosa, leucosis in mice, etc.).

The same reactions that have been associated with the temperature rise (thermoregulatory polypnea, tachycardia, dilatation of vessels, etc.) may be modified substantially on repeated exposures. This is probably why the body-temperature increase under subjection to identical treatments and the rise in femoral-muscle temperature under local irradiation both decreased and the animal withstood the thermal treatments with considerably greater ease.

Chapter 3

METABOLIC CHANGES

This chapter deals with material on the influence of microwave radiation on protein and carbohydrate metabolism and oxidative processes.

PROTEIN METABOLISM

A decrease in albumen content and a rise in γ-globulins was observed in the blood serum of rabbits after 10-20 microwave treatments lasting 1 hour each (centimetric and decimetric bands, PFD = = 10 mW/cm^2), with no change in the rectal temperature of the animals. Total blood protein remained unchanged, but the albumen-globulin coefficient dropped from 1.6 to 1.1. On subsequent irradiations, beginning with the 40th to 60th treatment, the contents of α- and β-globulins decreased without any pronounced changes in over-all blood protein (S.V. Nikogosyan, 1962).

The experiments of A.G. Subbota et al. (1967) established a marked decrease in albumens and gamma-globulins and a depression of total blood-serum protein in rabbits with no marked change in the albumen-globulin coefficient (Table 13) under the influence of whole-body irradiation at frequencies of 13.2-13.6 MHz with an unmodulated-field strength of 25 V/m. The electrophoregrams had the usual appearance, reflecting quantitative changes in individual fractions. There are several known studies of blood-serum protein fractions in humans exposed to microwave energy (I.A. Gel'fon, M. N. Sadchikova, 1960; V.A. Syngayevskaya et al., 1962, and others).

The changes in the contents of the protein fractions can be linked to a change in the protein function of the liver and with functional changes in the hypophysis and adrenal cortex.

Under exposure to centimetric and decimetric microwaves, enhanced functioning of the anterior pituitary and adrenal cortex has been observed in rats, rabbits, and dogs. The dogs showed a substantial increase in blood glucocorticoids, and ascorbic acid was down significantly in the adrenal cortex of the rabbits and rats, also indicating enhancement of the hormone-producing functions of these glands (V.A. Syngayevskaya, G.F. Sinenko, O.S. Ignat'yeva, 1962; I.R. Petrov, V.A. Syngayevskaya, 1966).

Gruszeski (1962) observed a decrease in γ-globulins and an increase in the α- and β-globulins of the blood serum in microwave-irradiated animals (λ = 3 cm, PFD = 100 mW/cm^2), with a simultaneous increase in the activity of the enzyme glutaminooxalace-

TABLE 13. TOTAL BLOOD SERUM PROTEIN AND ITS FRACTIONS BEFORE AND AFTER IRRADIATION OF RABBITS AT FREQUENCIES OF 13.2-13.6 MHz (Field 25 V/cm, single irradiation)

Conditions of examination	Total (protein in g-%) (M ± m)	Protein fractions in g-%				Coefficient A/G
		Albumens in g-%	Globulins (M ± m)			
			$\alpha_1+\alpha_2$	β	γ	
Control rabbits						
1. First blood sample	5,81±0,18	3,64±0,11	0,77±0,04	0,63±0,07	0,77±0,07	1,7
2. After 15 minutes	5,78±0,22	3,85±0,13	0,69±0,03	0,50±0,04	0,74±0,03	2,0
3. After 1 hour	5,61±0,17	3,72±0,16	0,68±0,05	0,52±0,05	0,69±0,04	2,0
Change in g-%	—0,20	±0,08	—0,09	—0,11	—0,08	+12%
f = 13,2 MHz						
1. Before irradiation	5,67±0,20	3,68±0,16	0,68±0,03	0,69±0,05	0,62±0,06	1,9
2. 15 minutes after irradiation	5,10±0,17	3,34±0,12	0,63±0,06	0,60±0,04	0,53±0,05	1,9
3. After 1 hour	5,02±0,15	3,38±0,11	0,59±0,06	0,62±0,03	0,43±0,03	2,1
Change in g-%	—0,65	—0,30	—0,09	—0,07	—0,19	+10%
f = 13,6 MHz						
1. Before irradiation	5,27±0,17	3,53±0,12	0,63±0,04	0,55±0,03	0,56±0,06	1,9
2. 15 minutes after irradiation	4,98±0,14	3,47±0,11	0,53±0,03	0,52±0,05	0,46±0,02	2,2
3. After 1 hour » »	4,64±0,13	3,22±0,10	0,50±0,04	0,53±0,04	0,39±0,03	2,0
Change in g-%	—0,63	—0,31	—0,13	—0,02	—0,17	+10%

Note. There were 5 rabbits in each series. Average data are given.

tate transaminase. It is known that this enzyme participates in /53 transamination processes, which are closely related to the protein functions of the liver.

On the basis of the above observations, the changes in the protein fractions under microwave irradiation would appear to result from changes in the liver's protein function (its enzymatic processes) and changes in the functions of the hypophysis and adrenal cortex. The dysproteinemia that arises in animals irradiated with microwaves may lower the resistance properties of the organism. The molecules of γ-globulin are asymmetrical, a fact which governs their activity in respect to the formation of compounds with other proteins and electrolytes. Consequently, γ-globulin is more closely related to the immune bodies than any other protein fraction. A substantial decrease in albumen content under intense irradiation is also a danger signal.

It is known that changes in amino-acid metabolism may also occur under the influence of adrenal-cortex hormones. On the one hand, the synthesis of proteins from amino acids may be inhibited and, on the other, they may be metabolized at a higher rate with formation of carbohydrates (gluconeogenesis).

V.A. Syngayevskaya and G.F. Sinenko (1966) established that the levels of 8 out of 16 amino acids determined chromatographically increased substantially in the blood serum of dogs exposed to microwave radiation (metric band, PFD = 3000 $\mu W/cm^2$, exposure 30 minutes): cystine, lysine, arginine, glutamine, glycine, glutamic acid, tryptophan, and phenylalanine. The levels of tyrosine and leucine decreased, while the contents of the remaining amino acids were not substantially changed (Table 14). Rabbits exposed to the same microwave radiation also showed increased amino-acid contents in their blood serum (Table 15).

N.A. Yudayev (1961) reported that administration of corticosterone disturbs amino-acid synthesis not only in the liver, but also in the muscles. This could also occur when animals are exposed to microwave radiation, since, as we noted earlier, the hormone-production functions of the pituitary and adrenal cortex are enhanced.

An effect of microwaves on nuclein metabolism has also been established in recent years. Heller (1959) showed that chromosomes, which, of course, contain DNA, can be affected by microwave irradiation. The same author found that microwaves inhibit multiplication of yeasts, which are rich in RNA.

A number of investigators (S.Ya. Turlygin and N.I. Kobozev, 1937; Mumford, 1961; Klinger, 1954; Leary, 1959) consider it possible that the structure of protein and nucleic-acid molecules /55 in the cells of living organisms may change under exposure to high-intensity microwaves at the shortest centimetric and

TABLE 14. AMINO ACID CONTENTS IN DOG BLOOD SERUM

Animal No.	Weight in kg	Amino acids in mg-%														
		Cystine	Lysine	Histidine	Arginine	Glutamine	Aspartic acid	Serine	Glycine	Glutamic acid	Threonine	Alanine	Tryptophan	Truosine	Phenylalanine	Leucine + isoleucine
Before irradiation																
1	14,2	9,6	6,19	4,32	2,29	10,44	4,62	3,31	1,38	2,89	—	4,02	0,78	1,29	2,76	4,27
2	10,5	5,83	3,08	3,09	3,06	—	5,82	2,98	1,11	2,47	3,31	—	1,37	1,63	2,71	2,84
3	17,8	—	2,03	3,59	2,75	8,39	6.02	1,18	1,79	3,59	3,03	5,72	Traces	1,90	2,28	5,25
Average	—	7,7	2,66	3,67	2,7	9,41	5,49	2,49	1,42	2,98	3,17	4,87	1,07	1,65	2,58	4,12
After irradiation (PFD = 3000 μW/cm², exposure 30 minutes)																
1	14,2	13,9	3,22	5,05	6,68	11,64	5,43	3,61	1,78	2,55	2,33	4,37	2,74	0,49	1,77	3,09
2	10,5	8,29	3,13	3,09	2,97	13,54	5,05	2,89	1,38	2,21	2,02	4,89	Traces	Traces	1,92	2,29
3	17,8	—	2,29	4,80	3,37	9,23	6,12	1,57	1,57	6,31	4,47	4,16	1,47	»	8,67	3,88
Average	—	11,06	2,88	4,31	4,34	11,47	5,53	2,69	1,75	3,66	2,94	4,47	2,10	0,49	4,12	3,09
% deviation	—	+40	No change	+17	+61	+22	No change	No change	+23	+23	No change	No change	+96	—70	+60	—25

TABLE 15. AMINO ACID CONTENTS IN RABBIT BLOOD SERUM (in mg-%)
(Data averaged for 15 animals)

Cystine	Lysine	Histidine	Arginine	Glutamine	Aspartic acid	Serine	Glycine	Glutamic acid	Threonine	Alanine	Tyrosine	Trypotophan	Phenylalanine	Leucine + isoleucine
Before irradiation														
3,48	2,32	1,51	1,27	2,59	2,9	2,27	2,22	2,[illegible]2	1,19	[illegible],76	0,74	1,49	1,79	2,48
After irradiation (PFD = 3000 μW/cm², exposure 30 minutes)														
5,03 +45%	3,69 +59%	2,18 +44%	1,70 +34%	2.32 No change	3,96 +37%	2,58 +14%	1,58 —27%	3,[illegible]4 —28%	1,44 +21%	2,19 +24%	0,87 No change	0,77 —48%	1,62 No change	1,49 —40%

millimetric wavelengths.

N.I. Kerova (1964) established an increase in RNA content and a decrease in DNA in the skin and internal organs of rats irradiated with 3-centimeter microwaves (PFD = 0.5 W/cm^2 and 0.1 W/cm^2, exposure 6 min). The change in the nucleic acid contents was accompanied by a greater or lesser degree of inactivation of RNAase and DNAase.

V.A. Syngayevskaya, O.S. Ignat'yeva, and T.P. Pliskina (1963) noted a decrease in skin RNA and DNA and an increase in the spleen in white rats irradiated with microwaves shorter than 1 cm at a PFD of 0.2 W/cm^2 and a 30-minute exposure (the rectal temperature varied in a 0.5°C range). A more significant increase in the DNA content was observed on the day following irradiation. The RNA content remained practically unchanged in the liver on the day of treatment, while DNA decreased (Fig. 8).

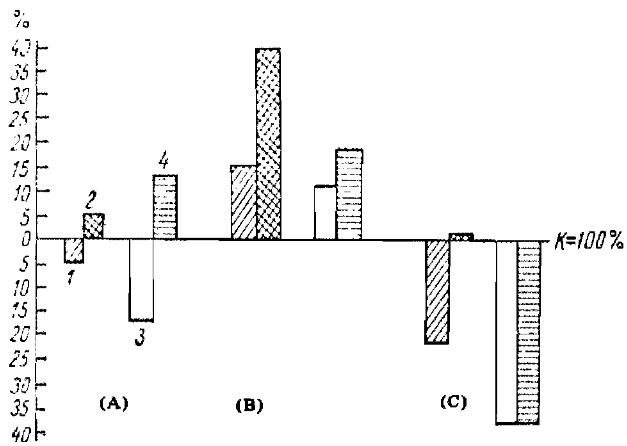

Figure 8. Changes in RNA and DNA in Rats After Microwave Irradiation. A) Liver; B) spleen; C) skin; 1) RNA 1 hour after irradiation; 2) RNA on the day following irradiation; 3) DNA 1 hour after irradiation; 4) DNA on day following irradiation.

Repeated irradiations (21-22 days) with centimetric microwaves, for 10-20 minutes on each day, amplified or maintained the changes observed after a single dose of radiation. The deviations in the nucleic-acid contents were different in different organs /56 and tissues (liver, spleen, skin) of the irradiated animal. This is apparently related to wavelength and the degree of absorption of the waves by these organs and tissues. The fact that the changes in the nucleic-acid contents either persisted or were even slightly greater on the day following irradiation suggests that disturbances arising during irradiation persist for a certain time after it is terminated.

More pronounced changes were observed in the intact organism after subjection to irradiation at higher intensities, and were accompanied by an increase in rectal temperature. Wavelength is also an important factor. N.I. Kerova's view that the changes in nuclein metabolism are the same under the thermal effects of microwaves and under ordinary infrared heating of the outer tissues may be valid only for the specific conditions of this experiment

(λ = 3 cm, PFD = 0.5 W/cm^2, exposure 6 minutes). Comparison of the effects of microwave irradiation at other wavelengths that do not raise temperature on the nucleic-acid contents in various organs and tissues indicates that the microwaves have a nonthermal action on nuclein metabolism.

The extent of the disturbances to the structure of RNA and DNA and their hereditary properties was not discussed in the above studies. The mechanism of the quantitative change in the nucleic-acid contents and their qualitative interrelationships is not perfectly clear. Polynucleases (RNAase and DNAase) participate in this process; their suppression and activation under the influence of the radiation tend either to promote the formation of the nucleic acids or their degradation or to suppress their synthesis. It is possible that changes in neuroendocrine functions play a certain role in the appearance of these changes.

CARBOHYDRATE METABOLISM /57

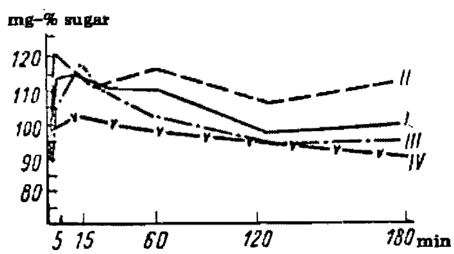

Figure 9. Blood-Sugar Dynamics in Rabbits After Single Irradiation with Microwaves (PFD = 1-3 mW/cm^2). I) Centimetric band; II) decimetric; III) metric; IV) control.

Schliephake (1960) observed a rise in the blood sugar of rabbits by 30-60% of the initial level on irradiation of the upper abdomen and pituitary with radio waves having λ = 12.5 cm and 11 m. When only the head of the rabbit was irradiated, blood sugar rose by 90-100%.

The change in the character of the sugar curves (hyper- and hypoglycemic coefficients, shift of the curve to the right), hyperglycemia, hypophosphoremia, and an increase in blood adrenaline were observed after exposure of animals to microwaves at both low (with no marked temperature rise) and high (with a rise in rectal temperature) intensities. The strength and nature of the disturbance depended on the intensity of the radiation and on its wavelength (V.A. Syngayevskaya et al. 1962). The blood sugar levels rose by 18, 36, and 22%, respectively (Fig. 9), within 15-20 minutes after termination of exposure of rabbits to centimetric, decimetric, and metric waves (PFD = 1-3 mW/cm^2, exposure 20 or 30 minutes) with no resultant temperature rise.

When rabbits were irradiated with microwaves shorter than /58
1 cm but at a PFD of 100 mW/cm^2, no rise in rectal temperature was observed, but the maximum rise in blood sugar was to 17% above the original level (before irradiation). A 4-5°C rectal-temperature increase and a blood sugar increase of 40-45% were noted in rabbits exposed to centimetric microwaves (PFD = 125 mW/cm^2, exposure 20 minutes). Convulsions were observed in many

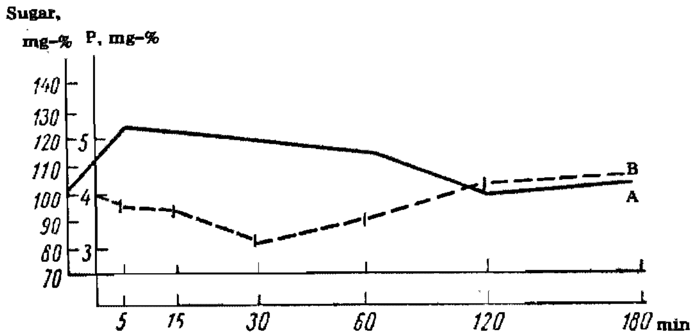

Figure 10. Dynamics of Blood Sugar and Phosphorus in Rabbits after Single Irradiation (PFD = 125 mW/cm^2, exposure 20 minutes, centimetric band). A) Blood sugar; B) blood phosphorus.

of the rabbits. On injection of insulin or glucose, the response reaction was distorted. Most of the rabbits perished in this experiment.

It is known that microwaves exert a strong influence not only on the functions of the pancreas and liver, but also on other organs and systems. Repeated (20-25 20-minute treatments daily) exposure to a thermal dose resulted in a blood-sugar-content change, but it was not as pronounced as after a single dose of radiation. Blood phosphorus was down 30 minutes after the end of irradiation (in thermal doses) to 2.8-3 mg-%, reached its initial level after 1.5-2 hours, and then remained slightly above the initial level (Fig. 10).

The content of lactic acid — an intermediate product in carbohydrate metabolism — had changed insignificantly from the initial level immediately after termination of irradiation of the rabbits, but within an hour it had dropped from the level of the control (by 46% after irradiation with decimetric microwaves and by 20% after exposure to waves in the metric band).

The glycogen-producing function of the liver was enhanced an hour after decimetric (PFD = 1 mW/cm^2) and metric (PFD = 3 mW/cm^2) /59 microwave irradiation of rabbits; liver glycogen content was up 67 and 56%, respectively, after administration of glucose (2 g/kg) to the experimental animals as compared with the content in control animals given the same amount of glucose. Blood sugar increased in anesthetized rabbits (subcutaneous injection of 200 mg/kg of hexenal) when they were exposed to thermal microwave intensities, but the dynamic picture differed from the curve obtained on irradiation of nonanesthetized rabbits. A small blood-sugar increase (10-18%) persisted as long as the anesthetic was acting. This permitted the hypothesis that the observed changes in carbohydrate metabolism result from the influence of irradiation not only on the endocrine system, but on the CNS (V.A. Syngayevskaya, G.F. Sinenko, 1963).

Microwaves influence absorption in isolated dog intestine under either local or general irradiation. The experiments of V.R. Faytel'berg-Blank (1964) established increased absorption of glucose in isolated intestine when the epigastric region was irradiated with centimetric microwaves from a 50-W generator for 10 minutes. In our own studies in which dogs were subjected to centrimetric microwaves for one minute at a PFD of 50 mW/cm^2, we reported a 28-35% decrease in glucose absorption.

It may be assumed on the basis of the above material that microwaves, acting through the central nervous system and its vegetative divisions on the secretory function of the pancreas and hypophysis, cause a disturbance to the regulation of carbohydrate metabolism in the first phase of phosphorylation (of glucose-6-phosphate), which is manifested as hypophosphoremia at certain stages. The modified oxidative processes under microwave exposure (see below) in organs and tissues result either in intensified breakdown of glucose in the tissues or in accumulation of glycogen in the liver and other tissues. As a result, a decrease in blood lactic acid may be observed under these conditions owing to faster resynthesis of the acid to glycogen.

Strong thermal irradiation intensities result in significant pathological changes (convulsions, excitation with a transition to inhibition); weak thermal and short-term exposures result in minor metabolic shifts of reversible nature and in functional changes that remain within the normal range (A.G. Subbota, 1958; Z.P. Svetlova, 1963, and others).

The changes in carbohydrate metabolism that follow nonthermal irradiation are of the nature of an adaptive reaction, since the increase in blood sugar with a simultaneous increase in the rates /60 of oxidative processes help step up metabolism and thus prevent pathological changes.

OXIDATIVE PROCESSES

Study of the activities of oxidative enzymes in various tissues of animals after irradiation with microwaves in the 3- and 10-centimeter bands established that microwaves influence the activities of the enzymes succindehydrase and cytochrome oxidase (A.I. Moskalyuk, 1957; V.A. Syngayevskaya, 1964). Irradiation of animals (rats) with microwaves in the 3-centimeter band at a PFD of 30-40 mW/cm^2 for 30 minutes (0.7-1.2°C rectal-temperature rise) produced a slight suppression of the oxidative enzymes (succindehydrase and cytochrome oxidase), while irradiation not accompanied by a temperature rise increased the activities of these enzymes.

TABLE 16. CONTENTS OF ATP, ADP, AND IP IN CERTAIN TISSUES OF RATS BEFORE AND AFTER MICROWAVE IRRADIATION

Tissues and organs studied	ATP – ADP in µmoles (M ± m)		ATP + ADP	ATP/ADP	Inorganic phosphorus in mg-%	ATP – ADP in µmoles (M ± m)		ATP + ADP	ATP/ADP	ADP in µmoles/g (M ± m)	Inorganic phosphorus in mg-%
	Control animals					11 – 14-minute irradiation, PFD = 100 mW/cm^2					
Liver	1,43±0,12	0,49±0,07	1,92	2,9	8,9±0,67	1,19±0,10	0,85±0,08	2,04	1,4	0,23±0,01	17,9±1,63
Heart	2,12±0,14	0,51±0,05	2,63	4,1	11,2±0,21	1,36±0,12	0,65±0,05	2,01	2,0	0,26±0,02	18,0±0,58
Skeletal muscle . . .	3,30±0,11	0,48±0,06	3,78	6,8	15,4±0,32	1,9±0,11	0,61±0,04	2,51	3,1	0,48±0,02	46,4±0,72
Brain	1,65±0,09	0,54±0,04	2,19	3,0	10,6±0,35	0,87±0,08	0,98±0,07	1,85	0,88	0,48±0,04	35,2±1,30
	5-minute irradiation, PFD = 100 mW/cm^2					1-hour irradiation. PFD = 100 mW/cm^2					
Liver	1,93±0,13	0,45±0,03	2,38	4,3	11,4±0,19	1,65±0,10	0,56±0,07	2,21	2,9	—	14,0±0,33
Heart	1,66±0,10	0,59±0,04	2,25	2,8	26,6±0,9	2,22±0,09	0,69±0,08	2,91	3,2	—	10,8±0,15
Skeletal muscle . . .	3,62±0,12	0,67±0,05	4,29	5,4	24,5±1,62	3,35±0,13	0,91±0,06	4,26	3,7	—	28,3±0,70
Brain	1,85±0,14	0,42±0,04	2,27	4,4	19,6±0,57	1,8±0,12	1,05±0,09	2,85	1,8	—	32,5±1,84

Oxidative processes were sharply reduced after the animals had been exposed to microwaves in the same band (λ = 3 cm), but at a PFD of 150-170 mW/cm^2. Succindehydrase activity was reduced almost by half in cardiac tissue, by 49-50% in the tissues of the kidneys, liver, and brain; cytochrome-oxidase activity was down 40% in the heart, liver, and kidneys and down 24% in the brain. In these experiments, the rectal temperatures of the rats were raised by 4-5°C in 12 minutes of irradiation.

Almost no activity suppression of these enzymes was observed on irradiation of anesthetized animals (PFD = 150-170 mW/cm^2). Their rectal temperatures rose only by 1.5-2.5°C, while it has /61 risen 4-5°C in unanesthetized animals irradiated under the same conditions. This may be due to inhibition of the CNS under the anesthetic, which is accompanied by suppression of metabolic processes (oxidative processes).

More profound changes in the activity of succindehydrase and cytochrome oxidase were observed on irradiation of the animals with 10-cm electromagnetic waves than for 3-cm waves at the same PFD's and exposure times.

In rabbits irradiated with high-intensity microwaves, A.I. Moskalyuk (1957) found increased ATPase activity in the kidneys, heart, and skeletal muscles; irradiation at low intensities produced no appreciable changes in the activity of this enzyme. The suppression of the oxidative processes in the irradiated animals with an increase in rectal temperatures and a simultaneous increase in adenosine triphosphatase activity could have been due to slackening of phosphorylation processes.

The studies of V.A. Syngayevskaya (1966) established a change in the contents of ATP, ADP, and inorganic phosphorus in the liver, heart, skeletal muscles, and brain (Table 16) of rats exposed to microwave energy at various intensities (λ = 10 cm, PFD = 10 mW/cm^2, exposure 1 hour and 5 minutes and exposure at PFD = 100 mW/cm^2).

Under exposure to low-intensity microwave energy, when the animals did not show increased rectal temperatures, marked dephosphorylation of ATP took place, along with an increase in ADP and inorganic phosphorus in the organs studied. The ATP/ADP /62 ratio definitely decreased, while the total content of ATP and ADP increased by as much as 15% as compared with the control (see Table 16). It appears that the processes in which ATP is degraded to ADP were compensated by simultaneous processes in which ATP is synthesized. It had been reported previously (A.I. Moskalyuk, 1957; V.A. Syngayevskaya, 1964) that the dehydrase and cytochrome oxidase activities increased in the same organs under similar irradiation and that there was no appreciable increase in the activity of the enzyme adenosine triphosphatase.

Thermal microwave intensities that caused an increase in body temperature (to 40-40.5°C) caused an increase in ATP, the total content of ATP and ADP, and their ratio in the liver, skeletal muscles, and brain. An increase in inorganic-phosphorus content was observed simultaneously. In heart muscle, on the other hand, the ATP content, the total of ATP and ADP, and the ATP:ADP ratio all decreased, but the inorganic-phosphorus content increased. This can apparently be linked to changes not only in the adenyl system, but also in the creatine-creatine-phosphate system.

Under exposure to thermal-intensity microwaves, when the animals were on the brink of death (see Table 16), a substantial decrease in ATP was observed, along with increases in ADP and AMP in the tissues and organs studied. Inorganic phosphorus increased, sometimes to a greater degree than would be possible as a result of degredation of ATP to ADP and AMP; this may also indicate intensive degradation of creatine phosphate at this time. During this period, decay of adenosine phosphates took place without compensation by synthesis. The total content of ATP and ADP and their ratio showed a reliable decrease, while the studies of A.I. Moskalyuk indicated that adenosine triphosphatase activity rose under such irradiation with marked suppression of the activities of dehydrase and cytochrome oxidase.

The suppression of energy processes in the skeletal muscles should result in accumulation of incompletely oxidized metabolic processes in those muscles (hypoxia) and fatigue, and a longer period of rest would be required under these conditions to restore skeletal-muscular activity. Suppression of energy processes and depression of phosphorylation processes in the liver would result in a lowering of metabolic processes in the organism. Heart muscle, unlike skeletal muscle, functions continuously. It contains much less ATP than the skeletal muscles, but its presence is absolutely necessary for the contractile event. Under intense irradiation, suppression of energy and phosphorylation processes was observed in cardiac muscle. A slackening of cardiac activity, /63 a lower pulse rate (bradycardia), and suppression of metabolism are therefore possible under these circumstances (S.Ye. Severin, 1961). It appears that these processes may be more or less manifest depending on the intensity of irradiation (PFD and exposure time), wavelength, and the initial functional state of the animal.

The metabolic-process shifts observed on microwave irradiation of animals are reflected to one degree or another in the functional state of the internal organs, enzymatic activity, and the functions of the nervous and endocrine systems. The most profound changes are noted under thermal microwave irradiation, when the organism's adaptive responses are not adequate. It appears that the disturbed thermogenesis in the organism and the continuing physical heating from the microwaves are additive under thermal irradiation, while dissipation of heat is insufficient. This results in a temperature rise and the death of the intact organism under irradiation with intense microwave fields.

Suppression of oxidative phosphorylation under thermal irradiation lowers the rate of formation of macroergic compounds. This may cause an increase in the dissipation of energy directly in the form of heat. Low (nonthermal) irradiation levels stimulate oxidative and metabolic processes in the animals, and phosphorylation and dephosphorylation processes offset one another to a major degree. Brief stimulation of these processes may be helpful for the organism, and use is made of this fact in microwave physiotherapy. However, systematic and long-term exposure of the living organism to microwaves results in adaptive failure and the appearance of neurasthenic vegetative, cardiovascular, and other disturbances and a lowering of natural defenses (I.R. Petrov, 1966; A.G. Subbota, 1966; Z.P. Svetlova, 1966; B.A. Chukhlovin, 1963, and others).

Chapter 4

COMBINED EFFECTS OF MICROWAVE ELECTROMAGNETIC RADIATION AND OTHER FACTORS ON THE ORGANISM

It is known that under real conditions, people working with microwave generators are subjected not only to the microwaves, but also to other factors operating in the occupational environment. However, their importance in pathogenesis has not been adequately studied. Simultaneously with the microwaves, the worker /64 may be affected by such factors as soft x-rays, noise, noxious gases (CO, etc.), high and low temperatures, a thin atmosphere, etc.

Establishment of the role of factors acting on the organism simultaneously with the microwaves is important for the elaboration of preventive measures on the one hand and, on the other, proper understanding of the etiology of the pathological processes that arise in people working with microwave generators. According to Michaelson's experimental results (1961), dogs that had survived x-irradiation were more sensitive to microwaves (PFD = 100-165 mW/cm^2, 2800 MHz) than dogs exposed only to microwaves.

Studies of the blood of animals irradiated with microwaves and ionizing radiation showed more pronounced changes in the erythrocytes and delayed recovery of the lymphocyte count as compared with exposure to ionizing radiation (Thomson, 1966). Similar changes in blood lymphocytes and a quicker return of the neutrophils to normal were reported by Michaelson (1961) under the influence of microwave (PFD = 100 mW/cm^2, 2800 MHz) and ionizing radiation.

The literature data cited above indicate more acute changes under the influence of combined exposure to microwaves and ionizing radiation. Admittedly, the researchers used high, thermal microwave powers, while the exposure sustained under real conditions is usually to nonthermal intensities of the microwave field. It is therefore necessary to study the effects of low microwave intensities and soft x-rays.

Practical interest attaches to study of the combined effects of microwaves and climatic factors, i.e., establishment of the cause and conditions of such affections. In a study of the state of health of radar technicians in France and Algeria, Miro (1963) found that they complained of headache, nausea, dizziness, etc.; some of them required hospitalization, while no marked changes were observed in the health of the technicians working in France. These changes in the state of health of the specialists in Algeria were associated with features of the torrid climate. However, the importance of microwaves when exposure to them is combined with high temperatures cannot be established on the basis of Miro's observations.

The results of certain experimental studies suggest that the changes occurring under combined exposure to microwaves and high temperature are determined by the electromagnetic energy to the extent that they do not cause acute changes. These results indicated that the decrease in arterial pressure (AP) that had been observed in the first irradiation does not occur as an effect of the 4th or 5th irradiation with infrared rays (PFD = 350 mW/cm^2). Smoothing of the AP variations is also observed under repeated microwave irradiation (λ = 12.6 cm, PFD = 50 mW/cm^2), which causes the same body-temperature decrease as occurs under exposure to IR, but after the 9th to 10th treatment rather than the 4th or 5th, i.e., much later (A.G. Subbota, 1966). /65

It is important to note that in animals with acquired signs of adaptation to infrared rays (absence of AP changes under exposure to IR rays), a single exposure to microwaves (λ = 12.6 cm, PFD = 1 mW/cm^2) broke it down. Subsequent infrared irradiation was again accompanied by AP changes. Adaptive failure was also observed after microwave irradiation of animals with a developed adaptation to high ambient temperatures.

Thus, the effects of microwaves on the organism are substantially different from the thermal action of infrared light. Microwaves have thermal and specific (nonthermal) effects.

On the basis of the above, we have reason to assume that the basic changes occurring under combined exposure to microwaves and elevated ambient temperature are due to the microwaves to the extent that they cause no marked rise in body temperature. The disturbance of an acquired adaptation to IR under the influence of irradiation at nonthermal microwave-field intensities (PFD = 1 mW/cm^2) is especially convincing in this respect.

Another argument in favor of the proposition that microwaves have thermal and nonthermal (specific) action is found in the need for twice the number of microwave irradiation treatments to produce signs of adaptation of the organism to the microwaves.

The research results indicated inhibition of some of the organism's important adaptive reactions to oxygen insufficiency under the influence of combined exposure to microwaves (λ = 12.6 cm, PFD = 10 mW/cm^2) and a thin atmosphere (11.2% of oxygen in the inspired air) (I.R. Petrov, N.Ya.Yarokhno, 1967); for example, a decrease in erythrocyte count rather than erythrocytosis was observed in the typical response to rarefied atmospheres (Table 17).

Inhibition of the organism's adaptive reactions was also reported on irradiation with microwaves at a PFD of 1 mW/cm^2 during inspiration of a gas mixture with 11.2% oxygen, which corresponds to the oxygen content in the air at an altitude of 5000 m. In /66
fact, an erythrocyte-count increase of 1,440,000 was observed after the first combined treatment, a 1,820,000 increase after five treatments, and an increase of only 390,000 erythrocytes per cubic millimeter of blood after the 10th treatment, i.e., this important adaptive reaction had been suppressed. In these experiments, the absence of an increase in leucocyte count was also noted after the 10th combined exposure, although it had occurred after the 1st and 5th treatments.

TABLE 17. COMPARISON OF THE EFFECTS ON RABBITS OF MICROWAVE RADIATION, BREATHING A GAS MIXTURE WITH 11.2% OXYGEN AND BOTH TOGETHER

Experimental conditions	Number of rabbits	Arterial pressure in mm Hg		Erythrocytes per mm^3			Leucocytes per mm^3		
		Initial	10 days after start of experiment	Initial count	10 days after start of experiment	Difference	Initial count	10 days after start of experiment	Difference
Microwave irradiation (PFD = 10 mW6cm²) . .	6	107	113	4 910 000	4 850 000	—60 000	7610	7530	—80
Breathing gas mixture (O_2 11.2%–N_2 88.8%)	5	91	106	5 090 000	6 030 000	+940 000	7370	8020	+650
Breathing gas mixture and microwave irradiation	4	102	111	5 660 000	4 800 000	—86 000	7490	5910	—1580

It is also important to note the fact that under repeated treatments with a combination of microwaves and a thin atmosphere, the degree of eosinopenia diminished in rabbits, and no changes in the eosinophil count were observed after the 10th treatment; this indicates a weakening of anterior pituitary and adrenal cortex function, which was enhanced under exposure to the first radiation treatments and, as we know, is a nonspecific adaptive reaction.

Under the combined disturbance, oxygen demand nearly doubled by comparison with control experiments in which the animals only inspired a gas mixture with an abnormally low oxygen content; this indicates a manifest oxygen insufficiency when the two factors are combined.

The most pronounced inhibition of this adaptive reaction was observed under combined exposure to microwaves (λ = 12.6 cm, PFD = = 30 mW/cm^2) and breathing of a gas mixture with 8.5% oxygen. In

TABLE 18. COMPARISON OF THE EFFECTS ON RABBITS OF MICROWAVE RADIATION, BREATHING A GAS MIXTURE WITH 8.5% OXYGEN AND BOTH TOGETHER

Conditions of experiment	Number of rabbits	Arterial pressure, mm Hg		Erythrocytes per mm^3			Leucocytes per mm^3		
		initial	10 days after start of experiment	initial count	10 days after start of experiment	difference	initial count	10 days after start of experiment	difference
Irradiation in microwave field (PFD 10 mW/cm^2)	[illegible]	107	113	4 910 000	4 850 000	−60 000	7610	7530	−80
Breathing gas mixture (O_2 8.5%—N_2 91.5%)...	3	99	114						
		115	95	5 330 000	6 290 000	+960 000	7800	8800	+1000
Breathing gas mixture and irradiation	2	111	120						
	2	116	105	4 950 000	5 690 000	+74 000	7300	8000	+700

this series of experiments, not only the absence of erythrocytosis, but even a decrease in erythrocyte count by 1,410,000 per cubic millimeter was observed 10 days after the start of the experiment. Thus, the above results indicate that the microwaves have the dominant influence in the development of pathological changes. /67

However, this problem has been found to be considerably more complex than might be supposed on the basis of study of the influence of microwaves on an organism that has been subjected to repeated infrared irradiation and the combined influence of microwaves and breathing of a gas mixture with 11.2% oxygen, when the leading role of the microwaves came clearly into evidence.

Contrary to the above, microwaves (λ = 12.6 cm, PFD = 10 mW/cm^2) had no pronounced effect on rabbits that had first breathed a gas mixture with a reduced oxygen content (11.2%) for 20 days; no appreciable differences were observed in these animals in the changes of erythrocyte count as compared with the changes that occurred under the influence of the low-oxygen gas mixture alone. Eosinopenia was manifest to the same degree in these animals as in rabbits that had been subjected only to the rarefied atmosphere.

Consequently, the adaptive reactions that arise under the influence of repeated breathing of low-oxygen air are quite complete and are not subject to inhibition on subsequent combined subjection to microwaves (λ = 12.6 cm, PFD = 10 mW/cm^2) and breathing of a gas mixture whose oxygen content corresponds to that of the air at 5000 meters altitude. /68

It is important to note that when microwaves of moderate power (PFD = 10 mW/cm^2) were combined with a substantial decrease in the oxygen content (8.5%) of the inspired air, there was again, after 10 daily treatments each lasting 1 hour, no pronounced suppression of the adaptive reactions that usually appear under the influence of oxygen insufficiency (Table 18).

Under this combined distrubance, therefore, the action of oxygen insufficiency on the organism predominates, and the microwave irradiation cannot suppress the adaptive reactions characteristic for oxygen insufficiency. It is important to note that in order to prevent the detrimental effects of microwave radiation that may be produced when microwaves are combined with thin air, conditions should first be created for adaptation of the man to hypoxia, since the stability of the organism that has been adapted to the rarefied atmosphere is also accompanied by an increase in the organism's stability to the effects of radio waves in the microwave band.

It was proposed on the basis of the research results that the crews assigned to radar stations at elevations of 2500-3000 m be allowed to work only after preliminary acclimatization to altitude for 1-2 months, during which the necessary studies of the blood, respiration, and cardiac activity would be made (I.R. Petrov, N.Ya. Yarokhno, 1967).

Dogs kept at an elevation of 2500 m for one month were found to be fully adapted to alpine hypoxia. These animals were also found to have increased stability to loss of blood.

A proper physical-culture program is another requisite to improving the organism's stability to microwaves under the conditions of residence on high terrain, since regular muscular activity increases the organism's stability to the action of various environmental factors and, in particular, radio waves in the microwave band.

Part II

/69

INFLUENCE OF LOW- (NONTHERMAL-) INTENSITY MICROWAVE RADIATION ON THE ORGANISM

As we noted above, certain biological effects of exposure to high-intensity microwave fields (above 10 mW/cm^2) cannot be explained solely in terms of thermal changes in organs and tissues (development of cataracts, ulceration of the gastric mucosa, etc.). It was supposed that these pathological changes arose as a result of combined thermal and nonthermal effects of the microwaves. However, to prove the nonthermal effects of microwaves, it was important to acquire data that singled out this one (specific) effect. For this reason, the overwhelming majority of studies devoted to this type of action have been carried out at intensities at which the amount of heat formed in the tissues was negligibly small. /70

The question as to the nonthermal influence of microwaves on the organism is the principal one in the entire problem of the biological effects of radio waves. Without resolving it, it will not be possible to understand the pathology of persons who have been microwave-irradiated over the long term, to determine the degree of the hazard posed to man by microwave radiation, or to evaluate theories of biological (including telepathic) radio communication.

Under this heading, we shall present experimental material on the changes in the functions of the basic systems and immunobiological reactivity of the animal organism.

Chapter 5

CHANGES IN FUNCTIONS OF VARIOUS SYSTEMS OF THE ORGANISM

The influence of microwaves in producing the functional changes that arise in the central nervous and cardiovascular systems, the digestive organs, excretory system, and blood when the animal organism is exposed to low microwave intensities has been studied basically at a PFD of 10 mW/cm^2.

Although the amount of excess heat does exceed the normal heat emission (Deichmann, 1961), the observed shifts in the organism are still difficult to explain in terms of temperature changes in the organs and tissues. For this reason, these shifts are regarded basically as nonthermal. /71

THE CENTRAL NERVOUS SYSTEM

The most distinct changes under exposure at low intensities are observed in the conditioned-reflex activity of animals. Thus, undulating changes in motor conditioned reflexes were frequently observed in rats irradiated with microwaves (λ = 10 cm and PFD = = 10 mW/cm^2). Here the latent time of the reactions first became shorter and then longer; after the 15th-17th treatment (treatments were given once a day), still stronger suppression was noted, and sometimes even disappearance of the reflexes. This is interpreted as indicating the development of trans-limit inhibition (Ye.A. Lobanova, 1963).

Under almost identical experimental conditions (λ = 12.6 cm, PFD = 10 mW/cm^2), extinction of conditioned reflexes took place three times as fast in irradiated rats as in control animals. Reversal of an inhibitory stimulus to positive was also delayed in these animals. With developing inhibition in the higher divisions of the central nervous system as a background, it also became more difficult to reproduce previously formed temporary connections (vestigial memory). R.I. Kruglikov (1968) concluded on the basis of these experiments that the suppressive action of microwaves is due not to trans-limit inhibition, but to changes in intercentral relationships, although this problem requires further study.

Under exposure to 3-cm waves, the changes occurred in two phases: the picture that developed at first was one of an enhanced excitation process and weakening of active inhibition, and then gave way to one of trans-limit inhibition (Ye.A. Lobanova, 1963).

The first phase, that of stimulation, was seldom observed under exposure to decimetric waves (wavelength of a few decimeters). Suppression of positive conditioned reflexes was usually observed immediately after the first few treatments. Recovery of normal cerebral-cortex activity was observed in rats only 2 months after the exposures had been discontinued.

Histological examination of the brain in such irradiated rats (PFD = 10 mW/cm^2) showed distinct changes in the interneuron axodendral and axosomatic connections in the cortex. In particular, there were changes in the synaptic apparatus of the cortical pyramidal cells (M.S. Tolgskaya et al., 1959, 1960, 1964; Z.V. Gordon, 1966; Ye.A. Lobanova, M.S. Tolgskaya, 1960). /72

However, M.M. Aleksandrovskaya and R.I. Kruglikov (1968) found no significant changes in the nerve cells of rats and mice that had been irradiated with microwaves of the same intensity (10 mW/cm^2), although there were distinct shifts in the neuroglia: the number of astrocytes had increased, their reactivity to gamma radiation had changed, etc. These phenomena were interpreted as a morphological expression of the inhibited state of the CNS.

Electrophysiological studies of the influence of microwaves on the CNS were also performed initially at a PFD of 10 mW/cm^2. Suppression of the basic rhythm of cortical-cell electrical activity was reported. Under chronic irradiation, signs of asthenization of the CNS were also observed. Anelectrotonic shifts at a high level of lability were registered very often in rabbits. This led the author to assume that the nonthermal effects result from hyperpolarization of brain cells (M.S. Bychkov, 1962, 1963).

Under similar experimental conditions (PFD from 0.02 mW/cm^2 to 10-30 mW/cm^2), I.N. Zenina (1963, 1964) noted a shortening of the average latent period of brain-cortex reactions for the most part only under exposure to decimetric waves (wavelength of several decimeters).

Comparative electrophysiological research showed that under intermittent (rotating antenna) and continuous (fixed antenna) exposures, an electrical-activity suppression of the anelectrotonic type is observed, but the lability variations were irregular when the antenna was used for circular scanning.

In most experiments, subordination chronaxia was shorter under constant irradiation and also decreased, though less often, under intermittent exposure (M.S. Bychkov and V.A. Syngayevskaya, 1962).

At a PFD of about 1-10 mW/cm^2, Yu.A. Kholodov (1966) observed changes similar to those that he had observed previously under the influence of microwaves with PFD's above 40 mW/cm^2: an increase in the number of "spindles" and slow waves. This generalized synchronization reaction occurred 20-40 seconds after the generator was switched on. A neuronally isolated strip of cortex also responded to a microwave field of this intensity with a shorter latent period than did the intact cortex. The EEG was also studied in rabbits with brain intact and isolated (section made at midbrain level) and after administration of caffeine under exposure to long microwaves (λ = several decimeters). Again in these experiments, the isolated brain reacted more frequently and more rapidly than the intact brain.

On the basis of these and certain other data, the author advanced the hypothesis that the brain, and its glial cells in particular, have a receptor function with respect to electromagnetic fields (Yu.A. Kholodov, 1967). /73

Promotion of primary and secondary responses to light flashes was observed when the heads of rabbits were exposed to microwaves in the 12.6-cm band with a PFD of about 3-4 mW/cm^2; this was also interpreted as indicating the development of an inhibited CNS state (R.I. Kruglikov, 1967).

Under somewhat different experimental conditions, I.A. Kitsovskaya (1960, 1964) registered motor reactions in rats preselected for sensitivity to a strong acoustic stimulus (a bell) under daily irradiation with microwaves at a PFD of 10 mW/cm^2. A sharp decrease in the reactivity of the rats to the bell was noted, amounting in some cases to disappearance of the spasm (after 25-30 treatments). The reactions to the bell reappeared when the radiation treatments were discontinued. The most distinct shifts were observed under exposure to decimetric waves. The suppression was less distinct after treatment with 3-centimeter and millimetric waves.

Studies of the influence of low-intensity microwaves on central nervous system function were also made on dogs (A.G. Subbota, 1957, 1958, 1962, 1963, 1966; Z.P. Svetlova, 1962, 1963, 1964, 1966). The advantages of experiments on these animals are obvious, since the brain is at practically the same distance from the surface of the skin as it is in man. This is, as we know, of substantial importance in view of the limited depth of penetration of the microwave field.

The intensity of the radiation used on dogs was set at a much lower level — usually 1 mW/cm^2. Here it was established that higher nervous activity also changes quite conspicuously in these animals, and that functional disturbances appear in the cerebral cortex under certain conditions. Thus, under unilateral exposure to a pulsed microwave field in the 10-cm band with a PFD = 1-5 mW/cm^2 (exposure 2 hours), the strength of food conditioned reflexes increased on the opposite side and the latent periods became shorter. The reactions to differential stimuli showed almost no change.

Under repeated irradiation (one treatment each day), this stimulating effect of the microwaves was even more clearly manifested, and compensatory and paradoxal phases of the reflexes were observed (Table 19). These are obviously signs of experimental neurosis caused by overstressing of the excitation process. Later, however, in spite of the continuing exposures, the conditioned-reflex-activity shifts may subside to a major degree and even practically disappear (Fig. 11). This is interpreted as a /74
sign of adaptation of the animal to microwave irradiation.

In animals in which the excitation process predominates, and in dogs with artificially modified cortical excitability, identical microwave exposures suppressed positive conditioned reflexes. There was almost no attendant change in the differentiations (A.G.

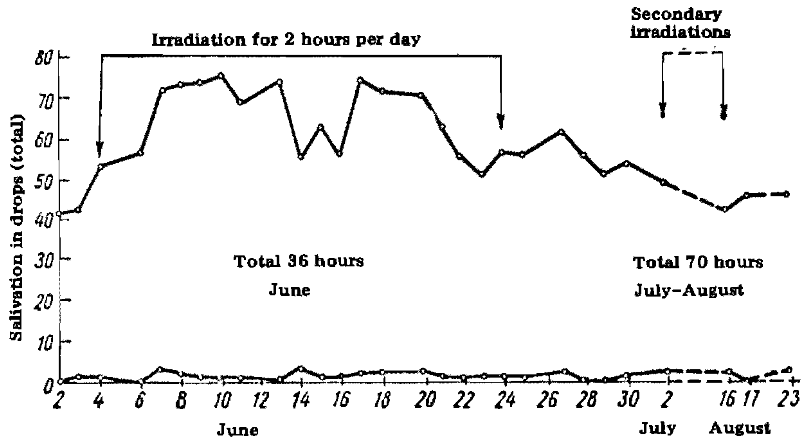

Figure 11. Total Strengths of Conditioned Reflexes to Positive Signals (Upper Curve) and Differential Stimuli (Lower Curve) During Repeated Irradiation of the Dog Dzhek with Microwaves at PFD = 1-5 mW/cm^2.

Subbota, 1957, 1958).

The previously obtained data were basically confirmed when conditioned and unconditioned salivary reflexes were registered bilaterally, but new facts were also noted (A.G. Subbota, Z.P. Svetlova, 1966; Z.P. Svetlova, 1966). Thus, in dogs with uniform symmetrical conditioned and unconditioned salivary reflexes, unilateral irradiation caused more pronounced shifts on the opposite side, usually immediately after the end of the microwave treatment. Cortex function had returned on the next day, and sometimes the vestigial effect was more persistent on the irradiated side (Table 20). Such asymmetry phenomena are evidently due to the fact that the functional changes occurred chiefly in the surface tissues on the irradiated side of the body under treatment with the pulsed 10-cm microwave field, owing to the limited depth of penetration. The metabolism in the irradiated tissues was probably affected. Since stimulation of chemoreceptors, whose presence has been demonstrated (V.N. Chernigovskiy, 1961; V.A. Lebedeva, /76
1965), was possible, the pulses should go to the opposite hemisphere by crossing of afferent pathways. Nor can we exclude a direct influence of the microwave field on receptors and peripheral nerves (McAfee et al., 1961, 1962) on the irradiated side of the body. In these cases, however, the impulses should go to the opposite hemisphere; it is therefore also probable that the excitability of the unirradiated hemisphere was affected. Since the afferent impulses going to the higher divisions of the CNS also go to the reticular formation, an activating role of this center must probably also be taken into account. Such is the possible

TABLE 19. CHANGES IN CONDITIONED-REFLEX SALIVATION UNDER REPEATED IRRADIATION (Dog Dzhek)

Conditioned stimuli	Background			Irradiations for 2 hours per day (PFD = 1–5 mW/cm²)												Irradiation discontinued			After 35th radiation exposure (total 70 hours)		
	3 VI			1st treatment 4 VI			5th treatment 9 VI			10th treatment 15 VI			17th treatment 23 VI			2 VII			[illegible] VIII		
	Latent period in seconds	Amount in drops		Latent period in seconds	Amount in drops		Latent period in seconds	Amount in drops		Latent period in seconds	Amount in drops		Latent period in seconds	Amount in drops		Latent period in seconds	Amount in drops		Latent period in seconds	Amount in drops	
		CR	UR		CR	UR		CR	UR		CR	UR		CR	UR		CR	UR		CR	UR
M-120	5	8	29	4	12	39	2	17	46	4	14	45	8	8	46	5	8	39	3	13	52
Light	3	5	30	3	8	35	2	14	38	3	10	43	3	9	41	3	9	31	2	6	50
Balloon +	4	8	27	3	9	35	3	14	48	3	12	45	4	8	48	5	8	29	4	8	47
Balloon –	—	1	—	—	1	—	—	1	—	—	1	—	—	1	—	—	2	—	—	2	—
M-60	—	0	—	—	0	—	—	0	—	—	0	—	—	1	—	—	0	—	—	0	—
M-120	11	5	27	8	6	36	4	7	30	7	7	45	11	4	41	13	4	35	—	0	40
Light	3	6	28	3	7	34	3	6	29	3	7	45	4	8	46	6	7	38	5	4	46
Bell	4	10	33	2	11	34	3	15	29	3	13	47	3	13	47	3	12	39	4	10	48
Total		42/1	174		53/1	213		73/1	220		63/1	270		50/2	275		48/2	211		41/2	283

Note. M-120 (positive stimulus) beating of a metronome at 120 beats per minute; M-60 (differentiation) 60 beats per minute. Light: lighting of a lamp in front of the dog's muzzle. Balloon + (positive interoceptive stimulus): inflation of a balloon in the colon at a frequency of 1 Hz; balloon – (differentiation): inflation at frequency of 0.2 Hz. Bell: ringing of an electric bell at 80 dB. CR: conditioned reflex; UR: unconditioned reflex.

TABLE 20. CHANGES IN SYMMETRICAL CONDITIONED AND UNCONDITIONED SALIVATION REFLEXES (IN DROPS) ON UNILATERAL EXPOSURE OF A DOG TO MICROWAVES IN THE 10-cm BAND AT A PFD OF 2-3 mW/cm^2

Conditioned stimuli	Side	Background						Irradiation on right			Aftereffect			Irradiation on left		
		27 VIII			2 IX			3 IX			4 IX			5 IX		
		Latent period in sec	Amount		Latent period in sec	Amount		Latent period in sec	Amount		Latent period in sec	Amount		Latent period in sec	Amount	
			CR	UR		CR	UR		CR	UR		CR	UR		CR	UR
Bell	Left	1	10	61	1	[illegible]	[illegible]	1	11	61	1	12	65	1	9	70
M-120		5	7	60	9	[illegible]	[illegible]	1	13	61	2	7	65	2	8	61
M-60		—	0	—	—		—	—	0	—	—	1	—	—	1	—
Light		4	7	64	3	—	[illegible]	3	13	58	5	8	55	1	8	64
Bell		2	6	67	2	[illegible]	[illegible]	5	16	51	2	8	55	2	6	51
Total			30/0	252		[illegible]	[illegible]		53/0	244		35/1	240		31/1	256
Bell	Right	1	9	62	1	12	[illegible]	1	12	65	1	11	66	11	12	68
M-120		5	7	63	5	7	57	1	9	57	2	7	63	1	10	63
M-60		—	0	—	—	[illegible]	—	—	2	—	—	1	—	—	2	—
Light		3	9	60	1	7	53	1	12	60	1	9	51	1	10	65
Bell		2	7	63	2	9	63	1	11	61	3	7	59	2	8	59
Total			32/0	248		55/[illegible]	233		44/2	243		34/1	232		40/2	255

Note. Symbols same as in Table 19.

pattern of the conditioned-reflex changes on the opposite side.

Under exposure to decimetric waves (wavelengths of several decimeters), the conditioned-reflex shifts were probably greater on the irradiated side owing to their greater depth of penetration. Functional changes due to direct action on the hemisphere /77 of the brain closer to the radiator may dominate here. Cases of experimental neurosis were also reported much more frequently in such cases (A.G. Subbota, 1962, 1966; Z.P. Svetlova, 1962, 1966; Z.P. Svetlova and A.G. Subbota, 1966).

However, even under exposure to these longer radio waves, the direct effect on the peripheral tissues is still of importance. This has been established on dogs that were irradiated with their heads shielded with fine-mesh brass screening (irradiation of the brain was excluded) in some cases and with their torsos shielded in others (while the head region was irradiated). The shifts were more distinct in the former case.

Finally, under exposure to metric waves with PFD's of about 1 mW/cm^2, waves for which the animal organism is to a certain degree even "transparent," the changes in the food conditioned reflexes were usually identical on the right and left sides (see Fig. 13). This effect may have been due to the simultaneous irradiation of both hemispheres. On the other hand, when asymmetry /78 was observed, it was usually independent of the direction of irradiation (latent asymmetries were apparently brought out).

A.G. Subbota and Z.P. Svetlova also studied the influence of microwaves (λ = 10 cm, PFD = 1 mW/cm^2) on the stability of dogs to high ambient temperature. In these experiments, the animals were first accustomed to the temperature procedures in an ordinary hot box (air temperature 35°C) until their conditioned reflexes showed no further changes.

Against the background of this acquired stability to ordinary heat, which was first established by the conditioned-reflex method by Ye.B. Babskiy et al. back in 1934, the animals were subjected to a single microwave exposure at a PFD of 1 mW/cm^2. It was found that after this treatment, returning the dog to the hot box would again initiate a change in the conditioned reflexes, in almost the same way as at the very start of acclimatization of the dogs to heat (Fig. 12).

This is interpreted as a deadaptation effect of the microwaves. It could also be brought out in dogs accustomed to a loud noise stimulus. The vestigial effect that disturbs the adaptation of the animal to these adequate stimuli (heat, noise) lasts 1-2 days.

When dogs were exposed to a microwave field in the 3-cm band at a PFD around 1-10 mW/cm^2 (whole-body and local irradiation of

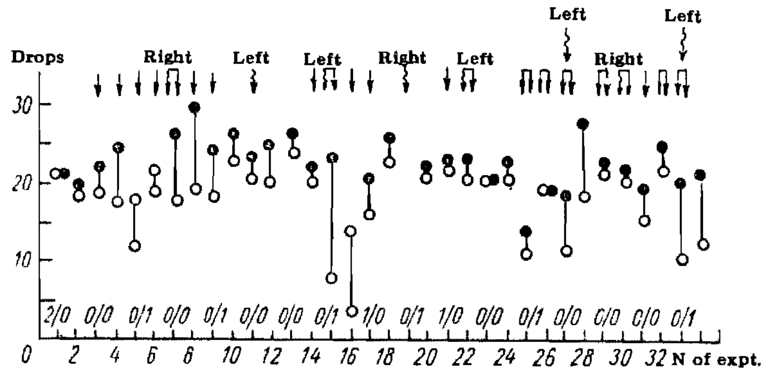

Figure 12. Variation of Total Strengths of Conditioned Reactions to Positive Signals (Dark Circles - Right Parotid Gland, Open Circles - Left Parotid Gland) and to Differential Stimulus (Right Gland in Numerator, Left Gland in Denominator). Straight arrows mark exposure to high ambient temperature and paired (straight and wavy) arrows exposure first to microwaves and then to heat (temperature in hot box 34°C); paired (straight and dashed) arrows indicate subjection to noise (110 dB) and heat.

the head region), there was practically no change in conditioned-reflex activity. Small shifts were observed only at low thermal levels: 20-30 mW/cm^2. Quite possibly, this was due to superficial absorption of the electromagnetic energy (almost all of it is absorbed in the skin) and activation of natural adaptive mechanisms (those developed for infrared rays). /79

The influence of a combination of microwave bands (metric and decimetric) was also investigated. Two successive treatments were given, consisting of 1/2 and 1 hour with PFD's of 0.5 and 1 mW/cm^2. The effect was strengthened by the decimetric waves (Fig. 13). The figure shows that the salivary conditioned reflexes changed first on the side irradiated with the decimetric waves. Later, since the exposure to radiation was made from alternating sides, the shifts appeared on both sides. The typical picture of experimental neurosis developed.

On comparing the effects of microwave fields in different bands on the higher nervous activity of dogs (at PFD's from 0.5 to 5 mW/cm^2), we note that decimetric waves (wavelengths of a few decimeters) must be rated highest, with metric waves next. The 3-cm waves are least active as regards the cerebral cortex. These data may be used as a basis for arriving at maximum permissible

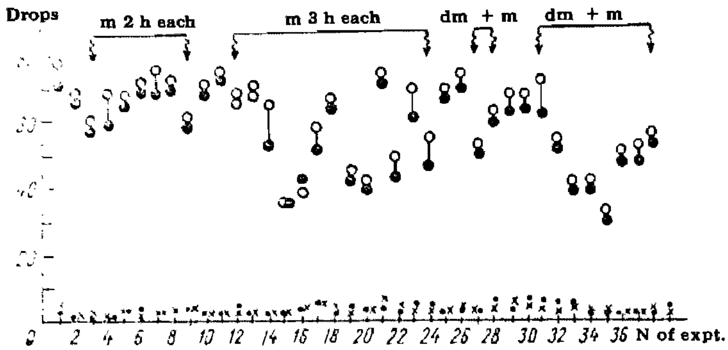

Figure 13. Variations of Symmetrical Conditioned Salivary Reflexes in the Dog Boy. Circles represent over-all strength of responses to positive signals (dark circles for the right side and open circles for the left side). The dots represent differentiation on the right and the crosses differentiation on the left; m indicates exposure to metric waves and dm + m exposure to a combination of decimetric and metric waves.

irradiation levels for humans (A.G. Subbota, 1966).

Biological effects of microwave radiation (at frequencies of 225-400 MHz) that remain mystifying to this day have also been reported in the literature. Monkeys were placed in a resonator /80 and their heads irradiated. The intensity of the radiation was such that no body-temperature rise occurred. At first, the animals sat quietly; they then became sluggish and sleepy. A few minutes later, they were excited abruptly and showed signs of brain-function disturbance: grimacing, vertical nystagmus, dilation of the pupils, intermittent breathing, convulsions. Half of the animals perished, apparently because of "disintegration" of molecules in the brain as a result of resonance effects at these frequencies (Beily, 1959).

The vital-staining method was used to establish a definite increase in the sorption capacity of the brain cortex, brainstem, and cerebellum on irradiation of rats with decimetric waves having a PFD of about 70 $\mu W/cm^2$ (L.N. Aleksandrov and M.I. Zolotashko, 1966).

THE CARDIOVASCULAR SYSTEM

This system has also been investigated in some detail under exposure of the organism to microwave fields of nonthermal intensity. The first observations were made on dogs irradiated with microwaves in the 10-cm band at a PFD around 5 mW/cm^2. Bradycardia, sinus arrhythmia, retardation of auricular and ventricular conduction, changes (usually a decrease) in the P- and T-deflections (the latter was sometimes inverted), and a broadening of the QRS complex were observed.

Dogs with artificial heart damage showed more distinct ECG changes. Local irradiation of the head, torso, and thigh produced closely similar ECG shifts in dogs (N.V. Tyagin, 1957).

Reliable changes in heart rate were reported in rabbits under somewhat different exposure conditions; the animals were exposed ventrally at PFD's around 10 mW/cm^2 (λ = 12.6 cm). These shifts were also linked to the effects of the microwave field on skin receptors (A.S. Presman and N.A. Levitina, 1960).

A hypotensive effect was reported on chronic irradiation of rats with millimetric, centimetric, and decimetric waves (PFD = = 1-10 mW/cm^2). Arterial pressure returned to normal only 8-10 weeks after termination of the exposure series. The hypotensive effect appeared earliest under exposure to millimetric and three-centimeter waves. Quite possibly, this was also due to superficial absorption resulting in activation of the ordinary temperature-regulation mechanisms in the analogy with infrared exposure.

A two-phase reaction was observed under irradiation with decimetric waves (PFD = 10 mW/cm^2): arterial pressure rose after /81 the first radiation exposures but then decreased. Since decimetric waves (wavelength of a few decimeters) penetrate through the entire body of a rat, the two-phase changes probably reflected more serious disturbances to vitally important organs, which are practically unprotected from microwave energy in these animals (Z.V. Gordon, 1960, 1966).

In larger animals (rabbits), similar irradiation (λ = 12.6 cm, PFD = 10 mW/cm^2) produced little change in arterial pressure. However, hemodynamic shifts were quite clearly in evidence even at PFD = 1 mW/cm^2 on development of stability to certain unfavorable factors. Thus, working with rabbits with a carotid artery diverted into a skin flap, we found sharp changes in arterial pressure (usually a decrease) only after the first few exposures to infrared rays at intensities that produce a 1-1.5°C rectal-temperature increase. No hemodynamic shifts were observed beginning with the 4th or 5th treatment. When the same rabbits were irradiated with a microwave field in the 12.6-cm band (PFD = 1 mW/cm^2), the same infrared exposure given on the second and even on the third day would again produce manifest arterial-pressure shifts (Fig. 14). It was as though the microwaves had broken down the stability that the cardiovascular system had developed /82 during the repeated exposures to the natural thermal stimulus.

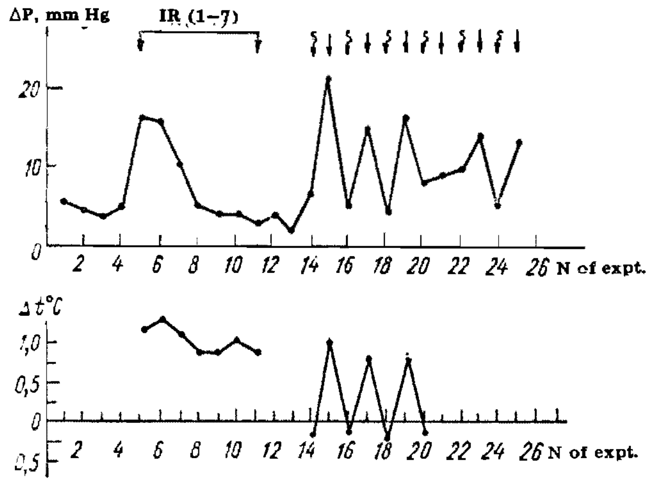

Figure 14. Influence of Microwave Field in 12.6-cm Band with PFD = 1 mW/cm^2 on Hemodynamic Stability to Infrared Rays in 5 Rabbits. Symbols same as in Fig. 5.

A similar deadaptation effect of low (nonthermal) microwave levels has been established not only with respect to infrared rays, but also to chlorpromazine and even microwaves of different wavelengths. Thus, in one series of experiments, rabbits were first accustomed to exposure to a 12.6-cm microwave field with a PFD around 50 mW/cm^2. When their arterial pressures had stopped changing, they were irradiated with decimetric waves (wavelengths of a few decimeters) with a PFD of 1 mW/cm^2. The pressure did not change at this intensity, but on subsequent irradiation with 12.6-cm microwaves there were conspicuous hemodynamic shifts (Fig. 15). A disadapting effect of a very-low-intensity microwave field in a different band was observed just as it was in experiments in which conditioned reflexes were studied over two days (vestigial effect).

For comparison, it is appropriate to cite our own data from experiments in which the same rabbits were given a 100-R dose of x-rays. In these animals, disturbance to a previously developed stability of arterial pressure to microwaves in the 12.6-cm band /83
was observed for two months after x-irradiation.

Microwaves have not been found to deadapt with respect to all stimuli. Thus, when rabbits developed cardiovascular stability to the vertical position of the body (head up), a microwave field with a PFD of 1 mW/cm^2 had almost no destabilizing influence.

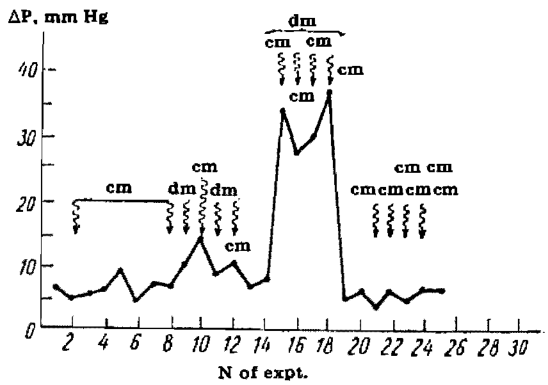

Figure 15. Influence of Microwave Field in Decimetric Band (Wavelengths Several dm) on Stability of Arterial Pressure to Disturbance in 5 Rabbits. Symbols: wavy arrows mark radiation treatments; cm indicates exposure to waves in the 12.6-cm band with PFD = = 50 mW/cm^2; dm indicates decimetric waves with PFD = = 1 mW/cm^2; dm/cm indicates combined irradiation first with decimetric waves at PFD = = 1 mW/cm^2 and then with centimetric waves with PFD = 50 mW/cm^2; cm/cm indicates combined exposure, first to centimetric waves with PFD = 1 mW/cm^2 and then the same waves at PFD = 50 mW/cm^2 (control experiments).

Since hemodynamic stability is not developed in rabbits with denervated sinocarotid reflexogenic zones, such stability obviously arises with participation of the CNS. We may assume that the organism's acquisition of the ability to maintain a constant arterial pressure under repeated disturbances by various factors (heat, noise, microwaves, chlorpromazine, etc.) is determined by the formation of a special adaptive program in the CNS and that it is probably reinforced by the conditioned-reflex mechanism. Under exposure to microwaves and x-rays, this program was broken down for a more or less extended time, as manifested in the reappearance of the arterial-pressure changes (A.G. Subbota, 1968).

Since the organism of man and animals is always adapted to a variety of environmental factors, including unfavorable ones (high temperatures in summer, low temperatures in winter, etc.), the deadapting effects of microwaves with respect to stability that has been developed against other factors may be of basic importance for understanding of the causes and mechanisms of the disturbances to cardiovascular system activity, and disturbances to arterial-pressure regulation in particular.

A certain decrease in all pressures (final, lateral, mean, and minimum) was observed in dogs (exposure to metric waves with PFD of 2.5 mW/cm^2) under chronic radiation exposure. The reactions to injection of adrenalin were also changed (Ye.V. Gembitskiy and O.Ye. Gavrilova, 1968).

THE DIGESTIVE ORGANS

The motor function of the gastrointestinal tract and the secretory function of the stomach were studied under exposure to low-intensity microwaves. Under the influence of the microwaves

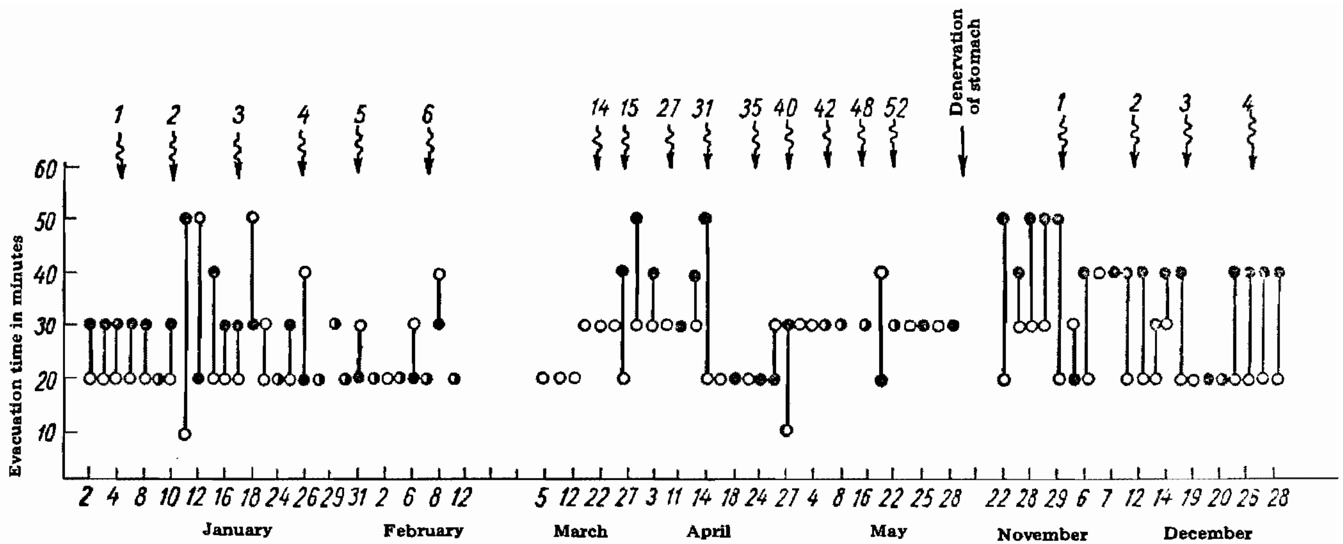

Figure 16. Variation of Time for Evacuation of Water from the Stomach into the Intestine under Whole-Body Microwave Irradiation of the Dog Sil'va (PFD = 1 mW/cm^2). Open circles represent first determination, dark circles the second (one hour later). Wavy arrows indicate radiation exposure after each first determination; the numerals above the arrows number the irradiations.

(PFD below 10 mW/cm^2), the functions of these organs showed distinct changes. Thus, in dogs with the Basov chronic fistula, evacuation of water from the stomach slowed down immediately after the end of the microwave exposure (λ = 10 mm, exposure time 30 minutes, PFD about 1 mW/cm^2). As the microwave irradiations were repeated, the inhibition of the evacuatory function became weaker or was even totally absent; thus, in the dog Sil'va (Fig. 16), beginning with the second radiation exposure with decimetric waves /85
(wavelength a few decimeters, PFD around 0.5 mW/cm^2), there was a substantial reduction of the transfer of water from the stomach into the intestine. This applies in particular to the aftereffect periods (on the second and third days after the microwave exposures were discontinued).

It is also clear from the figure that the changes in the evacuatory function subsided as the radiation treatments were repeated. This may be another sign of adaptation of the organism to the microwaves. However, when the animals were put on daily irradiation, evacuation of water from the stomach was again retarded, although the effect subsequently receded again.

Similar shifts were observed in two other dogs: suppression of the stomach's evacuatory function and weakening of the shifts on repetition of the radiation exposures (signs of adaptation), etc.

In a fourth dog, stimulation of transfer of water from the stomach to the intestine was observed from the very beginning. This was probably due to the fact that the initial evacuation times were somewhat longer for this animal than for the others. The shifts also died out under repeated irradiation, as in the other dogs.

After partial denervation of the stomach of one of the dogs (all visible nerve trunks at the junction of the esophagus with the stomach were cut), the picture observed was the opposite: faster evacuation of water from the stomach (A.M. Grebeshechnikova, 1962, 1966; A.G. Subbota, 1962, 1964).

Similar changes in the evacuatory function of the gastrointestinal tract were established in guinea pigs by the x-ray method. After these animals were irradiated with decimetric microwaves (PFD of 0.5-1 mW/cm^2), the barium mixture was discharged from the stomach more slowly than in control animals for which the barium evacuation time remained the same on repeated ingestion of the material into the stomach.

The microwave field accelerated evacuation of the barium from the stomach in five guinea pigs out of 16. Characteristically, this stimulating effect was observed in those animals in which movement of the barium was slow before irradiation, i.e., the effect depended on the animal's initial functional state.

Comparison of the effects observed in dogs and guinea pigs under irradiation with metric and decimetric waves confirmed the previously established dependence of the sharpness of the shifts on wavelength. Under exposure to decimetric waves, even though the PFD was lower (0.5 mW/cm^2), the changes were more pronounced than under irradiation with metric waves at a PFD of 1 mW/cm^2. According to the results of A.M. Grebeshechnikova (1962, 1966) and A.G. Subbota (1962, 1966), periodic hunger contractions of the /86 stomach were usually observed less frequently and were shorter in duration (with correspondingly longer rest periods) immediately after the end of a decimetric or metric-wave irradiation (PFD about 1 mW/cm^2). Thus, for the dog Laska, 2-3 periods of gastric activity of normal duration (51-132 minutes, resting time 116-205 minutes) were observed before exposure (control) over four hours of observation. After microwave irradiation with decimetric waves (PFD = 0.5 mW/cm^2), there were sometimes no hunger contractions at all over the same 4 hours, and where they were observed they lasted no longer than 37 minutes in all.

Under repeated exposures, the degree of suppression of periodic hunger activity also usually declined; this is interpreted as a sign of adaptation to the microwave field. The tonic and rhythmical contractions of isolated intestine segments varied little under the same irradiation conditions.

Thus, under exposure to microwaves of low (nonthermal) intensity, the dominating picture is one of suppression of the evacuatory motor function of the gastrointestinal tract. Since the opposite picture appeared on partial denervation of the stomach, it must be assumed that microwaves at nonthermal levels have a dual effect on this function of the gastrointestinal tract: a mediated action (through changes in the function of the CNS) and a direct effect on the organ or its local innervation. Nor is it possible to exclude humoral-chemical changes capable of producing the same shifts.

It was established in a study of stomach secretory function that when dogs with Pavlov's stomach were irradiated with metric or decimetric waves at PFD's around 1 mW/cm^2, secretion of gastric juices in response to meat was suppressed significantly, especially during the first (nervous-reflex) phase, and that its acidity was lowered. Usually, the content of free hydrochloric acid was down sharply in the first portions (after the first and second hours) following ingestion of the meat. Sometimes there was none at all. In the second (humoral-chemical) phase, there was even a slight increase in the amount of juice. In some dogs, inhibition of juice secretion in response to meat was more distinct on repeated irradiations. The latent periods were also greatly prolonged (Fig. 17).

Acidity (total and free) varied little during the second phase. Recovery of normal gastric-juice secretion after

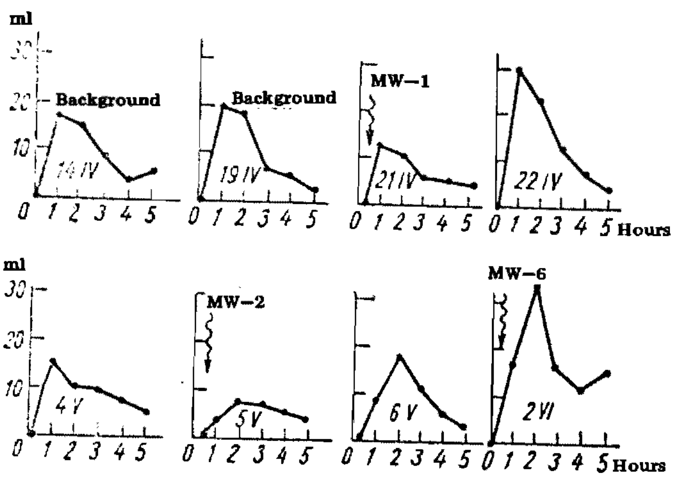

Figure 17. Curves of Gastric-Juice Secretion for the Dog Irma (Pavlov's Stomach) under Irradiation with Microwaves Having a PFD of 1 mW/cm^2. MW-1, MW-2, and MW-6 indicate and number the radiation exposures.

individual microwave exposures was drawn out to as much as 1 or 2 months in some of the dogs (Fig. 18). The digestive strength of the gastric juice either showed no change or increased slightly.

Similar changes in the secretory function of the stomach were reported by the present author jointly with A.M. Grebeshechnikova when metric and decimetric waves were /88
combined in irradiation (two successive treatments of half an hour each). The results indicated that the secretory function changed less and less as the radiation exposures were repeated. This pertained to the amount of gastric juice in particular. This can also be regarded as an indication of adaptation of the dogs to the microwave radiation.

The amount of gastric juice was even observed to increase in some cases in dogs with Heidenhain stomachs. The acidity either showed no change or also decreased. The distinctness of the shifts remained the same under repeated exposures.

Characteristically, there was no correlation between the variations in the amount of juice secreted, its acidity, and its digestive strength in the dogs with Pavlov's and Heidenhain stomachs.

Since it is known (B.P. Babkin, 1960, and others) that gastric juice is the product of three groups of epithelial cells, each with its own innervation, the dissociated secretory-function effect was apparently determined by selective action of the microwaves on these nerve systems.

Since changes were observed in the secretory activity of the stomach even in dogs with Heidenhain stomachs, it must be assumed that the microwave field also has a direct effect on glandular cells or the local innervation of the stomach itself.

THE EXCRETORY SYSTEM

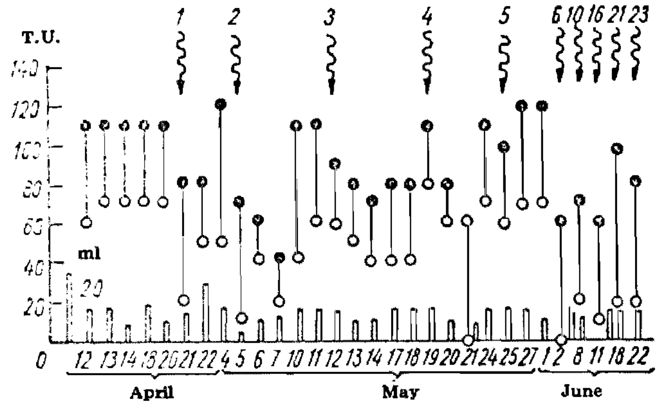

Figure 18. Free (Open Circles) and Total (Dark Circles) Gastric-Juice Acidity for the Dog Irma under Microwave Irradiation at PFD of 1 mW/cm^2. The bars indicate amounts of juice during the first hour; T.U. stands for titration units.

Polyuria was observed in a study of kidney function in mice exposed to a microwave electric field (λ = 80 cm) (Denier, 1932). Later, uropoiesis was investigated in dogs with ureters diverted to the outer surface of the abdomen in L.A. Orbeli's operation (A.G. Subbota, 1966). The nature of uropoiesis from the right and left kidneys was investigated after water-milk loading (the dog was given 500 ml of a mixture of milk and water to drink). It was established that immediately after termination of the microwave exposure (wavelength 10 cm, PFD 1-5 mW/cm^2, exposure 30 minutes), the excretion of urine by the kidney on the irradiated side was reduced and that on the opposite side was increased.

The nature of the uropoiesis also changed. Thus, on the irradiated side, the uropoiesis curve was flatter and lower, while considerably larger amounts of urine were excreted on the opposite side during the first 30 minutes (Fig. 19). Similar changes in diuresis were obtained on irradiation with decimetric waves (λ = = several decimeters) with a PFD of 0.5 mW/cm^2.

This functional asymmetry in the work of two paired organs /90
was observed not only just after termination of a radiation exposure, but also on the next day (vestigial effect). Usually, the uropoiesis picture on the following day was a perfect mirror image: more urine was excreted on the irradiated side than on the unirradiated side. The amounts of urine collected on each day of the experiment indicate the same type of variation of the functional activity of these symmetrical organs (Fig. 20).

The shifts in the water-excretion function also became less distinct as the treatments were repeated. This may also indicate adaptation of the organism to microwaves.

In the dog Maritsa, which had a suppurative pyelonephritis on the left side, irradiation of this side of the body caused a sharp rise in uropoiesis. The total amount of urine excreted on this day was also larger. The same microwave exposure of a dog with a

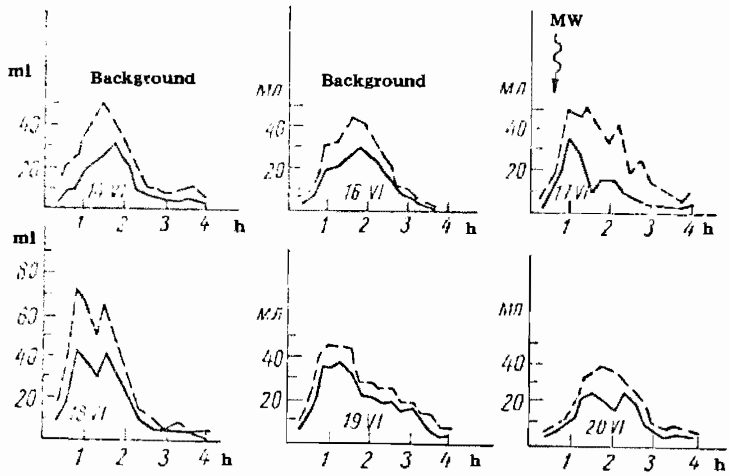

Figure 19. Curves of Uropoiesis in the Dog Mal'va (After Taking 500 ml of Water-Milk Mixture) on Microwave Irradiation. Right kidney is represented by solid line and left kidney by dashed line. Wavy arrow indicates microwave exposure on right side.

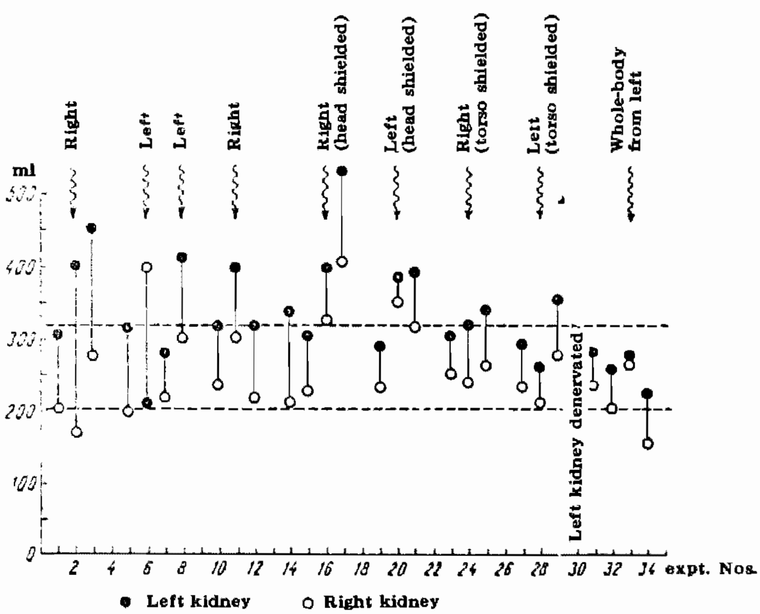

Figure 20. Amount of Urine Excreted by Dog Norka After Taking a Mixture of Milk and Water (500 ml) From Right and Left Kidneys After Unilateral Microwave Irradiations with PFD = 0.5 mW/cm^2.

denervated kidney (decapsulation) at a PFD of 0.5-1 mW/cm^2 caused practically no changes in uropoiesis. At higher (PFD around 70 mW/cm^2) radiation intensities, which resulted in a slight hyperthermia (the temperature in the colon rose 1°C and the animal panted), bilateral suppression of uropoiesis was observed in this dog. It is quite possible that the effect resulted from retention of water in the organism owing to water losses during irradiation. This assumption would be consistent with the observations of other authors (Michaelson et al., 1961), who observed thirst in dogs suffering from microwave hyperthermia.

A study of specialized forms of appetite in 300 rats (V.V. Kulakova, 1964) showed that appetite increases for solutions containing calcium beginning at the 5th or 6th exposure (PFD = 40 /91 mW/cm^2). The calcium content in the urine had increased at this point in the exposure program. The author assumes that an increase in appetite for a solution of glucose with an admixture of this preparation was also observed as a result of calcium excretion.

THE BLOOD SYSTEM

Many authors have studied the blood of animals exposed to microwaves with PFD = 10 mW/cm^2 and below. The shifts in the morphological blood picture were either insignificant (N.V. Tyagin, 1957) or could be detected only after chronic irradiation. Thus, I.A. Kitsovskaya (1964) observed leucopenia, an increase of segment-nuclear nucleophils, and a lower lymphocyte count in white rats after they had been exposed to a microwave field in the 10-cm band with a PFD = 10 mW/cm^2 for 9 months. The blood had not returned to its normal state even 3 months after the series of irradiations was discontinued.

Different shifts occurred in rabbits exposed to a microwave field with a PFD of 4-8 mW/cm^2: lymphopenia was observed in some rabbits and lymphocytosis in others. An increase in the number of reticulocytes and mature normoblasts was also observed in 40% of the rabbits (Gruszecki, 1962).

Changes in the morphological composition of the bone marrow under exposure to microwaves have not been adequately studied. Some investigators have been unable to detect any shifts (N.V. Tyagin, 1957). I.A. Kitsovskaya (1964) observed only a slight /92 decrease in the number of segment-nuclear neutrophils. Using chronic exposure to metric-band microwaves with a PFD = 1 mW/cm^2, A.I. Ivanov reported distinct changes in the proportions of white and red bone-marrow stem cells in rabbits: it was 1.7:1 instead of 1:1.3 (Table 21).

Thus, exposure to microwaves produced distinct changes in the functions of various systems not only at PFD's around 10 mW/cm^2, the level below which it is the custom to assume that

TABLE 21. COMPOSITION OF BONE MARROW IN RABBITS IRRADIATED WITH MICROWAVES (PFD 1 mW/cm^2)

Animal No.	Reticuloendothelial cells	Plasma cells	Hemocytoblasts	Myeloblasts	Promyelocytes	Myelocytes			Metamyelocytes			Rod neutrophils			Segment-nuclear			Lymphocytes	Monocytes	Proerythroblasts	Erythroblasts			Megakaryocytes	Number of white stem elements	Number of red stem elements	Ratio of white to red stem elements
						neutrophilic	eosinophilic	basophilic	neutrophilic	eosinophilic	basophilic	neutrophilic	eosinophilic	basophilic	neutrophilic	eosinophilic	basophilic				I	II	III				
Controls																											
№ 2	0,6	0,8	0,2	1,5	1,3	2,3	0,1	0,1	4,2	0,2	—	11,0	—	—	21,0	0,5	0,6	7,6	0,9	0,3	4,0	29,8	12,9	0,1	42,8	47,0	1 : 1,1
№ 3	0,3	0,2	0,2	1,3	1,7	2,8	0,1	0,1	5,0	0,1	—	7,5	—	—	18,3	0,1	0,1	5,1	0,2	0,6	6,2	30,7	18,5	0,2	37,3	55,9	1 : 1,5
Irradiated																											
№ 6	1,5	0,8	0,6	2,6	2,8	9,2	0,7	0,7	7,9	0,6	0,2	9,6	0,3	—	18,5	0,3	1,2	12,5	0,4	0,4	4,8	18,1	6,1	0,3	54,8	29,1	1,8 : 1
№ 1	0,4	0,5	0,2	1,3	1,2	5,5	0,2	0,1	6,6	0,1	0,1	11,8	0,2	—	20,7	0,1	1,0	10,2	1,1	0,2	3,1	21,4	13,9	0,2	48,9	38,6	1,3 : 1
№ 11	0,4	0,1	0,1	1,6	1,9	8,4	—	0,3	10,1	0,1	—	16,8	0,1	—	23,1	0,3	0,4	6,8	1,1	0,2	2,2	13,4	11,2	0,2	63,1	27,0	2,3 : 1
№ 7	0,5	0,1	0,1	2,2	1,9	6,3	0,2	0,4	7,7	0,1	—	10,6	—	—	22,0	0,3	1,0	8,0	0,8	0,5	2,6	21,7	12,8	0,1	52,7	27,6	1,4 : 1

Translator's Note: Commas indicate decimal points.

there are no pronounced thermal changes, but also at lower levels: 1-0.5 mW/cm^2.

The nature of these changes depended strongly on the number of repeated exposures. Two types of phenomena have been observed under repeated applications: 1) declining magnitude of the observed shifts and, quite frequently, their disappearance as the irradiations were continued (at one treatment daily for 1-6 days). This is interpreted as a sign of adaptation of the organism to the microwaves; 2) aggravation of functional changes in the organism, which, as the radiation treatments are continued, often culminates in the appearance of serious signs of disturbance to the activity of some of its systems (cumulative effect). The most sensitive systems, as we saw from the data presented, are the central nervous and cardiovascular systems. This can be seen not only on the basis of the development of the typical picture of experimental neurosis and hypotonia, but also in the appearance of persistent disturbances to gastric-juice secretion, especially in the nervous-reflex phase, and in reports of disturbance of stability acquired by animals to various other adequate stimuli (high ambient temperature, noise, etc.).

It may be assumed that a change in the normal activity of the central nervous system is the primary link in the various functional disturbances, and that endocrine-gland activity changes are secondary. On the other hand, derangement of cardiovascular, gastric, and other functions is a consequence of disturbed neuro-endocrine regulation.

The cases in which the organism adapts to microwaves are testimony to its extremely broad adaptive capabilities, which maintain stability even against factors that the organism has practically never encountered during the evolutionary process. However, such adaptation is probably not highly reliable, since serious functional disturbances intervene sooner or later in many cases. Finally, although they occurred under high intensities, the previously examined cases of damage to the mucosa of the stomach, crystalline lens, testicles, and bone marrow were nevertheless due basically to the nonthermal effect and indicate a direct action of the microwaves on the irradiated tissues.

Chapter 6

/93

CHANGES IN THE IMMUNOLOGICAL REACTIVITY OF THE ORGANISM AND IN THE PROPERTIES OF BACTERIA, VIRUSES, AND SIMPLE ANIMALS

The nature of the organism's interaction with agents of infection changes sharply when humans and experimental animals are irradiated with electromagnetic waves in the radio band; there may be either an increase (A.V. Ponomarev, 1940, and others) or a decrease in its resistance to the microorganisms (K.V. Stroykova, T.I. Belyayeva, 1958), or, in certain cases, even development of secondary infections (N.A. Solov'yev, 1962; Fukui, 1959, and others). Even an increase in the intensity of atmospheric electromagnetic radiation may aggravate certain infectious processes, such as tuberculosis of the lungs (A.I. Konko et al., 1966).

Suudy of the influence of electromagnetic radiation on the infectious process was begun back in the 1930's, when most of the effort was concentrated on establishing the therapeutic value of this type of radiation and justifying its use in the treatment of infectious diseases (P. Libezin, 1936; N.A. Mukhina, 1940; G.L. Frenkel', 1940; Schliephake, 1960, and others).

At the present time, with the extensive introduction of radioelectronic gear into various branches of the national economy, investigators have turned most of their attention to the ways in which the organism is affected by whole-body microwave irradiation at low PFD's, but over the long term, and to whole-body short-term irradiation by microwaves of thermal intensity.

A distinct aggravation of infection and the associated toxic process in an experiment with exposure to microwaves of thermal intensity (PFD = 45 mW/cm^2, 30 minutes daily for 15-30 days) was reported by I.M. Ibragimov and G.S. Mironov (1966), S.A. Vartanov (1966) and L.P. Sviridov (1967), who subjected cats innoculated with a dysentery culture and white mice infected with Salmonella breslau or exposed to botulismotoxin to whole-body microwave irradiation (λ = 12.6 cm). On the other hand, low microwave intensities (PFD = 5 mW/cm^2) produced no substantial changes in the course of the infection and toxicosis in these experiments.

At the same time, prolonged exposure to low microwave intensities is accompanied, as we know, by asthenization of the organism. The latter, and, specifically, a lowering of the organism's resistance during the development of the asthenic syndrome, may perhaps account for the more difficult course and higher frequency of infectious diseases that have been observed by certain authors in persons who have been exposed to microwave irradiation over the long term. /94

A considerable number of specialized studies has now been carried out with the object of ascertaining the nature and mechanism of disturbances to the immunobiological properties of the organism under exposure to the microwave field. They can be divided arbitrarily into two basic groups: study of nonspecific factors in protection against infection and study of specific antimicrobic immunity and immunological reactivity when the organism is exposed to microwaves. Studies of the effects of the microwave field on the agents of infection and on other microorganisms of bacterial or virus nature and simple animals form a special group.

NONSPECIFIC RESISTANCE TO INFECTION

Thus far, the research done in this direction has been concerned only with specific indices to the organism's nonspecific protective functions, such as phagocytic activity of leucocytes, the absorptive capacity of the RES, complement activity and the bactericidal properties of blood serum, vascular permeability, etc. Attempts have been made to generalize the acquired data and determine their place in the over-all pathology that arises when biological objects are irradiated with radio-band electromagnetic waves.

Phagocytic activity of leucocytes. Ye.A. Koton and T.N. Danilova (1963) observed a significant drop in leucocyte phagocytic activity in the blood of humans subject over the long term to irradiation by electromagnetic waves in the metric band under occupational conditions.

A.I. Ivanov (1962) also showed that single and repeated (7-10 times) meter-band microwave irradiation of humans at intensities of 1-3 mW/cm^2 for 30-40 minutes daily cause a lowering of neutrophil phagocytic activity (with respect to staphylococcus) in most subjects immediately after exposure, by amounts ranging from 7 to 52%.

Various degrees of change in phagocytic activity were observed in experimental studies (on cats) with exposure to centimetric waves of various intensities. Reliable changes (usually downward) occur at a PFD of 1 mW/cm^2 (exposure 30 minutes) and above. It was also noted in these experiments that the observed shifts are short-lived after a single microwave exposure, persisting for only a few hours after irradiation. A.I. Ivanov and B.A. Chukhlovin (1966, 1968) irradiated cats under similar conditions and observed distinct phasing of the changes in neutrophil phagocytic reaction: a stimulation phase lasting for the /95 first 10 minutes of irradiation was supplanted by suppression of phagocytosis, with a subsequent return, over 3-24 hours, to the initial level or even above it.

Ye.I. Smurova (1966) irradiated white rats with centimetric waves at a PFD of 10 mW/cm^2 for 1 hour daily for 2½ months and observed an initial stimulation of neutrophil absorptive capacity with respect to B. coli, followed by a suppression that persisted for 3½ months after the end of the microwave-exposure program. Phased changes in leucocyte phagocytic activity under the influence of electromagnetic radiation were also observed by Ye.G. Tkachenko and V.S. Padalka (1965). An increase in neutrophil absorptive capacity was observed for the first 30 days in white mice placed in the electromagnetic field of a 2000-MHz radio-relay link, and was followed by suppression.

Thus, even on the basis of available material, we may conclude that the phagocytic function of human and experimental-animal blood neutrophils is subject to substantial variations under the influence of microwaves, and that the degree of the changes is determined by intensity and the time of exposure.

Bactericidal properties of blood serum. Comparatively little study has as yet been given the bactericidal properties of blood serum under exposure of the organism to microwave electromagnetic radiation. When rabbits were exposed to a single dose of centimetric microwaves at a PFD of 50-60 mW/cm^2 for 30 minutes, accompanied by a 2-3° body-temperature increase, a decrease in blood-serum bactericidal properties was observed in most of the animals (B.A. Chukhlovin, 1963, 1965, 1966), but these indicators had returned to their initial level within as few as 1-5 days.

When rabbits are exposed to lower microwave energies (5-10 mW/cm^2), but for a long time (1 hour per day for 1½ months), there is a slight increase in the bactericidal activity of their blood serum. Single or repeated (once a day for 8-10 days) exposure of humans to microwaves does not produce appreciable changes in blood-serum bactericidal properties.

Microwave irradiation of rabbits at a PFD of 45 mW/cm^2 30 minutes a day for 15 days (L.P. Sviridov, 1967) against the background of an infection caused by Salmonella breslau was accompanied by a substantial decrease in the bactericidal strength of their blood. Low energy intensities (5 mW/cm^2) had no marked influence on this indicator under the same exposure conditions.

Phased changes were observed in the bactericidal properties of the blood of white rats irradiated 60 minutes daily for 2½ months with centimetric microwaves having a PFD of 10 mW/cm^2: a period of stimulation gave way to suppression as early as the 7th day of irradiation (Ye.I. Smurova, 1966). In another series /96 of experiments (A.P. Volkova, Ye.I. Smurova, 1967) performed on white rats, which were irradiated for 6 months under the same conditions, an increase in the bactericidal property of the blood serum was noted in some of the animals simultaneously with a decrease in neutrophil phagocytic activity; the authors interpret the latter as an adaptive reaction of the organism that helps it to maintain resistance to infection under long-term exposure to electromagnetic fields.

Complement activity of blood serum. B.A. Chukhlovin (1966) observed changes in blood-serum complement activity in humans and animals under exposure to microwave irradiation. After a single whole-body irradiation of rabbits with centimetric waves at PFD = 40-60 mW/cm^2 with 30 minutes' duration, a decrease in the titer of the complement was observed in 28 out of 32 animals immediately after exposure to the microwave field; there were no changes in one animal, while the titer increased in three. The observed shifts in complement content were of short duration: during the one or two days of rest that followed, the complement level returned to or even exceeded its original value. Daily irradiation of rabbits for 10-30 days under the same conditions also caused a transient decrease in blood serum complement titer in most of the experimental animals. Lower radiation intensities in the centimetric band (PFD = 5-10 mW/cm^2), which do not raise the body temperature of the rabbits, also tended to increase complement titer.

No changes were found in blood serum complement level on examination of humans who had been subjected to a series of whole-body irradiations with decimetric waves at a PFD of 1-2 mW/cm^2 (1 hour daily) (B.A. Chukhlovin, 1966).

Thus far, other factors in the organism's nonspecific immunobiological defenses (RES absorptive capacity, barrier-fixing properties of tissues, etc.) have not been adequately studied under the influence of electromagnetic radiation. We can refer only to the data of N.P. Derevyagin (1939), who reported a two-phased reaction of the RES of rabbits to exposure to electromagnetic waves (λ = 6-9 meters) at both high and "low" (with a 0.2-0.3°C body-temperature rise) intensities: brief stimulation was supplanted by suppression of the absorptive function. Later, similar data were obtained by Plurien et al. (1966) in a study of RES phagocytic function in white mice irradiated with radar waves.

Finally, observations indicating increased vascular permeability and a decrease in tissue barrier properties after whole-body and local irradiation of the organism with electromagnetic waves in various bands were reported (V.Ya. Batunina and Ye.V. Gernet, 1938; A.P. Parfenov and Ye.V. Molchanov, 1960; Fiandesio, 1961). /97

SPECIFIC IMMUNOLOGICAL REACTIONS

In experiments on guinea pigs immunized with a culture of Samonella breslau and irradiated with centimetric waves at a PFD = 50 mW/cm^2 for 30 minutes daily for two weeks, it was established (B.A. Chukhlovin, 1966) that the antibody levels lag behind controls by a factor of about 2½ under these irradiation conditions. However, this decrease in agglutinin titer was of short duration: within as few as 5-10 days after termination of irradiation, the titer had approached the level in the control animals.

Similar results were also obtained in experiments on rabbits that were immunized with intravenous typhus monovaccine three times at one-week intervals and given 1-hour-per-day irradiations at a PFD of 50 mW/cm^2 (for a total of 30 treatments over 40 days), both during and after the vaccination cycle. Other irradiation conditions the same, the lower electromagnetic energy intensities (10 mW/cm^2) tended to stimulate antibody production in the rabbits. An increased antibody level was observed to persist for two weeks after the end of the radiation-treatment cycle.

According to Sacchitelli and Lerza (1964), guinea pigs immunized with typhus vaccine showed the most distinct decrease in agglutinin production after irradiation with microwaves during vaccination, while previously irradiated animals showed a less distinct decrease.

Thermal microwave intensities (45 mW/cm^2 in rabbits and 30 mW/cm^2 in white mice, for 30 minutes a day over 15 days) also lowered agglutinin titer in animals innoculated with a culture of S. typhi murium (L.P. Sviridov, 1967).

A change in immunogenesis when the organism is exposed to low-energy electromagnetic radiation has also been observed with respect to viruses (N.V. Vasil'yev et al., 1965) and protozoa (Pautrizel, Riviere, 1966).

The nature of the changes in the organism's immunological reactivity under the influence of electromagnetic radiation can also be judged from the results of study of allergic and anaphylactic reactions under these conditions. F.M. Suponitskaya (1938) found no changes in the anaphylactic reaction after multiple irradiation (λ = 3.6 m) of guinea pigs during sensitization with normal horse serum. At the same time, irradiation of the animals immediately after administration of the assaulting dose of the /98
antigen provided protection from the development of anaphylactic shock in all cases.

However, it is difficult to evaluate these interesting data, since the paper indicates neither the temperature reaction of the animals to the disturbance nor the intensity of irradiation. The results obtained by B.A. Chukhlovin (1966) gave reason to assume that only microwave radiation intensities above 10 mW/cm^2 can prevent or mitigate anaphylactic shock in animals when the assaulting antigen dose is administered immediately after irradiation.

Attempts have also been made in recent years to determine the mechanism of the observed changes in the organism's immunobiological reactions under microwave exposure. In a study carried out jointly by B.A. Chukhlovin (1966), V.A. Syngayevskaya, and O.S. Ignat'yeva on the phagocytic activity of neutrophils in dogs, with simultaneous investigation of blood-plasma glucocorticoid content, a relation could be traced between changes in the leucocyte function under study and adrenal-cortex function under exposure to microwaves (PFD = 10 mW/cm^2 or 50 mW/cm^2, single dose). It was found that only a slight increase in blood glucocorticoid level under irradiation is accompanied by stimulation of phagocytosis. These results are consistent with the contemporary view that small glucocorticoid doses stimulate the immunobiological functions of the organism, while large ones inhibit them (A.N. Meshalova, 1961, and others).

In our own experiments on dogs, which were irradiated long-term (one hour per day over 1½ months) with microwaves in the centimetric band (PFD = 10 mW/cm^2) or decimetric band (PFD = = 1 mW/cm^2), we observed a definite correlation between changes in neutrophil phagocytic activity and the dynamics of central nervous activity shifts in the experimental animals. In dogs with depressed CNS function in the initial state, the phagocytic function of the neutrophils was also sharply reduced. The absorptive capacity of the leucocytes showed a persistent change during the period of irradiation of the animals against a background of developing experimental neurosis. The nature of these changes depended on the radiation band to which the animals were exposed. Thus, while exposure to centimetric waves excited the brain cortex of the dogs and the neutrophil absorptive function declined against this background, the opposite effect was observed under the influence of decimetric waves — excitation of the CNS was accompanied by stimulation of phagocytosis, and inhibition of the cortex by its suppression. This may indicate that the centimetric waves act primarily through reflex mechanisms and that decimetric waves have a direct influence on the brain.

In evaluating changes in the organism's immunobiological properties, it is also necessary to recognize the possibility of a direct effect of the electromagnetic energy on the organs and tissues responsible for production of immunologically active substances. /99

The possibility of changes in protein structures and, consequently, in the properties of tissues under radiation exposure can be judged on the basis of the appearance of C_x-reactive protein in the blood serum of animals irradiated with microwaves (B.A. Chukhlovin et al., 1966) and on the basis of the experimental results of Bach (1965), who exposed human gamma globulin to radiation at various frequencies (from 40 to 200 MHz) and observed a change in the antigen properties of the protein even at low intensities (averaging 13.5 mW/cm^2). This circumstance may be of considerable importance in the over-all mechanism of the pathological changes that arise under microwave exposure, since the organism's own tissues may, as we know, trigger the production of cytotoxic antibodies when antigenically modified, with subsequent development of pathological processes.

There is no doubt that observed changes in protein metabolism, and especially in that of the globulins (V.A. Syngayevskaya, 1964; S.V. Nikogosyan, 1964, and others) and metabolic disturbances in the formed elements of the blood (phagocytes) (A.I. Ivanov, 1966) also have a bearing on the mechanism of the immunological shifts under exposure to microwave radiation.

INFLUENCE OF MICROWAVE RADIATION ON BACTERIA, VIRUSES, AND PROTOZOA

Two basic and closely interrelated trends can be discerned in study of the influence of electromagnetic radiation in the radio band on bacteria and other single-celled organisms: investigation of the bactericidal properties of the electromagnetic waves or, conversely, of their stimulating action on microorganisms, and establishment of the mechanism of action of the electromagnetic energy using bacteria and protozoa as biological models.

Even in the very early Soviet surveys of the literature on the biological action of centimetric and decimetric waves (N.A. Mukhina, 1940; F.M. Suponitskaya, 1940), we find a considerable amount of material — contradictory though it may be — on the effects of microwaves on microorganisms.

There is now no doubt that microwaves exert an influence on the vital activity of bacteria and other single-celled organisms. Even in the simplest experiments, in which only cell growth and multiplication are taken into account quantitatively, stimulation or suppression of these processes under the influence of electro- /100 magnetic energy is noted under certain conditions. The experiments of Denier (1937), the first investigator of the biological effects of microwaves, who made his studies on bacteria in vitro and in vivo (with reproduction of experimental infections), showed that microwaves in the decimetric band (λ = 80 cm) have a substantial influence on the course of streptococcal, staphylococcal, diphtherial, and other infections.

Hasche and Loch (1937) observed a definite injurious effect of decimetric waves (λ = 52 cm) on staphylococci even when the authors attempted to exclude the possibility of even "point" heating by constant agitation of the culture. Using decimetric waves (λ = 40 cm) to irradiate diphtheria bacillus on a solid nutrient medium, Ye.N. Gorkin and K.I. Suchkova (1938) noted a decrease in its toxicity. New data on bactericidal effects of electromagnetic waves with respect to various species of microorganisms were reported in the years that followed (Sequin, 1949; Robert and Cook, 1952, and others), and research was even begun on the possibility of practical utilization of this effect. D.V. Semdomskaya (1956) obtained good results in the use of high-frequency current to decontaminate milk.

V.F. Glibin (1952) studied the possibility of using electromagnetic waves to decontaminate water and found that the effect depends on the initial number of bacteria, the irradiation time, and the layer thickness of the water irradiated. He established that microwaves (λ = 3 cm and λ = 10 cm) are more bactericidal than ultrashort waves (λ = 6 m and λ = 12 m).

A.N. Karaseva et al. (1956) used electromagnetic waves (λ = = 4.5-6 m) to disinfect clothing and obtained better results at a lower temperature level and in a shorter time than when ordinary thermal disinfection is used; it was also noted that the bactericidal effect was more conspicuous when the clothes were more densely packed. Millimetric waves were found to be bactericidal with respect to the microflora of the air (V.F. Kondrat'yeva and Ye.N. Chistyakova, 1967). A distinct bactericidal effect of radiation with a frequency of 9370 MHz on spores and vegetative forms of bacteria was reported by V.N. Lystsov et al. (1965). However, this effect was observed only when the temperature of the irradiated object was raised.

No less interesting are reports from certain authors of a stimulating effect of electromagnetic waves on bacteria and protozoa, as well as tissue cultures. Niffenegger (1962) observed more rapid growth of microorganisms in fields with frequencies from 30 to 270 MHz and relatively low power. Stimulation of the /101
growth of a chick-embryo tissue culture under irradiation with microwaves (λ = 3 cm and λ = 21 cm) was reported from the experiments of Sequin et al.(1948).

According to Fleming (1944), almost all living cells and microorganisms in particular grow more rapidly under exposure to high-frequency fields. This effect increases progressively with increasing radiation intensity up to a certain limit, at which the reverse process sets in: delay of cell division and death of cells as a result of excessive irritation.

In attempting to clarify the mechanism by which electromagnetic energy acts on living organisms, certain investigators

(Brown, Morrison, 1954; Epstein, Cook, 1951; Tomberg, 1961) recognized only the possibility of thermal effects of microwaves on bacteria and viruses, arguing that when the culture is cooled during irradiation, no injurious effects of the electromagnetic energy are observed.

However, most reports, including some from the above-named authors, emphasize an extremely interesting peculiarity of microwaves: when they are used to irradiate suspensions of bacteria or viruses in a nutrient medium, physiological solution, or distilled water, the microorganisms may be observed to perish in cases when the temperature of the medium has not exceeded 37-38°C, i.e., has remained in the optimum (thermostat) range of conditions for growth and multiplication of the cultures studied.

Nyrop (1946) irradiated bacterial and virus cultures with a pulsed field with the pauses between pulses modulated in such a way that there was no marked increase in the temperature of the medium during irradiation. Under these conditions, with a field strength of 230 V/cm, 99.5% of B. coli perished after 7 seconds of irradiation, without the temperature of the medium having risen above 12-40°C. In the case of simple heating, the same effect is observed only at 60°C and an exposure time of 600 sec. The virus of foot and mouth disease was inactivated within 10 seconds at a field strength of 260 V/cm, when the temperature of the medium was no higher than 36°C. Similar heat inactivation of the virus required 60 hours at 37°C.

Sequin (1949) observed inhibition or even cessation of cell division in B. coli, the turbeculosis bacillus, and staphylococcus after microwave irradiation (λ = 21 cm) at low energy intensities with no biologically significant increase in the temperature of the medium. The author regards this effect as nonthermal. Boiteau (1960) also reported the death of B. coli after five minutes of exposure to radiation at 12-30 MHz, again without raising the temperature of the medium above 37°C.

Yu.G. Talayeva (1956) found a substantial bactericidal effect for pulsed electromagnetic waves (λ = 10.7 cm) on water-suspended B. coli. This effect was not attended by a rise in the temperature of the water, and on this basis the author also concludes that the electromagnetic waves acted nonthermally. /102

P.I. Schastnaya (1958) studied the effectiveness of centimetric and millimetric microwaves with various model microorganisms (staphylococci, Friedländer's bacillus, B. coli, and others) and reported that these radiations cause substantial disturbances to the vital activity of the cells, lower their virulence, and produce morphological changes and death under optimum environmental-temperature conditions. However, the microwaves had no injurious effect on the bacteria at medium temperatures below the optimum. The author is inclined to explain the observed effects in terms of thermally selective heating of the bacteria to levels that are detrimental to cell function and structure.

Selective heating of specific structures or microbic particles to temperature levels that are critical for them had been examined even earlier, before the biological effects of USW radiation had come under study, as a primary mechanism in the action of electromagnetic energy (D.Ya. Glezer, 1937). Recognition of such an action appeared to be the most logical way of explaining the observed effects.

However, disregarding the fact that this selective heating has not yet been demonstrated experimentally, and the fact that certain experiments and calculations tend to negate it (P. Libezni, 1936; Barber, 1962, and others), the hypothesis in itself gives rise to a number of questions. Indeed, if we take the calculations of Schwan and Piersol (1954), selective heating by microwaves is possible only when the diameter of the suspended particles is at least 1 mm. At the same time, we know that most bacteria are no larger than a few microns in diameter.

It is also difficult to reconcile the notion of selective heating of microbic particles with the experimental results of Esaux,[1] which indicate that tissues and regions rich in water are most strongly heated. In this case, we should expect heating of the water and the medium first, and only then heating of particles or bacteria suspended in it, which, of course, contain less water. However, experiments in which bacteria were irradiated produced the opposite observation: microorganisms suspended in water or physiological solution perish at the environmental temperature that is optimum for them.

Finally, how is the theory to explain the thermal action of electromagnetic waves on certain viruses? In Nyrop's experiments /103 (1946), in which pulsed 20-MHz fields were directed at the virus of foot and mouth disease, the virus was not only inactivated, but its antigenic properties also changed without the temperature of the medium having exceeded 36°. At the same time, known methods of vaccine production are based precisely on the use of heat, which usually causes only a lowering of the virulence of the strain, while preserving its antigenicity.

Nor do other studies support a purely thermal action of microwaves on microorganisms. Thus, a calculation of the time constant for heating of bacterial cells indicates (Barber, 1961) that their temperature and the temperature of their medium remain practically the same, i.e., there is no selective heating of the bacteria.

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[1]Cited after P. Libezni (1936).

The experiments of P. Libezni (1936), in which suspended yeast cells were irradiated, also failed to indicate selective heating of the microorganisms as against the medium surrounding them. At the same time, it is known that electromagnetic waves are injurious to the microbe cell at lower temperatures than those required to produce similar disturbances with heat. On this basis, the author states that the electromagnetic energy has a specific and nonthermal effect on the microorganisms.

In the opinion of certain authors, the specific nature of the action of microwaves is also evident in experiments on protozoa. Thus, if paramecium suspensions are exposed in parallel experiments to microwave radiation, infrared light, and convective heat of various intensities, but in such a way that the times of exposure to the agent and the temperature rise in the medium remain the same in all compared experiments, the change in the phagocytic function of the cells under the influence of microwaves differs from that observed under the conventional thermal factors (Ye.T. Kulin and Ye.I. Morozov, 1965).

Convective heat and infrared radiation usually cause the same two-phased reaction in the phagocytic function of the cells: stimulation at low intensities gives way to suppression, extending to the total absence of reaction, at high intensities. Under the influence of microwaves, however, we observe four phases in the reaction: stimulation of phagocytosis occurs at temperatures of 24-26° and 39-40°C, and suppression of the phagocytic function is maximal between these phases. The last suppressive phase under microwave exposure intervenes only at sublethal temperatures.

Obviously, some other imperfectly understood mechanism comes into play here in addition to the thermal effect.

The experiments of A.S. Presman and S.M. Rappoport (1965) indicate much the same thing. The authors observed a so-called "electric-shock" reaction in paramecia exposed to microwaves when /104
the medium was heated only by 1.0-1.5°. Under exposure to heat, the same reaction occurs only at very high, sublethal temperatures.

Great interest also attaches to other studies in which the behavior of bacteria and protozoa was observed in electromagnetic fields. Heller (1959) showed in experiments with paramecia swimming free in a medium that at certain frequencies (in the low megacycle range) the animals move only parallel to the field. At higher frequencies, they turn at right angles and swim perpendicular to the lines of force. The author reported that intensities close to the maximum permissible levels are required to produce the observed nonthermal effects.

Teixeire-Pinto (1960) also makes reference to an effect in which individual cell structures in amoebas orient themselves differently in electric fields at different frequencies. Hübner (1960), Niffenegger (1962), and other authors also regard differential orientation of cellular structures and changes in the positions of chromosomes under the action of electromagnetic energy as one of the causes of disturbances to cell function and structure, taking the view that electromagnetic oscillations could be used as a potent mutagenic factor.

Heller (1959) and other authors also point to the possibility of genetic changes in the cell under exposure to radio waves. Irradiating certain species of bacteria with electromagnetic waves at frequencies from 5 to 30 MHz, Heller observed the appearance of new generations of the microorganisms that differed from their ancestors.

It appears that mechanisms of some sort more complex than simple or selective heating of particles in the medium participate in the action of microwaves on bacteria, viruses, and simple animals; their identification would aid in discovery of the primary mechanism of microwave action on highly organized biological objects as well.

Part III /105

INFLUENCE OF MICROWAVE IRRADIATION ON THE HUMAN ORGANISM

Features of the influence of low (nonthermal) microwave intensities on the human organism have been under serious investigation for some time. This is because it is difficult and sometimes impossible to transfer data obtained on animals to man. This applies in particular to the centimetric and decimetric waves, which penetrate to limited depths, so that a given organ is irradiated differently in animals (especially small ones) and man. In addition, animals and man differ in regard to certain tissue parameters (ε, σ, etc.) and in the degree of development of their adaptive mechanisms. /106

Study of the effects of microwaves on the human organism is necessary as a basis for establishing maximum permissible irradiation levels, developing therapeutic and preventive measures, and for protection of technicians engaged in work with microwave apparatus. Moreover, correct diagnosis and treatment of affected individuals would be impossible without prior research on human subjects.

Investigation of the effects of microwaves on man has taken two trends: one involving exposure of volunteers and one which studies the state of health of specialists servicing microwave generators.

Chapter 7

FUNCTIONAL CHANGES IN HEALTHY HUMANS EXPOSED TO LOW-INTENSITY MICROWAVE FIELDS

One of the first observations on the influence of centimetric waves on the human organism was made by S.Ya. Turlygin and N.I. Kobozev (1937). They studied the adaptation curves of the eyes of subjects under irradiation directed at the occipital region and established that the light sensitivity of the retina was distinctly increased. In addition, the subjects reported deeper and longer sleep and a general nervous "relaxation." The author calculated that these effects occurred at an energy density of about 5 lux, i.e., at nonthermal levels. However, it was not possible /107 at that time to measure the radiant intensities instrumentally.

N.I. Matuzov (1959) was apparently the first to use measured microwave exposures. He reported that in himself and one other subject, a pulsed microwave field in the 10-cm band with a PFD around 1-3 mW/cm^2 had narrowed the projection area of the blind spot and reduced the optical rheobase and optical adequate chronaxy. When the 10-minute exposure was ended, these indicators usually returned to normal after a phase in which the spot projection broadened beyond its initial level and the rheobase and chronaxy increased. There were no reported subjective sensations under this exposure.

S.F. Libikh (1962) confirmed these data in the main and reported that the lowest PFD at which constriction of the scotoma intervenes under exposure to decimetric waves is 100 $\mu W/cm^2$. M.A. Pivovarov (1962) supplemented these facts with studies of the visual field in humans. Narrowing of these fields was observed at PFD's around 1 mW/cm^2 as early as the second day. Further, in a study of visual after-images in 16 subjects, the author noted an increase in their duration in only two. Finally, among 33 subjects exposed to centimetric, decimetric, and metric waves with a PFD around 1 mW/cm^2, almost half showed a decrease in the critical flicker-fusion frequency.

It is known that the link of the visual analyzer that is most sensitive to various disturbances is its cortical terminus. It is quite possible that the increase in the sensitivity of the retina to light, the narrowing of the blind-spot projection area, and the decrease in optical adequate chronaxy and optical rheobase in the irradiated subjects indicate enhancement of excitation, basically of the cerebral cortex. This hypothesis is also supported by the fact that when the occipital region is irradiated in the human, the eyes are either totally undisturbed or a sharply attenuated microwave field gets through to them. As for the decrease in critical flicker frequency, this would tend to reflect changes in the level of lability of the visual-analyzer cortical terminus.

The speed of processing and loss of information in the visual analyzer was also investigated in 43 human subjects by means of correction tables, but no distinct changes were noted. The times of simple sensomotor reactions to a light stimulus did changes, but only slightly. These results were obtained under exposure to metric, decimetric, and centimetric waves with PFD = 1 mW/cm^2 /108
(E.N. Goncharuk and M.A. Pivovarov, 1966).

Visual-analyzer function was also investigated under exposure to a microwave field (λ = from 50 cm to 1 m). The subjects were told to indicate the point in space at which something unusual would be observed when the microwave generator was switched on; it was found that the subjects would almost always point at the same place at frequencies of 380-500 MHz. Some of them experienced a pulsating sensation in the brain, ringing in the ears, and "the desire to sink my teeth into the experimenter next to me" (Jaski, 1960).

According to results of study of the human auditory analyzer (Frey, 1961, 1963) under exposure to a pulsed microwave field with a wavelength of 1.5 m (F = 200 MHz, f = 27-400 Hz, pulse duration 1 to 2000 μsec, PFD around 0.3 mW/cm^2), the subjects hear buzzing or whistling, depending on the pulse repetition rate ("radio sound"). The sound was not perceived when their heads were shielded.

As would be expected, insertion of plugs into the external ear passage lowered the level of perception of ordinary sound signals, but enhanced perception of the "radio sound." Deaf persons heard this sound almost as clearly as people with normal hearing. On the basis of these experiments, Frey advanced the hypothesis that perception of radio pulses by the auditory analyzer results from demodulation in the acoustic nerves or in cells in the brain. Since the average PFD was far below the thermal-intensity threshold, the radio-sound phenomenon is also of nonthermal nature.

D.V. Gusarov (1966) investigated the function of the kinesthetic analyzer in persons exposed to a centimetric microwave field with PFD of approximately 40 to 1000 μW/cm^2, using a special kinesthesiometer that made it possible to meter the speed, strength, and form of the stimulus. He noted a substantial increase in the latent periods of the kinesthetic reactions, an increase in the number of errors, and a disturbance to kinesthetic differentiation (the subjects confused an oval with a circle).

The author correctly associated the changes that he had observed with weakening of the inhibitory process in the cerebral cortex under the influence of the microwaves. These effects were obtained in persons who had been exposed to microwaves for some time and in some cases showed signs of an asthenovegetative syndrome; they therefore indicate more profound disturbances to CNS function.

It was found in a study of the functional state of the olfactory analyzer in persons under occupational conditions (during tuning and debugging of microwave apparatus) that this analyzer responds to electromagnetic radiation; the perception thresholds /109
for thymol, rosemary, and other olfactory stimuli were higher after radiation exposure (Ye.A. Lobanova, Z.V. Gordon, 1960).

In addition to the functional states of various analyzers in persons exposed to microwaves, the motor sphere has been studied in some detail. Thus, of 25 subjects irradiated with metric and centimetric waves with PFD = 1 mW/cm^2, 18 showed somewhat

TABLE 22. CONTENTS OF AMINO ACIDS IN BLOOD SERUM OF IRRADIATED HUMANS (PFD = 1000 μW/cm², exposure 1 hour). CONSTANT EXPOSURE

(After V.A. Syngayevskaya and G.F. Sinenko, 1966)

Conditions of study	Average amino acid contents in mg–%													
	Cystine	Lysine	Histidine	Arginine	Glutamine	Aspartic acid	Serine	Glycine	Glutamic acid	Threonine	Alanine	Tyrosine	Phenyl-alanine	Leucine + isoleucine
Initial	3,37	1,63	1,12	0,66	6,61	0,78	1,12	0,87	1,9	1,11	2,49	0,63	1,49	1,22
After 2nd irradiation	2,62	3,32	2,25	0,58	8,01	1,05	1,17	0,85	2,13	1,13	2,84	0,53	2,08	1,39
After 5th irradiation	2,41	3,77	2,47	0,63	4,22	1,24	[illegible]	1,3	1,97	1,36	2,29	0,76	2,03	1,25
On 3rd day after 5th irradiation	4,92	2,95	2,04	0,68	6,89	1,19	1,23	1,15	2,06	1,62	2,23	0,72	1,86	1,19
Normal (according to Meister, Bloch, and Braun)	1,5–3,8	0,8–3,0	1,0–3,0	0,8–2,5	5,8–9,7	0,6–1,4	1,6–1,7	1,2–3,5	0,7–1,6	0,6–3,1	1,8–4,2	1,0–1,5	0,8–2,0	1,2–3,2

increased tremor in performing movements with their arms. Simultaneously, the precision of fine movements of the hand decreased. These changes were most distinct when the intensity of the radiation was increased to 3 mW/cm^2. Motor activity also increased during sleep in 3 men out of 4 who were irradiated with metric waves having a PFD = 3 mW/cm^2 for 7 days (one hour per day).

When the irradiations were discontinued, motor activity returned to normal only after 2-3 days (E.N. Goncharuk and M.A. Pivovarov, 1966). The changes described above, which attest basically to increased excitation of the cerebral cortex and perhaps also of the subcortex, have been confirmed in research done by other methods. Thus, oxygen demand was up in 6 persons after the end of a microwave treatment (PFD = 1-3 mW/cm^2). However, this stimulating effect of the microwaves diminished on repeated exposures, and a suppression of O_2 demand was even observed (N.M. Listova, 1962, 1963).

The stroke and minute heart volumes in subjects exposed to microwaves increased at PFD = 1 mW/cm^2 but decreased at PFD = 3 mW/cm^2. Peripheral resistance, on the other hand, decreased at the lower powers and increased at the higher ones (P.N. Fofanov, 1966).

Data obtained by biochemical methods also support the stimulating action of microwaves on the human organism (V.A. Syngayevskaya et al., 1962, 1966). In particular, 36 subjects showed some increase in total blood protein, basically in the gamma globulins, and an increase in total urine nitrogen after five exposures to microwaves in the metric, decimetric, or centimetric bands (exposure 1 hour daily, PFD = 1-3 mW/cm^2). As a rule, these shifts appeared after 3-5 exposures and persisted for 2-3 days after termination of the exposures.

Combined irradiation with centimetric and metric waves (exposure 30 minutes, PFD = 1-3 mW/cm^2) in the studies of the same authors produced similar changes in the total blood protein content; by the 9th treatment, there was an increase in gamma-globulins. The total nitrogen content of the urine was increased /110
in these subjects, but there was no change in the daily urine volume. At the end of the series of treatments, however, diuresis was slightly lower, although the specific gravity of the urine remained unchanged and its pH was also in the normal range. No albumin was found in the urine.

Studies of free blood-serum amino acids in humans exposed to a microwave field with PFD = 1 mW/cm^2 (one treatment per day, total of 6 treatments) showed distinct changes. Thus, of the 14 amino acids determined in the blood, the contents of lysine, histidine, glutamine, aspartic acid, glutamic acid, glycine, and phenylalanine had increased after the second and fifth treatments; the contents of the remaining amino acids were practically unchanged (Table 22). Three days after the five radiation treatments, the shifts in amino-acid composition were slightly more pronounced.

F.I. Komarov, L.V. Zakharov, I.P. Smirnov, and V.S. Nivikov found increased amino nitrogen contents in the blood and increased excretion of uropepsinogen with the urine.

The same subjects showed a decrease in blood potassium on irradiation with microwaves having a PFD = 1-3 mW/cm^2; blood sodium content increased, as did the urine content of 17-ketosteroids (V.A. Syngayevskaya et al., 1962).

The results of biochemical research have made it possible to suggest a link between the observed changes and an enhancement of pituitary and adrenal cortex function. This is consistent with the previously described changes in the functions of certain analyzers (increased excitability), higher gas metabolism, increased motor activity of subjects during sleep, etc.

Studies of bioelectric activity in the human cerebral cortex also supplement the stimulating role brought out for low-(nonthermal-)intensity microwave fields. M.S. Bychkov (1962) /111 reported that he observed a decrease in the excitability of cortical cells against a background of increased lability in humans repeatedly irradiated with microwaves at PFD's of 1-3 mW/cm^2.

It was also established that at very low intensities (10-20 μW/cm^2), irradiation of a man's hand increases its skin temperature by as much as 1°C. This effect was observed not only on the irradiated extremity, but also in the opposite one and on the skin of the forehead (Yu.A. Osipov and T.V. Kalyada, 1962; Yu.A. Osipov, 1965). However, E.N. Goncharuk and M.A. Pivovarov (1966) reported that even at PFD of 1-3 mW/cm^2, they had observed similar shifts among 18 subjects even when the radiation exposure was imaginary.

It may be assumed that the various reactions described above as occurring in humans irradiated with microwaves are for the most part adaptive. The primary changes apparently begin in the central nervous system, and inclusion of the hypophyseal-adrenal system is probably secondary. I.R. Petrov (1958) was among the first to suggest that it is not stimulation of hypophyseal and adrenal-cortex function that occurs first, but a generalized excitation of the CNS, which results in intensified functioning of these glands, in the development of the general adaptation syndrome described by G. Sel'ye (1960). The facts examined above can be reconciled satisfactorily with one another on the basis of the above concept of the action of the extremal factors.

Chapter 8

/112

CHANGES IN THE FUNCTIONS OF THE INTERNAL ORGANS OF PERSONNEL OPERATING MICROWAVE GENERATORS

Visceral disorders developing in humans as a result of exposure to microwave electromagnetic fields have not been adequately studied, although disturbances of this kind were first described back in the 1940's (A.A. Kevork'yan, 1948; Deily, 1943, and others). Almost to this day, this fact has been reflected in the differing and often contradictory descriptions of the states of internal organs that have been given by different authors. Thus, some of them deny the existence of any visceral changes that are functions of microwave exposure under occupational conditions (G.S. Korsun, G.V. Mikhaylova, 1956).

During the same time, however, other authors (E.A. Kevork'yan, 1948, and others) described cases of severe myocardial damage and manifest forms of anemia and leucopenia in individuals exposed over the long term to microwave fields in the course of their work. Finally, a majority of authors (E.A. Drogichina et al., 1960, 1962; N.V. Uspenskaya, 1961; N.V. Tyagin, 1960, and others) described various moderately severe functional changes in the circulatory and blood systems and in certain other organs.

These varying evaluations of the state of the internal organs in persons exposed to microwave fields are due in large part to the fact that the different authors studied groups of people that differed substantially both in age and sex composition and in the industrial-hygiene conditions to which they were exposed, especially in respect to the intensity and duration of microwave exposure. Further, general hygienic and, specifically, dosimetric data were given inadequate attention or disregarded altogether in many of the early studies. The fact that the authors of some of the papers were limited in large part to polyclinic examinations also exerted a certain influence.

Over the past 10-12 years, there has been a marked increase in the amount of attention given to the state of the internal organs in persons engaged full-time in the operation of microwave generators. A number of agencies have made systematic multi-year studies of problems with a bearing on the clinical medicine of visceral disorders (Ye.V. Gembitskiy, 1966; Z.V. Gordon, 1966; L.V. Zakharov, 1962; F.I. Komarov, 1963; F.A. Kolesnik, V.M. Malyshev, 1967; A.A. Orlova, 1960; P.N. Fofanov, 1966, and others) that arise as a result of prolonged microwave exposure. Experimental research in the same aspect of the problem has contributed substantially to understanding of the clinical picture and especially the pathogenesis of the disturbances that develop.

GENERAL CHARACTERIZATION OF SUBJECTS EXAMINED /113

Despite a certain amount of progress in study of the visceral disturbances that result from electromagnetic exposure, many aspects of this problem remain unclear and in dispute. In view of this, Ye.V. Gembitskiy generalized and compared with literature data material acquired over many years of observations of a group of individuals (numbering 150) whose work brought them under regular exposure to microwave electromagnetic fields (scientific research institute staff, persons employed in radioelectronics manufacturing plants and radio-engineering workshops, radar workers, etc.).

The selection criterion for special examination was submission of a complaint regarding the subject's health in the absence of any internal or nervous-system disorders of nonoccupational nature. As a rule, clinical observation was combined with extended follow-up observation.

The subjects were for the most part men ranging in age from 25 to 35 years. The overwhelming majority of the subjects had worked for a long time (3-10 years) under conditions that exposed them to radio waves in the microwave band; for the most part, they had been subject to different irradiation intensities at a variety of microwave frequencies and other conditions, and the exposure conditions had also varied widely over the years. However, the available dosimetric material and the corresponding calculations indicate that owing to failure to observe safety rules, the subjects had periodically been subject to irradiation intensities above the maximum permissible levels.

Although the complaints registered by the subjects varied substantially, they were, nevertheless, characteristic. Complaints indicating functional disturbance to the nervous system and circulatory apparatus were most frequent; less often, there were complaints reflecting changes in the functions of the digestive system and sex glands. A combination of complaints pointing to changes in the functions of the nervous and circulatory systems was characteristic to a high degree.

In most of the subjects, the disorders were of 2-4 years' standing. Complaints of deteriorating health appeared after various periods of time had elapsed since the subjects began their work with microwave generators. These differences are obviously due to the nature and intensity of radiation exposure and in some cases to the combined influence of other occupational-activity conditions (high or low temperature, vibration, psychoemotional stress, etc.) and the individual reactivity of the organism. Consistent with observations made by other authors, the complaints of most of the subjects originated 2-5 years after the start of work with the occupational hazard. The earliest complaints to be registered belonged to the aesthenic complex of symptoms (weakness, irritability, headache, uneasy sleep), and these were followed by complaints reflecting changes in circulatory-system function. /114

TABLE 23. FREQUENCY OF CERTAIN OBJECTIVE SYMPTOMS (IN %) AMONG PERSONNEL WORKING WITH MICROWAVE GENERATORS

Symptoms	%
Tremor of eyelids and fingers of extended hands	63
Hyperhidrosis	69
Acrocyanosis	52
Hypotonia	37
Deadening of first heart sound	62
Systolic murmur over apex of heart	20
Enlargement of liver	8
Enlargement of thyroid gland	6

The objective signs brought out by ordinary methods of physical examination were not acute and not specific in nature. The overwhelming majority of the subjects were individuals of normosthenic physique and well nourished. The symptoms that they displayed most consistently indicated functional changes of the nervous system and circulatory organs (Table 23).

VISCERAL SYMPTOMATICS UNDER ACUTE MICROWAVE EXPOSURE

F.A. Kolesnik and V.M. Malyshev (1967) submitted a clinical description of acute reactions to microwave exposure in 6 persons. Diencephalic disturbances (attacks of tachycardia, shaking of the entire body, seizures of headache, vomiting) were observed in one of the patients suffering from acute exposure of medium severity; the reaction was manifested only in asthenia in the remaining five.

The observations made by Ye.V. Gembitskiy extended over a comparatively short span of time after acute reactions that had appeared as a result of exposure to intense microwave fields. The subjects often reported a distinct general malaise during work and immediately after work with microwave generators; this subjective deterioration was usually transient in nature and disappeared completely after a few hours of rest or a night's sleep.

It may be that some of these patients were suffering mild acute reactions to microwave exposure. However, with only anamnestic data available, it is always difficult to determine the /115 etiological role of the microwave field in the development of such cases of "feeling poorly," since an individual may be subjected simultaneously to several unfavorable factors under his real occupational conditions. Only in five (out of the 150) patients did acute functional disturbances resulting from microwave exposure emerge distinctly. We cite one example.

L-kiy, 37 years of age, reported to the clinic on June 2, 1962, with complaints of headaches (in the frontal region), dizziness, the sensation that the blood vessels in his temples were pulsating, pronounced general debility, and disturbed sleep (inability to sleep).

These disturbances had appeared on May 28, 1962, and the patient associates their onset with his having worked for three days (May 26, 27, and 28) for 20 minutes each day on a new type of microwave generator. In addition to the above disturbances, he had been troubled on the first two or three days by a burning sensation on his face and neck; according to the patient, this was accompanied by pronounced reddening of the skin in these areas. After he left work (beginning on May 29, and especially on May 30), all of these disturbances began to subside, and he had improved markedly by the time he arrived at the clinic.

He is in his fifth year of work with microwave equipment. He feels good, although he suffers occasionally from headache, nausea, and lassitude, which vanish overnight and which he associates with his work.

He does not remember ever having been sick. He does not smoke. He is a moderate user of alcohol.

Objective notes: large, regular physique, slightly underweight (height 173 cm, weight 65 kg); somewhat pallid, palms cold and moist; emotionally labile, distinct "vasomotor slack." Pulse 80, rhythmical (on subsequent days 74 and 72); arterial pressure 150/100 mm Hg (on subsequent days 130/80, 125/75, 125/80). Heart of normal size; first sound slightly muffled over apex. Lungs and abdominal organs show no changes. Cranial nerves, tendon reflexes, sensitivity, coordination all normal. Body temperature normal.

X-rays show a slight enlargement of the heart involving the left ventricle. Analysis of the blood and urine showed no changes; leucocyte formula normal. Blood bilirubin 0.55 mg%, reaction indirect. On the ECG (June 3), high $T_{V_2-V_4}$ deflections with a slight elevation of the ST interval in the same leads; this may indicate mild myocardial hypoxia.

Capillaroscopy (June 3): turbid pink background. Six to eight drops 0.25-0.4 mm in length in a row, many of them convoluted. Arterial and venous inflections dilated. Blood flow granular.

EEG (June 3): the EEG was recorded in 12 unipolar leads. Lowered amplitude of α waves in all leads. Ten alpha waves per second. Unstable. Responses to light and sound strong but subsiding on repetitions. Rhythm maintained only at a frequency of 10 per second. Conclusion: lowered amplitude of alpha waves.

Valerian drops with bromine and multiple vitamins were prescribed. Recovery was rapid.

From June 5-6: No complaints. No changes in internal organs. Discharged June 11 in good condition.

Observations made on individuals subject to measured irradiation are of great value for understanding the effects of microwaves on man. L.V. Zakharov (1967) made a coordinated study of arterial hemodynamics in a small group of persons who were given a series of six microwave irradiations of 30 minutes' duration each at a PFD of about 1000 μW/cm². After this series of irradiations, the maximum and minimum pressures were down and the pulse amplitude had increased. Increases in the stroke and minute heart volumes and a basically adequate decrease in the specific peripheral resistance were observed. The speed of propagation of the pulse wave along arteries of the elastic (Se) and muscular (Sm) types decreased under exposure to radiation and the coefficient Sm/Se decreased, indicating a preferential lowering of tone in arteries of the muscular type. The subjects felt very little worse for the experience. /116

INFLUENCE OF PROLONGED MICROWAVE EXPOSURE ON THE INTERNAL ORGANS

Under this heading, we present certain results of research on the functions of internal organs (by systems) in individuals coming into contact with microwave generators over the long term.

Changes in circulatory system. The subjects frequently complained of various types of pain in the region of the heart and palpitations. The variety of unpleasant sensations in the heart region that were reported by the subjects were seldom of the nature of angina; they usually complained of persistent aching pains in the region of the apex of the heart, without irradiation and without aggravation due to physical exertion.

Objective symptoms in the form of lability of the pulse with a tendency to bradycardia, arterial hypotonia, slight enlargement of the heart on the left side, deadening of the first sound, and the presence of faint systolic noise over the apex of the heart must be recognized as quite consistent, since they were encountered in 1/3-1/2 of all of the subjects.

A few papers describe various electrocardiogram changes. Thus, E.A. Drogichina et al., (1962), A.A. Orlova (1960), A.S. Treskunova and G.N. Slizskiy (1962), V.A. Shchipkova (1959), and others observed retardation of intraatrial and intraventricular conduction in a number of subjects. Diffuse muscular changes (according to ECG data) were described by Yu.A. Osipov, N.V. Uspenskaya, P.N. Fofanov and others. The so-called "coronary changes" were seldom registered on the ECG's.

The ECG's were recorded in 12 leads on the intestigated group of patients. For almost half of them, ECG's were recorded not only at rest, but also under standard exertion. A test with glucose was also used. If we disregard bradycardia, deviations from the normal range were registered relatively rarely. Arrhythmia was reported in eleven subjects (respiratory arrhythmia in 6, extrasystole in 5); a moderate retardation of intraatrial /117
and intraventricular conduction was observed in 4 subjects; five showed electrocardiographic signs of coronary insufficiency. Moderate diffuse muscular changes (according to ECG data) were found in 11 of the subjects. Thus, various mild ECG changes were observed in 19 out of 120 subjects.

Vector cardiograms recorded by Ye.V. Gembitskiy and A.D. Pushkarev on 29 individuals made it possible to bring out muscular and coronary changes with slightly greater frequency than permitted by electrocardiographic data. On phonocardiography in accordance with auscultation data, almost half of the subjects registered a short systolic murmur with small oscillations preferentially at the apex (functional murmur according to the phonocardiographic description).

Ballistocardiograms were recorded on 43 subjects to evaluate myocardial contractile function; seven subjects showed a Brown's insufficiency of the first degree, and three a second-degree insufficiency. Phase analysis of the cardiac cycle showed a slight increase in the transformation phase and the stress period.

Although the individual variations were considerable, the systolic (SV) and minute (MV) volumes are found to be markedly increased (on the average by almost 40%), with the MV increase most distinct in persons with lower arterial pressure (AP).

As we see from the data given in Table 24, the subjects show a certain tendency to increased tone in arteries of the muscular type, in what is perhaps an adaptive reaction related to dilation of the precapillary (arteriole) bed. To evaluate the tonic state of the major arteries, Ye.V. Gembitskiy also used the so-called standard cold-pressor test, which brought out deviations (usually suppressive) in a number of subjects from the normal response to application of a cold stimulus (see the following two examples).

N.I. I-v, 39 years of age; a) background: pulse 52, AP 55, 70-90, 102[1] mm Hg, S_e 657 cm per second; S_m 177 cm per second;

[1]The minimum, lateral, mean, and final arterial pressures are listed in that order.

TABLE 24. PROPAGATION SPEED OF PULSE WAVE AND ELASTIC MODULUS OF ARTERIES IN INDIVIDUALS EXPOSED TO MICROWAVE FIELDS OVER THE LONG TERM

Indicator	Our own observations			Average S_e and E_e, S_m and E_m in healthy individuals according to Ye. A. Moshkin (1958)	
	maximum	minimum	average	21—30 years	31—40 years
Propagation speed of pulse wave along arteries of elastic type (S_e), cm/sec . . .	800	440	607	545	600
Elastic modulus of elastic arteries (E_e), dyn/cm²	8649	2917	5093	4000	4800
Propagation speed of pulse wave along arteries of muscular type (S_m), cm/sec .	1300	600	841	680	740
Elastic modulus of muscular arteries (E_m), dyn/cm²	12 857	3214	7226	—	—
Coefficient S_m/S_e	1,72	1,02	1,38	1,26	1,24

S_m/S_e = 1.7; b) immediately after application of cold (i.e., one minute later): pulse 56, AP 82, 100, 120, 130; S_e 767 cm per second, S_m 1370 cm per second; S_m/S_e 1.75; c) after 5 minutes: pulse, 52, AP 68, 78, 90, 112; S_e 657 cm per second, S_m 1117 cm per second, S_m/S_e = 1.7.

N.F. K-v, 28 years of age. a) Background: pulse 66, AP 68, 78, 104, 122 mm Hg, S_e 506 cm per second, S_m 800 cm per second, S_m/S_e 1.58; b) immediately after application of cold: pulse 64, /118 AP 66, 84, 108, 128 mm Hg; S_e 538 cm per second, S_m 753 cm per second, S_m/S_e = 1.4; c) after 5 minutes, pulse 62, AP 68, 78, 102, 118 mm Hg; S_e 538 cm per second, S_m 914 cm per second, S_m/S_e = = 1.7 (delayed reaction).

Suppression of the vascular response to cold has been registered on plethysmograms of a number of patients; this merits attention, since it indicates changes in the regulation of circulatory-system functions. Additional facts should be accumulated in this context, and the question as to the mechanism of the deviations established requires special study. As for the peripheral-resistance value, it was consistently low (by an average of 42%) despite substantial individual variations.

TABLE 25. FREQUENCY OF ARTERIAL HYPOTONIA IN PERSONS EXPOSED TO MICROWAVES OVER THE LONG TERM (ACCORDING TO VARIOUS AUTHORS)

AUTHORS	SUBJECTS STUDIED	NUMBER OF SUBJECTS	FREQUENCY OF HYPOTONIA (in %)	REMARKS
A.A. Kevork'yan et al. (1948)	Workers, aged 20-40 years	87	38	
Yu.A. Osipov (1952)	Same	108	34	Hypotonia in 74% of control group
V.A. Shipkova (1959)	Radiometry specialists	110	About 20	
A.A. Orlova (1960)	Workers	525	26-33	Hypotonia in 14% of control group
N.V. Uspenskaya (1961)	Young workers	100	30	
R.N. Vol'fovskaya et al. (1961)	Workers	101	27-45	
Ye.I. Smurova et al. (1962)	Same	54	53.7	
L.T. Frolova (1963)	"	172	25.6	
F.I. Komarov, L.V. Zakharov, F.A. Kolesnik (1963)	"	53	22.6	AP determined oscillographically: low minimum and lateral pressures
Ye.V. Gembitskiy (1966)	Radiometry specialists	210	14	6% in control

In conclusion, we note that the subjects exhibited increased systolic and minute volumes, a decrease in peripheral resistance, and some disturbance to coordination between the circulation minute volume and the peripheral resistance. Data indicating a change in the tone of muscular elements in major arteries were also obtained; they were registered by a tendency to increased speed of pulse-wave propagation along arteries of the muscular type and by the absence, in most cases, of an adequate reaction of the major arteries to the cold pressor stimulus.

ECG, VCG, BCG, PCG, and cardiac-activity phase-analysis data indicate mild dystrophic myocardial changes in a number of subjects, accompanied by a disturbance to its contractile function. Disturbances to the heart rhythm (not counting bradycardia) and coronary insufficiency were seldom encountered. /119

According to observations of a number of authors, the hypotonic syndrome is one of the reactions of the circulatory system consistently observed in individuals who have been subject to prolonged microwave exposure (Table 25).

To the data of this table, we should add that the papers of N.V. Tyagin (1963, 1965), A.S. Treskunova and G.N. Slizkiy (1962), A.V. Zelenskiy (1963), N.V. Uspenskaya (1963) and other authors also report a significant frequency of arterial hypotonia in persons subject to long-term microwave exposure. It must be stressed that the incidence of arterial hypotonia among the subjects must be recognized as quite high. For comparison, we note that according to N.S. Molchanov et al. (1962), hypotonia is registered in 5-7% of healthy individuals between 20 and 29 years of age and in an average of 2.4% of individuals aged 30-45.

According to the observations of Ye.V. Gembitskiy, persons with the hypotonic syndrome complain of dizziness and pains in the heart region more frequently (by a factor of 2-3) than persons in the same occupation who have normal arterial pressure. In persons with lower arterial pressure, other conditions the same, other objective symptoms of disturbance to circulatory-system function are encountered somewhat more often. Regular arterial-pressure measurements made on crews exposed periodically to microwave irradiation in excess of the maximum permissible level showed that lower arterial pressure occurred two to three times more often than in the corresponding control groups. /120

Ye.V. Gembitskiy (1966) used a mechanocardiograph to investigate the basic hemodynamic indicators in 50 "hypotonics" engaged in work with microwave generators. Table 26 shows that despite considerable individual variations, the SV and MV had a tendency to increase.

The author noted a certain increase in the tone of muscular-type arteries (a rise in the average S_m and S_m/S_e), a possible

TABLE 26. SYSTOLIC AND MINUTE HEART VOLUMES IN MICRO-WAVE GENERATOR WORKERS WITH LOW ARTERIAL PRESSURE (Ye. V. Gembitskiy, 1966)

Indicator	Maximum		Minimum		Average	
	in absolute units	in % of nominal	in absolute units	in % of nominal	in absolute units	in % of nominal
Systolic volume (SV)	118,3	—	42,7	—	78,7	—
SV (body surface)	66,1	—	33,8	—	46,4	—
Minute volume, nominal (MVN)	4,35	100	2,74	100	3,74	100
Minute volume, actual (MOA)	7,79	206 (+106)	3,79	88 (—12)	4,94	133 (+33)
Cardiac index, nominal (CIN)	2,35	100	1,39	100	2,14	100
Cardiac index, actual (CIA)	4,37	—	1,83	—	2,81	—

adaptive reaction. The actual specific peripheral resistance averaged 31% below normal. Basically similar data were recently obtained by L.V. Zakharov (1967), who reported an increase in heart mechanical activity and a slackening of its rhythm in a group of young males subject to chronic microwave exposure.

Blood changes. Blood changes in persons systematically /121
exposed to microwaves over the long term have not been adequately studied. The results that have been obtained vary. Thus, A.A. Kevork'yan (1948), who examined 87 microwave-generator workers, established anemia (hemoglobin below 60%) in 8 and leucopenia in 9 (leucocyte counts below 4500). On the other hand, Yu.A. Osipov (1965) reported a tendency to leucocytosis.

Barron and Baraff (1958) found no deviations from normal in a study of the blood of 335 men in work related to the operation of radar stations. At the same time, most investigators describe various mild quantitative and qualitative changes in the formed elements of the blood, for the most part in the leucocytes.

The above differences in the nature of the reported blood changes are apparently due to traits of the groups studied. The variety of results obtained was due in part to the fact that most of the blood studies were carried out in the course of ambulatory or dispensary examinations.

The results obtained by Ye.V. Gembitskiy (1966) indicate that the hemoglobin content and erythrocyte count were subject to no substantial deviations from normal, in agreement with most other authors (Table 27). Study of the numbers and quality of the leucocytes is of greater diagnostic value. A.A. Kevork'yan (1948) found leucopenia (3200-4500) in 15 of 87 persons examined.

TABLE 27. CERTAIN PERIPHERAL-BLOOD INDICATORS IN PERSONS WORKING WITH MICROWAVE GENERATORS

Total number of patients	Hemoglobin content (in Sahli units)			Leucocyte count			Thrombocyte count		
	70—79	80—89	90 and above	4000—4900	5000—8000	above 8000	below 150,000	150—200,000	above 200,000
120	20	45	55	36	72	12	7	63	21

M.L. Gershanovich (1959) also reported frequent decreases in leucocyte count to 3000-5000 owing to a decrease in the number of neutrophils. Yu.A. Osipov et al. (1961), on the other hand, reported a slight tendency to leucocytosis. Most authors report instability of leucocyte regulation and, in the most severe cases, leucopenia.

In a group of patients examined by Ye.V. Gembitskiy (1966), /122 the total leucocyte count was normal in most cases, averaging 5342. Attention was drawn to the lability and unusually high variability of the leucocyte count. Thus, 36 out of 120 subjects had leucocyte counts below 5000, and 12 registered counts above 8000. Considerable variations in leucocyte count were registered in a number of patients whose blood was examined repeatedly. In these patients, therefore, there was a certain polymorphism in the leucocyte count, characterized by some instability of the count and a tendency in some cases to leucopenia and in others to moderate lycocytosis; the average leucocyte counts remained within the normal range.

The leucocyte formula showed a tendency to relative lymphocytosis and monocytosis, as well as variable absolute and percentage lymphocyte, monocyte, and neutrophil contents. The neutrophil count averaged 3371 (norm 2700-5800), although a distinct (absolute and relative) neutropenia was registered for 22 subjects. Qualitative changes in the neutrophils were registered rarely, in agreement with the findings of most authors. M.L. Gershanovich (1959) found 1-3% of plasmatic cells in the blood of 25% of his subjects.

To study the functional state of the bone marrow, a test was run on 25 patients with intramuscular injection of 5 ml of a 1% solution of sodium nucleate and subsequent plotting of the so-called "leucocyte curve." In healthy individuals, leucocyte count usually doubles from the initial level within 6-8 hours after administration of this leucostimulator.

The "leucocyte curve" was normal in 18 out of the 25 subjects, sluggish and "asthenic" in 7, and showed no increase in leucocyte count at all in 2, and a paradoxical decrease in the number of white blood bodies was observed in one of the latter.

In most patients, thrombocyte count was at the lower limit of the normal range. The average number of thrombocytes was 183,500. Some of the patients showed a slight tendency to thrombocytopenia. No consistent changes in the thrombocyte formula were detected.

In a sternal-puncture study, Ye.V. Gembitskiy, F.A. Kolesnik, and V.M. Malyshev found the bone marrow to appear somewhat hyperplastic in the granulocytic stem in only five of 23 subjects with unstable leucopenia or transitory leucocytosis.

Thus, mild functional shifts characterized by instability of the leucocyte count, a tendency to leucopenia, neutropenia, and relative lymphocytosis, and a trend toward thrombocytopenia /123 have been brought out in study of the blood system. The change in the functional state of the blood system, basically in the direction of suppression, is also confirmed in a number of cases by a change in the reaction to intramuscular injection of 5 ml of 1% sodium nucleate solution.

Changes in digestive system. Few authors have studied the state of the digestive system in persons who have worked for extended periods with microwave generators. Most of this attention was devoted to liver functions. In a study of liver function in 57 men subject regularly to microwave exposure at low intensity, I.A. Gel'von and M.N. Sadchikova (1960) found no departures from normal in the thymol, formol, and Quick tests. Minor changes were detected in the mercuric-chloride test when the so-called glycemic curves were plotted. The latter were characterized by a steep rise and slow descent. The authors also noted a tendency to increased protein content in the blood serum due to an increase in the globulin fraction (α- and β-globulin fractions).

In a multi-objective clinical study of 100 young women, N.V. Uspenskaya (1963) failed to find any significant changes in the blood prothrombin, bilirubin, and cholesterol contents. The glycemic curves of 19 [of] 23 subjects studied were characterized by a double-peaked rise.

According to Ye.V. Gembitskiy's observations, subjects frequently complained of indigestion: of 150, almost half had suffered loss of appetite and 25 nausea. The patients complained much more infrequently of unpleasant sensations in the substernal region and irregularity. The objective symptomatics were spotty; a slight enlargement of the liver was registered in 12 subjects.

With the purpose of studying the functional state of the liver, the blood contents of bilirubin, cholesterol, lecithin, and prothrombin were determined; the Quick and sugar-load tests were performed and the excretion of urobilin with the urine was determined ("urobilin curve"); in some cases, the composition of the protein fractions was determined electrophoretically.

This study led to the establishment of certain disturbances of liver function in several of the patients. Thus, a mild transient hyperbilirubinemia (0.9-1.3 mg%) was found in 11 of 73 subjects, and the sodium benzoate test was moderately abnormal in 7 of 45. The total blood protein content showed individual variations from 6.55 to 8.44%, averaging 7.63%.

Thus, the total amount of protein in the blood was normal. The albumin content varied from 44 to 63% in different individuals. A moderate dysproteinemia due to a slight rise in the /124
content of coarse-dispersed proteins was registered in 9 of 35 subjects (increase in α- and β-globulins). In this respect, the data of Ye.V. Gembitskiy agree with the previously cited results of I.A. Gel'fon and M.N. Sadchikova.

In a number of patients, the "sugar curve" was "flat" and hyporeactive. By way of illustration, we might cite the glycemic curve of patient N., for which the following blood-sugar contents were found before breakfast and after the standard glucose load: 83, 115, 101, 97, and 85 mg%. No changes in cholesterol, lecithin, and prothrombin contents were detected. It can be stated in conclusion that changes in specific partial functions of the liver were observed in some of the patients and were reversible in nature.

The usual investigation of gastric juice and stomach-content acidity was performed for a small group of subjects; the stomach was also x-rayed. No regular changes were noted.

<u>Changes in functions of certain endocrine glands</u>. The literature offers only a few references, mostly to studies that have been made of the thyroid function and some pertaining to adrenal function. M.I. Smirnova and M.N. Sadchikova (1960) found thyroid enlargement (of first and second degree) in 14 of 50 subjects who had been in long-term contact with microwave generators; this is considerably above the incidence of enlargement of this organ observed in practically healthy people. In only one subject, however, was the thyroid enlargement accompanied by symptoms of hyperthyroidism.

In a radioiodine study of thyroid function in these 50 persons, the authors reported that 19 showed increased iodine absorption 24 hours after administration. In a more extensive series of observations, E.A. Drogichina et al. (1962) confirmed that an increase in thyroid activity is often observed, despite the fact that signs of thyrotoxicosis were infrequent and low-level.

Among the 150 subjects studied by Ye.V. Gembitskiy, only 9 were found to have a moderate thyroid enlargement. The basal metabolism, which was determined for 33 subjects, had individual variations from -8 to +15%, i.e., remained within the normal range. On the average, basal metabolism exceeded the corresponding norm in only 7% of cases. The radioiodine study of thyroid function was made in only 23 subjects, 9 of whom showed a moderate acceleration of absorption of the iodine (I^{131}) introduced.

Study of adrenal functional state (excretion of neutral 17-ketosteroids with the urine, Thorn test, and determination of 17-hydroxycorticosteroids in twenty-four-hour urine) failed to detect any distinct deviations from normal among the patients. /125

Changes in certain metabolic indicators. The state of the various forms of metabolism in persons working with microwave generators over the long term has been rather neglected. The existing literature data and our own observations have not yet brought out any distinct shifts of basal metabolism in persons of this occupation. Nor, to judge from general clinical examinations and the results of blood cholesterol and lecithin determinations, have any changes been detected in lipoid metabolism. Study of carbohydrate metabolism by the glycemic-curve method, according to literature data and our own observations, frequently indicates mild shifts, both enhancement and suppression, in the reaction to the standard sugar load. The changes in protein metabolism are more consistent; they are reflected in moderate dysproteinemia owing to an increase in the γ- and β-globulin fractions. I.A. Gel'fon and M.N. Sadchikova (1960) found elevated blood histamine levels in their subjects. N.V. Uspenskaya (1963) determined blood-serum K and Ca in 36 young women and reported that in 10 of them, the K/Ca coefficient had decreased below 1.7 to 1.2-1.3 (the K/Ca ratio is 1.7-2.2 in healthy individuals).

Such indicators of mineral metabolism as the sodium and potassium contents in the serum, erythrocytes, urine, and saliva remained for the most part within the normal range (Ye.V. Gembitskiy, 1966). At the same time, a trend to high blood potassium and reduced excretion of sodium with the urine can be noted.

TREATMENT

Very little has been published concerning treatment of the disorders produced by microwave irradiation. The therapeutic methods used by the authors have been symptomatic in nature, directed at the major symptoms and syndromes observed in the patients. As we noted above, either the asthenic (neurasthenic) or the neurocirculatory (more frequently, hypotonic) syndrome predominates in the clinical picture; in some individuals, both of these symptom complexes have been clearly in evidence.

Treatment is designed with consideration of features of the clinical course, i.e., with observance of the individualization principle. The authors have devoted most of their attention, with justification, to the use of measures aimed at normalizing /126 central nervous system functions. Sedatives and soporifics: Valerian and bromine preparations and various sleeping aids (Barbamyl, Bromural, phenobarbital, Veronal, Noxiron, sodium barbital, and others), antihistamines (Dimedrol, Diprazine, Suprastin, Pipalphene and others), Bellaspon, Apilac, etc. have been tested for this purpose with good results. Encouraging experience has been accumulated in the use of the so-called minor tranquilizers (trioxazine, Elenium, and others). The question as to therapeutic use of certain preparations that stimulate CNS function is considered below in connection with the therapy of the neurocirculatory (or neurohypotonic) syndrome.

To our knowledge, there have been no special studies devoted to treatment of hypotonic states in such patients. However, to judge from the available material, the authors have tried drugs that have come into use in recent years for the treatment of both primary and secondary hypotonias. It will therefore be appropriate to dwell briefly on the present state of the treatment of hypotonic states. In the opinion of most authors, these patients should receive a well-balanced high-calorie high-vitamin diet. Various methods of psychotherapy are, with justification, regarded as important in general complex treatment (M.S. Molchanov, 1962). Ye.V. Gembitskiy gave considerable time to psychotherapeutic consultation, since this patients included many who were alarmed by their illnesses and exaggerated the danger presented by the occupational factor. In such cases, a quiet conversation or series of conversations during which the nature of the illness was patiently explained dissipates unjustified anxiety and instills confidence in the outcome of treatment.

Among the medications used to treat hypotonic states, first mention should be made of vegetable stimulators of the nervous system: ginseng-root tincture, etc.

Therapeutic use of amphetamine in hypotonic conditions has been reported. V.P. Sil'vestrov (1956) does not recommend administration of amphetamine to these patients, since it overexcites some of them. A.P. Aleksandrova and V.S. Luk'yanov (1960) observed positive effects from the use of this preparation. Good results have been reported for Fetanol (0.005×3 internally).

Certain authors have also described good results from the use of synthetic preparations of the adrenalin series (Veritol-Prometin, Effortil), ephedrine, atropine, theobromine, and euphyllin, but these preparations have not been put to general use.

Nor is adrenalin used on a routine basis, because of the /127 short duration of its effect. In this context, prescription of noradrenaline (Pierach, Heynemann, 1959) appears somewhat more promising. Among the hormone preparations, cortin and desoxycorticosterone have been used much more widely (V.P. Sil'vestrov, 1956; Yu.D. Romanov, 1957; N.S. Molchanov, 1962).

The literature on the therapeutic use of vitamin B_1 in hypotonic states is somewhat contradictory, but on the whole a positive therapeutic effect of this preparation is acknowledged (N.S. Molchanov). Some authors have used a series of hypertonic glucose solution injections with good results.

In addition to his psychotherapeutic consultations, Ye.V. Gembitskiy prescribed sedatives to some of his patients and stimulants to others, depending on the specific clinical manifestations. Prime importance is attached to normalization of sleep and to control and elimination of the irritability and anxiety that are so regularly encountered in the group of patients considered. Thus, soporifics and sedatives (see above) are included in the prescribed medication complex.

As a rule, one of the vegetable nervous-system stimulants (ginseng-root tincture, aralin, leuzea, teaplant, schizandra; tincture of strychnine, securinine). In long-term therapy, one of the preparations is replaced by another after three or four weeks of use if no distinct improvement is obtained. No appreciable differences in the degree of effectiveness of these preparations has been observed. In more severe cases, caffeine preparations have been prescribed for 10-15 days simultaneously with one of the drugs indicated above. Patients with pronounced emotional excitability have frequently been put on strychnine together with valerian.

Under hospital conditions, vitamin B_1 injections (usually in hypertonic glucose solution) have often been combined with prescription of a stimulant. In addition to these agents, cortin or desoxycorticosterone injections have been given in the most severe cases.

Physical therapy and physical treatment methods (ionophoresis with calcium, sunlamp treatments, cool showers, etc.) have been used as a part of the general treatment given most of the patients.

In the opinion of Ye.V. Gembitskiy, treatment of persons in this occupation must be started under the conditions of an accredited hospital. This requirement is justified by the novelty and our inadequate understanding of this form of pathology. Subsequently, the patients should be kept under out-patient observation for a long time; here, there is every justification for /128
prescribing a stay at a health resort as part of the general plan of therapeutic and preventive measures.

TABLE 28. OUTCOME OF TREATMENT IN PATIENTS OF VARIOUS AGE GROUPS

Outcome	Age groups			Total
	20—29 years	30—39 years	above 40 years	
Cure	20	11	2	33
Improvement	35	27	5	67
Insignificant improvement or no effect	2	3	1	6
Total	57	41	8	106

For more precise evaluation of the data that we have collected, we analyze below the results of treatment of only 106 persons under hospital-clinic treatment. Since the treatment was, as we noted, standardized, the outcome depended in large measure on the vital statistics of the patients. We distinguished: 1) "cures," in which the patient was discharged with no complaints and normal arterial pressure; 2) "improvement," when there was a marked improvement in the way the patient felt and his objective data; finally, 3) "insignificant improvement or no therapeutic effect" (cases in which the subjective or objective improvement was negligible or none was observed at all).

In analyzing the possible influence of differing conditions on the outcome of treatment, we naturally evaluated the age factor first (Table 28).

Table 28 shows that positive therapeutic results ("cures" + "improvements") were distributed rather uniformly among the age groups. At the same time, cures were registered more frequently from ages 20-29. To illustrate the favorable results of treatment in younger patients with the hypotonic syndrome resulting from prolonged exposure to microwaves, we shall present only a brief extract from one case history.

Khv-v, 22 years old, radar technician, 2 years' experience. Treated in therapeutic division from April 22 through May 18, 1962. Reported with complaints of rapid fatiguing, headache, dizziness, stabbing pains in the heart region, shortness of breath and heart palpitations during physical exertion, restless sleep, forgetfulness.

Anamnesis: feels that he took sick about a year ago, when he first began to notice general weakness, rapid fatiguing, inefficiency at work, irritability, and then disturbing periodic pains in the region of the heart and headache. He was treated as an ambulatory patient without due effect. Arterial pressure in the range 104/62-90/56 mm Hg. He links his illness with the nature of his work. No past history of sickness. /129

Objective: condition satisfactory. Asthenic physique, somewhat underweight. Hands and feet clammy and cyanotic. Pulse 62, rhythmical, satisfactory filling. Heart dimensions normal. First sound at apex muffled; soft, inconstant systolic murmur over pulmonary artery. Arterial pressure 86/54 mm Hg.

No pathological symptoms of lungs and abdominal organs noted. Emotionally labile, persistent red dermographism, tendon reflexes somewhat lively, fine tremor of fingers of extended hands and closed eyelids. Eyes, ears, nose, and throat normal. "Heart" test with exertion (10 squats) and Stange test in normal range. Slightly lowered voltage of deflections in standard leads of ECG.

No pathology of heart or lungs evident on x-rays.

Hb 84%, erythrocytes 4,600,000, erythrocyte sedimentation reaction 3 mm per hour, l. 4200, p. 1%, s. 67%, lymph. 21%, mon. 7%, e. 4%.

After treatment (intravenous administration of glucose, vitamins, caffeine, phytin, showering, etc.), his condition improved. Discharged with no complaints for 15-day furlough. AP 110/68 mm Hg, pulse 78. Leucocytes 5100. Formula: p. 2%, s. 66%, lymph. 24%, mon. 7%, e. 1%.

TABLE 29. OUTCOME OF TREATMENT OF NEUROCIRCULATORY DYSTONIA PATIENTS IN VARIOUS OCCUPATIONAL SENIORITY GROUPS

Outcome	Years on job				Total
	less than 3	3–5	6–10	more than 10	
Cure	6	12	13	2	33
Improvement	5	7	42	13	67
Insignificant improvement or no effect	—	—	4	2	6
Total . . .	11	19	59	17	106

There is a definite relation between the outcome of treatment and the number of years spent in the occupation (Table 29).

It follows from Table 29 that favorable therapeutic outcomes ("cures" and "improvements") are distributed almost uniformly among the occupational-seniority groups into which the patients were broken down. However, cures are registered more frequently among individuals with less seniority. We present an example of favorable outcome in a patient with many years in his occupation.

L-chev, Ya.K., 32 years of age, technician working on radar since 1951. Reported to clinic in May 1962 complaining of persistent headache, rapid fatiguing, sleepiness (had to rest during the day), poor appetite, hyperhidrosis.

Anamnesis: mild headaches began to appear after work in the summer of 1960.

They became more severe and more frequent late in 1961; at the same time, he began to tire quickly. During the last 0.5 to 1 year, he began to show a certain indifference to his surroundings. He had seldom been sick (he remembers some sort of childhood infection and, in later years, grippe and angina). Smokes; uses alcohol rarely. /130

Objective: regular physique, weight normal. Emotional lability. Facially, pronounced "vasomotor play." Clammy palms, regional hyperhidrosis of armpits. Dermographism red and persistent. Pulse 54-58, rhythmical. Heart dimensions normal, sounds pure, AP 105/60-102/65 mm Hg. Other internal organs also unchanged. Cranial nerves normal. Tendon reflexes lively, uniform. Lowered surface abdominal reflexes. Sensitivity and coordination unaffected. Urine: no changes, but positive urobilin reaction.

Blood: Hb 98/16.3 g%, erythrocytes 5,100,000, l. 4850, 4600, 7550; leucocyte formula: p. 0.5%, s. 60%, lymph. 31.5%, mon. 6%, e. 2%, ESR 3 mm per hour. Reticulocytes 0.5%, thrombocytes 150,000, 160,000. Blood coagulation time and circulation time normal. Chest x-ray: heart and lungs unaffected, ECG normal. Prothrombin index 75%. Blood bilirubin: 1.2 mg-% to 0.8 mg-%; reaction indirect.

In blood plasma: sodium 334 mg-%, calcium 9.6 mg-%, potassium 19.5 mg-%. Blood proteins: total 8.17 g-%, albumins 64.8%, globulins 35.2%; $alpha_1$ 3.5%, $alpha_2$ 6.6%, beta 9.0%, gamma 16.1%.

The patient registered the characteristic hemodynamic changes, which were manifest in an increase in heart systolic volume and the Grol'man index by about 50% above the corresponding individualized normal values.

EEG (May 17, 1962): diffusely lowered brain-cortex activity, slow waves preferentially in the right frontal region. Predominance of inhibitory processes.

Treatment included psychiatric sessions. Schizandra, vitamin B_1, and physical therapy were prescribed. Patient discharged with improvement.

In summarizing the applied therapy, we might note that the outcome is influenced by the age of the patient, the number of years on the job, and especially the time of standing and severity of the disorders presented. No appreciable differences could be discerned in the therapeutic effectiveness of the drugs prescribed.

A basic prerequisite to successful treatment is combined use of appropriate methods with consideration of the individual peculiarities of the patient. By designing therapy on this basis, we obtained clear therapeutic results in 100 out of 106 patients (who were, as a rule, selected for hospitalization because of the manifest nature of their complaints).

Chapter 9 /130

DIAGNOSIS AND TREATMENT OF NEUROPSYCHIC DISTURBANCES

Exposure to microwave electromagnetic radiation causes vegetative, vegetative-vascular, endocrine, and sometimes neuropsychic and other changes in man. They are not strictly specific. It must be noted that there are qualitative similarities in the /131 effects of microwaves, UHF, and VHF radio waves on the human nervous system (M.N. Sadchikova, 1960; E.A. Drogichina and M.N. Sadchikova, 1963, 1965; T.P. Asanova, 1964; Yu.A. Osipov, 1964, 1965). Various other occupational factors may also produce psychoneurological disturbances of similar nature (Yu.A. Osipov, 1965; E.A. Drogichina, 1960).

Although the first studies of the biological action of microwave radiation in the decimetric and centimetric bands appeared in the 1930's, there was still no information at that time on disturbances to the functions of the human nervous system. It is probable that none were observed because of the low powers of the microwave generators in use at that time.

The first observations of effects of pulsed microwave exposure in radar technicians date from 1943-1948. Thus, during a 12-month period, Daily (1943) observed the state of health of 45 specialists who had been working with centimetric-band pulse generators for 2 months to 9 years. The author reported only complaints of periodic headaches, sometimes periodic rushes of blood to the face, and a burning sensation in the hands. In Daily's opinion, the microwave radiation had no marked detrimental effect on these workers. Similar conclusions were reached by Lidman and Cohn (1945).

Soviet authors were the first to describe changes in nervous-system function that arise in man under exposure to microwave radiation. A.A. Kevork'yan (1948) cited results from observation of 87 specialists engaged in work with 3-5-cm pulse generators on a daily basis or with 1-3-day interruptions. Many of them complained of headache, fatiguability, disturbed sleep, irritability, forgetfulness, and inability to concentrate. Paresthesia in the distal divisions of the arms and legs was reported in 12 cases and a loss of weight in another 12.

Observation showed dilation of the pupils in 7 subjects, tremor of the fingers in 16, pallor in 13 or acrocyanosis and decreased sensitivity in the distal divisions of the extremities in 9, stable diffuse dermographism in 24, a tendency to bradycardia in 24, and to arterial hypotonia in 31. All of these phenomena disappeared within 10 days to 2-3 and 5-6 weeks after the subjects were taken off work with microwave radiation. The headaches were first to disappear, then the parasthesia, and, last of all, the phenomena of asthenia and vegetodystonia.

A.G. Panov, A.I. Moskalyuk, and V.B. Barsov (1957)[1] studied acute microwave exposure in humans. Neurological tests were performed and EEG's recorded. No significant neurological shifts /132 were detected under these conditions. Various types of nervous-system responses to equal microwave intensities were noted among the subjects on the basis of reported subjective changes and the EEG's; this was later confirmed by D.A. Ginzburg, M.N. Sadchikova (1963) and Z.V. Gordon (1966). Observations of the effects of pulsed microwaves on radar technicians were subsequently published in the foreign literature (Hines, Randall, 1952; Brody, 1953, 1956; Barron et al., 1956; Barron, Baraff, 1958).

In these reports, in contrast to Daily's studies (1943, 1945), certain functional disturbances to the nervous system began to turn up among the radar technicians. These papers also presented data on the effects of thermal and subthermal microwave intensities on the radar specialists.

The most detailed investigation was carried out by Barron et al. (1956), who examined 226 specialists working with 3-cm-band radars and a 88-man control group. According to these authors, the radar specialists were exposed to microwaves of thermal intensity (PFD from 3.9 to 13.1 mW/cm^2) periodically or systematically for up to 4 hours per day. Overheating effects from proximity to radar antennas, clouding of the crystalline lens, and minor functional disturbances to the nervous system were noted in these individuals. The same information was given in a later report (Barron, Baraff, 1958).

A number of papers on the influence of pulsed microwaves on radar specialists have appeared in the Soviet literature (V.A. Spasskiy, 1956; N.F. Galanin et al., 1956; G.S. Korsun and G.V. Mikhaylova, 1956). Working independently of one another, these authors arrived at the conclusion that functional shifts do occur in radar specialists in some cases, but are governed chiefly by overwork as a result of failure to observe hygienic work and rest norms, and to a lesser degree by microwave exposure.

In contradiction to the above, S.I. Shemyakov (1955) reported that more than half of the 24 radar technicians that he examined had shown various abnormalities, including asthenic phenomena, a tendency to bradycardia and arterial hypotonia, a rise in basal metabolism, and a decrease in blood sugar, basically because of microwave exposure. N.V. Tyagin (1959), who gave physicals to radio specialists engaged in the repair and adjustment of radar

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[1]Cited after M.S. Bychkov, Vol. 73, Leningrad, 1957, p. 58.

apparatus, also noted an enhanced reaction to measured physical exertion, deterioration of sensomotor-reaction indicators, tendencies to bradycardia and low arterial pressure, and other vegetative disturbances consistent with the asthenic syndrome. He /133 also reported a certain instability of clear vision and lowered discrimination sensitivity of the eye, flicker frequency, and dark adaptation. In his later papers (1965, 1966), N.V. Tyagin reported deterioration of the state of the nervous system and an increase in the number of complaints as functions of the length of time spent working with microwave generators.

Klimkova-Deutschova (1957, 1963) examined 73 specialists who had worked with microwave generators for one month to 9 years, and reported complaints of headache (in 43 cases), rapid tiring (39), and uneasy sleep (35). Observations frequently made among the specialists examined included hyperhidrosis (in 1/3), acrocyanosis (in 1/4), and, in some, lowered sensitivity in the distal divisions of the arms. The EEG's showed a variety of changes.

Z.V. Gordon's monograph (1966) makes reference to a study by Klimkova-Deutschova and Roth (1963)[1], which proposes a highly original "three-stage" classification of the neurological changes that occur under chronic exposure to centimetric waves, namely:

Stage I — neurasthenic syndrome with functional symptoms and predominantly vegetative disturbances;

Stage II — "mild organic disturbances" of the nervous system;

Stage III — "organic affections of the nervous system" of the nature of transitory to pronounced "encephalopathias."

Sercle et al. (1961) made physical examinations of specialists who had worked with pulsed centimetric-wave generators. Some of them had been exposed to chronic low-intensity irradiation from radars under field conditions, and others had been periodically microwave-irradiated at high intensities (PFD of the order of 1 mW/cm^2 and higher). In both groups, the authors reported complaints of fatiguability, drowsiness, and headaches and detected EEG changes. These changes were encountered more frequently in those persons who had been exposed periodically to high microwave intensities. The authors did not observe organic affections of the nervous system.

Iranyi (1960) examined 73 men engaged in the operation of microwave generators; more than half of his subjects complained of headaches, quick fatiguing, disturbed sleep, and excessive perspiration. Examination showed tremor of the fingers (in 54 cases), exaggeration of reflexes (in 38), changes in dermographism

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[1]Cited from Z.V. Gordon, Moscow, 1966, p. 35.

(in 42), and changes in pupil size (in 33), usually dilation. No organic affections of the nervous system were observed.

It is characteristic for microwave exposure that the complaints appear earlier if the industrial-safety rules are disregarded. For example, the subjective symptoms may arise during the first few weeks or even days of work, and objectively observable signs during the first few months of work with microwave generators. It must be stressed that only some microwave-generator workers complain of deteriorating health when the safety rules are periodically violated. /134

As a rule, reversible shifts are observed in the functions of the nervous system and other organs; when work with the microwave generators is discontinued, these changes gradually disappear over a period of weeks or months. However, if a subject returns to his previous work with microwave generators, his symptoms frequently reappear (E.A. Drogichina, 1960; V.N. Gur'yev, 1962; Yu.A. Osipov, 1965).

Strongly manifest changes with the neurasthenic syndrome and neurocirculatory dystonia appear in approximately 3% of cases during the first few months of work with microwave generators (in 16 of 533 assigned to such work). In all cases, severe reaction to microwave irradiation was associated with prior overwork or functional weakening of the nervous system and other causes (V.N. Gur'yev, 1962). Dispensary observation of the workers is therefore important, with reassignment of persons with asthenovegetative disturbances, who are obviously most susceptible to microwave-exposure effects (E.A. Drogichina, 1960; Ye.B. Zakrzhevskiy and V.M. Malyshev, 1964).

The frequency and gravity of the pathological manifestations and the sensitivity to further microwave exposure increase with increasing time spent in work with microwave generators and with increasing irradiation intensity. The clinical picture of the nervous-system-function disturbances also changes to some degree. However, even under systematic microwave exposure, the symptoms are stubborn only in a few persons, usually among those who have been exposed to microwaves over the long term and have weakened nervous systems or have had an infectious disease (E.A. Drogichina, 1960; M.N. Sadchikova, 1960, 1963; V.N. Gur'yev, 1962, 1963; N.V. Uspenskaya, 1963; Yu.A. Osipov, 1965).

Chronic exposure to low microwave intensities usually produces asthenic conditions and causes vegetative disturbances less frequently. Periodic exposure to higher microwave intensities, on the other hand, is more likely to produce vegetative changes with a tendency to bradycardia and lowered arterial pressure and, less often, asthenic states. These disturbances take a protracted course in only some of the subjects, usually those with weakened /135
systems. Contracted infections are highly unfavorable. Vascular

vegetative instability appears in such cases, taking the course of the diencephalic syndrome in some individuals (E.A. Drogichina, 1960).

Under prolonged exposure to moderate microwave intensities, the asthenic phenomena may diminish, but the frequency and gravity of the vegetative disturbances increase, sometimes with diencephalic crises. All of these disturbances depend on individual peculiarities. Diencephalic crises are noted in about 5% of persons (16 out of 300 examined) who have worked with microwaves over the long term (V.N. Gur'yev, 1963).

In 1953-1960 and thereafter, the USSR Academy of Medicine Institute of Industrial Hygiene and Occupational Diseases studied the working conditions and health of 525 persons working with centimetric waves of varying intensity and under various irradiation conditions. The subjects had been engaged in their work for times ranging from a few months to 5-10 years and more, but basically for 4 years (66%); most were between 20 and 40 years of age.

Many of these persons were under observation over a number of years; 51 of them were examined in the hospital. M.N. Sadchikova (1960) and A.A. Orlova (1960) published summarized results of these studies.

Group I consisted of 184 persons who had been irradiated periodically (PFD's up to 3-4 mW/cm^2) and complained of headaches (12% of the subjects of this group), increased fatigueability (20%), irritability (8%), pains in the region of the heart or palpitations or shortness of breath (36%); objective examination showed weakened dermographism (16%), hyperhidrosis of the hands (6%), arterial hypotonia (27%), bradycardia (74%), sinus arrhythmia (21%), and moderate electrocardiogram shifts.

Group II, which consisted of 263 individuals who were also irradiated periodically but at higher PFD's (up to several hundred μW/cm^2), complained of headaches (39% of cases), increased fatiguability (35%), irritability (27%), drowsiness during the day (12%), and complaints of cardiovascular nature (37%); on examination, weakened dermographism was found in 40% of cases, hyperhidrosis of the hands in 28%, arterial hypotonia in 28%, bradycardia in 48%, sinus arrhythmia in 10%, and minor deviations from normal on the electrocardiograms (lengthening of the P-deflection to 0.1 second, lengthening of the QRS complex to 0.1 and more than 0.1 second).

Group III, 78 individuals systematically irradiated at PFD's of 100-10 μW/cm^2, submitted complaints the percentages of which were similar to those of group II.

Thus, the authors failed to bring out any conclusive differences in the state of health of individuals working under /136 systematic and periodic microwave exposure.

Exposure to high-intensity microwaves, even periodically, tends to produce vegetative reactions, principally functional changes in the cardiovascular system as a result of increased tonus of the parasympathetic system. With decreasing intensity of the radiation, these reactions become less distinct and less frequent. Systematic irradiation at low intensities is more likely to produce nonspecific asthenic and asthenic-neurotic re actions and less likely to cause vegetative shifts (E.A. Drogichina, 1960; Z.V. Gordon, 1960). These observations are justified in greater detail in the work of A.A. Orlova (1960) and M.N. Sadchikova (1960). M.N. Sadchikova (1960) reports that functional disturbances to the nervous system appeared in only 15% of subjects after 3 years of work with microwave generators; they were observed more frequently with increasing seniority, but usually had a favorable outcome. Only some subjects (51 out of 525) required treatment. After hospital treatment, most of them returned to work; 11 were taken off work with microwave generators for times ranging from several months to a year.

A.S. Treskunova and G.N. Slizskiy (1962) reported results of out-patient examination of 376 persons, and A.S. Treskunova (1962) submitted data from clinical examinations of 37 men who had worked with microwave generators for 3-10 years and more. The conclusions of these authors agree with those of A.A. Orlova and M.N. Sadchikova (1960).

V.N. Gur'yev (1962) examined 533 microwave-generator workers. During the first few months, 70% of them presented a neurasthenic syndrome, sometimes with vegetative and mild trophic disturbances. The author distinguished three stages in these changes. V.N. Gur'yev arrives at the conclusion that the degree of the disturbances in persons assigned to work with microwave radiation depends in many respects on their individual peculiarities and, in particular, on the typological peculiarities of the nervous system, as well as prior overwork and functional weakening of the nervous system. At the same time, the author stresses that the functional disturbances of the nervous and cardiovascular systems increased in severity even in stage II unless the time and intensity of irradiation were reduced. Under favorable working conditions, all of these disturbances gradually abated during subsequent months; the author regards this as a kind of adaptation to exposure to the microwave field.

Most authors who have observed microwave-generator workers have remarked on the variety and frequency of neurological complaints among these persons (Table 30).

The changes in nervous-system function are characterized by /137
the variety of their manifestations, while their polymorphism and dynamics depend on the phase and severity of the disorder, the

TABLE 30. CHARACTERISTICS OF COMPLAINTS SUBMITTED BY MICROWAVE-GENERATOR PERSONNEL ACCORDING TO VARIOUS AUTHORS (IN % OF NUMBER OF SUBJECTS)

Author	Headache	Increased fatiguability	Disturbed sleep	Irratibility	Dizziness	Sweating	Forgetful-ness	Number of examinations	Remark
N.V. Uspenskaya (1963)	37	31	29	16	9	7	4	100	
M.N. Sadchikova (1963)	12—39	20—35	—	8—27	—	—	6—28	447	Number of complaints varied with type of work
Klimakova-Deutschova (1963)	43	39	55					73	
Sercl et al. (1959)	43	4	45	10	—	—	—	103	
Iranyi (1960)	50	40	60	—	10	39	—	73	
N.V. Tyagin (1966)	33,5	46,2	25,3	9,6	—	25,5	—	573	
Our data	44	29	35	36	18	25	11	155	
Control group									
N.V. Uspenskaya (1963)	15	22	2	10	6	—	2	100	
M.N. Sadchikova (1963)	3	10	—	8	—	—	—	100	
N.V. Tyagin (1966)	10,6	5,9	6,7	—	—	2,7	—	184	
Our Data	7	8	3	—	—	4	—	50	

microwave-intensity levels to which the subject was exposed, and many other factors. This explains, in particular, the variety of complaints (see Table 30). This is why many authors who have observed various symptoms and syndromes have been unable to give an exhaustive classification of these shifts.

The first attempts at clinical description of the dynamics of development of the symptom complex were undertaken by E.A. Drogichina (1960) and E.A. Drogichina, M.N. Sadchikova (1963), V.I. Gur'yev (1963), N.V. Tyagin (1962), A.G. Panov and N.V. Tyagin (1966) and others. For the most part, the data that they presented correctly reflect the essence of the disturbances in question.

E.A. Drogichina and M.N. Sadchikova (1964) proposed that five syndromes be distinguished in the diagnosis and treatment of microwave sickness:

1. The vegetative syndrome, which was characterized by a vagotonic tendency in the cardiovascular reactions and metabolic shifts.

2. The asthenic syndrome, which they classify among the "non-specific reactions." /138

3. The asthenic-vegetative syndrome, which, in the opinion of the authors, unfolds with neurotic manifestations and is accompanied by angiospastic phenomena with arterial hypotonia and bradycardia, contraction of the retinal vessels, changes in heart function discernible on the ECG, changes in brain biopotentials, functional shifts of the endocrine organs, a decrease in sexual potency and ability to perform work.

4. An angiodystonic syndrome at advanced stages in chronic exposure with emotional instability, forgetfulness, inability to concentrate, weakened cardiovascular reactions, disturbances of heart electrical activity, and shifts in the blood picture.

5. A diencephalic syndrome in advanced stages of chronic exposure, with crises and functional disturbances of other internal organs and systems.

The proposed classification is inconvenient in a number of respects, since the diagnostic problem is not made easier by the differentiation of syndromes on the basis of a functional criterion on the one hand, and an anatomical-physiological criterion on the other.

A.G. Panov and N.V. Tyagin (1966) suggests recognition of three types of disturbances defined as "consequences of chronic microwave exposure," with the principal syndromes as follows:

1. An asthenic syndrome, which manifests in nervous exhaustibility with lowered emotional tonus and various disturbances of vegetative functions. These changes are comparatively quickly reversible and amenable to ambulatory treatment.

2. A syndrome of vegetative-vascular distonia, basically vascular instability, which has been interpreted by other authors as neurocirculatory dystonia. In many cases, in the opinion of these authors, there is no manifest asthenia. The disorder merely takes a protracted course in some cases.

3. A diencephalic syndrome, with complex visceral dysfunctions and crises. The changes take place against the background of an asthenic condition. Here the authors refer to the presence of apathetic-abulic disorders, hypersomnia, hypokinesia, hypothalamo-pituitary-adrenal weakness (manifest or latent), and suppression of sex and food reflexes. The changes are not always fully reversible.

A.G. Panov and N.V. Tyagin distinguish three stages in the "consequences of chronic microwave exposure," depending on the acuteness and gravity of the disturbances: stage I, a mild stage observed in many workers during the first 2-3 months of work with microwave generators. This is followed by a feeling of well-being that lasts for 1-1½ years. In the initial periods, the

patients complained of headache, sluggishness, drowsiness, lowered /139
working efficiency, and sometimes heart palpitation and pains in the chest. Objective examination failed to bring out any nervous-system disturbances. The symptoms were quick to disappear even without the use of medication.

Stage II, a moderate stage, was observed in a number of subjects with a 3-5-month duration of the initial period, with a shorter period of subjective well-being. Complaints of severe and persistent headaches, loss of strength, deterioration of mood, indifference, disturbed sleep, pains in the heart region, and shortness of breath appeared during this stage. Examination showed hyperhidrosis or dryness of the skin, falling hair, and fragility of the nails.

The pathological symptoms submit readily to treatment with dibazol, stimulants, and vitamins with a corresponding improvement of working conditions.

Stage III, the severe stage, was observed by the authors in 16 individuals; the neurotic states, neurocirculatory disturbances, and other nervous-system symptoms were observed to be more severe. Patients of this group required hospital treatment and prolonged rest.

In an analogy with intoxications and ionizing-radiation sickness, F.A. Kolesnik and V.Ya. Malyshev (1967) recommend a distinction between "acute and chronic microwave sickness," in three degrees of gravity: mild, medium, and severe.

Note should also be taken of a proposal endorsed by certain clinicians (Ye.A. Drogichina and M.N. Sadchikova, 1968; N.V. Tyagin, 1968), according to which this type of occupational disease would be recognized as an independent nosological entity under the name "radio-wave sickness." They propose distinguishing three stages of the sickness: initial, moderately advanced, and advanced with various clinical syndromes.

On the basis of literature data and our own clinical observations (155 individuals working with microwave sources), we feel that it is possible to offer a certain systematization for the development of neuropsychic disturbances under the action of microwave frequencies.

A distinction must be drawn between acute neuropsychic changes and the clinical aspects of chronic microwave exposure.

The clinical picture of acute affection. This is encountered in man on exposure to high PFD's, and is possible as a result of failure to observe safety rules or a breakdown of the equipment. Its mechanism has been studied for the most part in animal experiments. Four men who had been exposed to high microwave powers came under our observation; the clinical disturbances that they presented were quite consistent. The subjects reported that /140 they felt generally uncomfortable, tired, and debilitated immediately after the microwave exposure. As a rule, there were no other symptoms during exposure. On the next day, the following clinical symptoms developed: sharp headaches in the frontal region, a sensation of pressure in the eye sockets, heavy-headedness, noise (ringing) in the head and ears, the sensation of "cuts" in the eyes, recurring nosebleeds, sudden fainting spells, trembling of the entire body, cramps in the legs.

At night, sleep was anxious and superficial, and during the day the subjects felt drousy. These phenomena were accompanied by general weakness, adynamia, and anxiety. The symptoms developed, usually increasingly, over the course of two days. During the next 5-7 days, the patients felt somewhat better, but continued to complain of headache, dizziness, general weakness, adynamia, and fainting spells on an abrupt change in posture, palpitation of the heart, pains in the heart region, attacks of profuse sweating, trembling of the hands, poor sleep, drowsiness during the day, difficulty in concentrating, and loss of working efficiency.

General examination showed tachycardia during the acute period, and leucocytosis (up to 12,000) on the second day. After 7-10 days, the symptoms described had receded to the extent that the patients were able to return to work. From this time on, however, work with microwave sources easily led, even after short exposures, to deterioration of the subject's general condition. Similar clinical descriptions may be found in A.A. Kevork'yan (1948).

Experimental studies made on animals confirm these clinical observations. They indicate that on acute microwave affection, the experimental animals show distinct functional changes of the nervous system and brain and sometimes even morphological tissue changes (I.V. Pitenin, 1959; L.A. Dolina, 1959; M.S. Tolgskaya, Z.V. Gordon, Ye.A. Lobanova, 1959, 1960; M.S. Tolgskaya, Z.V. Gordon, 1960, 1964). The presence of organic nervous-system changes was also brought out by the EEG (appearance of pathological waves, epileptiform biopotentials).

In examining the diagnosis and treatment of acute exposure to electromagnetic radiation, it must be noted that these disturbances have been observed comparatively rarely in humans. Patients suffering from consequences of chronic microwave exposure are encountered much more frequently.

During the past two and a half decades, a certain amount of clinical material has been accumulated and has been systematized by various authors in a patently preliminary form. Most investigators who have studied this problem stress the fact that the /141 nervous system usually reacts to microwave exposure earlier than other systems. Functional shifts are first to be noted in the initial stage of this nervous-system affection. However, the variety of the clinical symptoms and their similarity to neurotic disturbances has frequently led to unsound conclusions regarding their clinical nature.

Diagnosis and treatment of chronic affection. A number of investigators (E.A. Drogichina, 1960; M.N. Sadchikova, 1960; N.V. Uspenskaya, 1963; V.N. Gur'yev, 1962; N.V. Tyagin, 1962, 1966; F.A. Kolesnik, 1961, and others) have noted phases in the course of neuropsychic disturbances accompanying chronic microwave exposure. The classifications of the nervous-system disturbances that they have submitted correctly reflect the clinical picture of this sickness. However, the absence of adequate literature descriptions of psychic disturbances associated with it has had its effects on the exposition. On the basis of the data of these authors and our own clinical observations (155 cases), we would distinguish four stages in the development of the neuropsychic disturbances in response to chronic microwave exposure.

In the first stage, which covers the first few months at work (3-6 months) with microwave generators, some of the subjects reported mild complaints consistent with the asthenic syndrome. They are characterized by a general feeling of ill-being toward the end of the working day, fatigue, mild frontal headaches, irritability, lowered performance, sometimes drowsiness and pains in the heart region. All of these symptoms are mildly expressed and, as a rule, disappear after rest and sleep.

No substantial deviations from normal are noted on objective study of nervous-system function. For the most part, the patients themselves attribute these changes to various exogenous (and psychogenic) factors, and they usually continue to report for work. As a rule, all complaints subside and disappear without treatment within a few months.

Most authors regard the disturbances of this period of the sickness as a response of the nervous system (organism) to the new threat and classify them as functional shifts, while regarding the improvement reported by the subjects at the end of this period as an adaptive readjustment to the disturbances (V.N. Gur'yev, 1962; N.V. Tyagin; A.G. Panov and N.V. Tyagin, 1966, and others).

In the second stage of the sickness, which lasts from six months to 2-3 years during work under exposure to microwaves, the /142
asthenic manifestations are aggravated and accompanied by distinct shifts in the emotional sphere. During this time, the disturbances are manifest clinically in a wide variety of syndromes: neurasthenia-like, asthenic with pronounced emotional reactions, obsessive (with fixed ideas and fears), asthenic with dysthymic

disturbances of mood. The polymorphism of the clinical manifestations is apparently to be explained by premorbid personality traits.

These neuropsychic disturbances are usually observed in those working under exposure to microwaves clearly in excess of the adopted norms. Given proper industrial-safety measures, they do not, as a rule, take sick. Deterioration of health progresses as seniority on the job is accumulated. During the first and second years of work with microwave generators, the symptoms are unstable, with deteriorations in the state of health coinciding with times of tight work schedules and improvements coinciding with rest periods. The most conspicuous disturbances usually occur during the third year of work with microwave generators, but this may also be a function of increases in the radiated microwave powers.

During this period, the patients submit numerous and varied complaints. Headaches in the frontal and occipital regions become particularly frequent. These headaches are at first transitory, but as the microwave PFD's rise, they become more severe and persistent. The headaches are accompanied by sensations of heavy-headedness and pressure on the eyeballs. The patients are periodically disturbed by dizziness, nausea, and vomiting. The headaches are sometimes described as "helmets" in which the head is being crushed. Palpitation and pains in the region of the heart occur quite frequently.

Together with these complaints, there are progressive weakness and fatiguability, especially during the second half of the working day. By the end of the day, the patients feel incapable of working and completely debilitated and broken down, so that they find it necessary to rest for 2-3 hours. Working efficiency declines sharply. Irritability and loss of self-control are noted. The subjects are irritated by bright light, flickering in front of the eyes, and sudden loud noises.

Increasing irritability is accompanied by the appearance of affective instability, conflicts, and emotional lability. Sleep at night deteriorates and often becomes superficial, accompanied by nightmares, of abbreviated duration, and unrefreshing. The patients feel weak and distraught on awakening. They are drowsy during the day. As the debility increases, they become indifferent to their surroundings and do not care to engage in any activity. The loss of ability to concentrate gives the subject the /143
impression that his short-term memory is deteriorating. Absentmindedness and inability to focus attention are still further detrimental to performance on the job.

A weakening of the sexual impulse appears during this period. Unpleasant domestic episodes and obsession with the weakening of the "libido" put the subject in a bad mood. There are periods of gloom and melancholy with irritability, frequently reaching the stage of depression. During this time, many patients develop fixed ideas and stubborn anxieties.

The objective signs of nervous-system functional changes are usually vague. It is impossible to detect symptoms of organic injury to the nervous system. Examination usually reveals manifest instability of vascular reactions, "play" of the facial vasomotors, tremor of the extended hands and eyelids, which is aggravated when the eyes are closed, instability in the Romberg position, stable red dermographism (sometimes diffuse, or in the form of a welt elevated above the skin), hyperhidrosis of the palms, armpits, or the entire body, phenomena of acrocyanosis, paresthesia of the skin of the arms and legs, twitching of the hands at night. The tendon reflexes are usually uniformly functionally enhanced, with broadened reflex zones. Pathological reflexes do not appear.

Investigation of brain bioelectric activity registered basically a moderate decrease in the brain biopotentials with prolonged nondamping reactions to stimuli (light, sound). No pathological waves are noted. Brain biopotentials of the normal type are registered in some patients. Numerous authors who have correctly described the changes that take place during this phase of the sickness have reported that the symptoms are reversible (V.N. Gur'yev, 1962; N.V. Tyagin, 1962; Z.A. Drogichina and M.N. Sadchikova, 1964; N.V. Uspenskaya, 1963; N.V. Tyagin and A.G. Panov, 1966, and others).

At the same time, a certain stability of the symptomatics is brought out even at this stage in the affection, with a tendency to deteriorating states of health under the action of various specific factors (overwork, intoxication, infections and colds, unpleasant episodes on the job and at home, and other factors, which sometimes substantially alter the picture of the disease).

At the same time, somatic illnesses are observed: neurocirculatory dystonia, stenocardiac pain, gastritis, and intestinal dyskinesia, to the substantial detriment of the neuropsychic symptomatics. The clinical picture of the sickness gradually becomes more and more distinct with increasing time spent working with microwave sources when the safety rules are not observed.

The period beyond 3-4 years of work with microwave generators should be regarded as the third stage in the sickness. Detailed clinical descriptions of this disorder will be found in E.A. Dragichina and M.N. Sadchikova (1964) and A.G. Panov and N.V. Tyagin (1966). During this period, the complaints enumerated above become much more severe and are compounded by a number of new symptoms indicating the presence of psychoorganic disturbance. This psychoorganic syndrome (which is generally recognized in the /144 psychiatric literature) may, as it progressively worsens, be diagnosed in a variety of ways: sometimes as a psychopathoid (encephalopathic) state, sometimes as an acute emotional disturbance with pronounced depression, sometimes as hypochondria with coenesthopathic disturbances, when the patient fixes his attention on the sickness, declaring it to be incurable; the coenesthopathic disturbances have manifested in various extremely distressing sensations – cramping, burning, pressure, etc. in various organs and regions of the body, but have not been confirmed by data from objective examinations.

During this period, the diencephalic crises become gradually more frequent. The course of the disease is not marked by constancy; there are periods of decompensation with manifest asthenic disturbances. Illusions involving a bright, flickering light become intolerable. Emotional weakness appears, the subject becomes querulous at the slightest pretext, and sometimes emotionally rigid – typically with affects of rancor and irritability, i.e., dysphoric disturbances.

As a rule, mood is unstable; the depressive states are frequent, last longer (up to several days), and are accompanied by anxiety and restlessness. The irritability and conflicts grow stronger. The affective reactions are accompanied by a sharp aggravation of the headaches and by violent vascular-vegetative shifts. As they grow stronger, the debilitating effects often result in total indifference to the surroundings, a state of apathy. Efficiency on the job deteriorates sharply.

After working for a short time, these persons are incapable of performing the most elementary occupational duties. Attention is drawn to the fussiness and "sluggish" thinking of the subjects and their tendency to become enmired in details. Fixed dreads and ideas, some exaggerated and with hypochondriac content, come clearly into the foreground in some patients: emotionally colored thoughts receive a disproportionate amount of attention and are hard to talk away. Some narrowing of the range of interests and desires is observed, although there are no pronounced intellectual derangements.

The patients are usually obsessed with their health and rivet their attention on their own sensations. This situation is to the still further detriment of mood. The asthenic manifestations /145 are aggravated in cases in which various attendant somatic illnesses occur. Memory for recent events becomes sharply weaker, and concentration more unstable.

At night, sleep is disturbed, often sharply curtailed and superficial with nightmares. Reports of sexual weakness are common during this phase, also with considerable influence on mood. Pronounced diencephalic disturbances have not been encountered frequently in these patients. Their clinical manifestations ranged from moderate vasomotor disturbances to distinct crises. The diencephalic crises were usually of sudden onset, manifesting in seizure-like headaches, dizziness, "graying out," facial pallor, profuse sweating, adynamia, and sudden debility.

The patients stood with difficulty and would try to sit or lie down as soon as possible. Fainting spells with brief loss of consciousness were sometimes observed. These crises passed rather quickly (within a few minutes), although they showed a tendency to recur in some of the patients.

The objective signs of nervous-system injury became more distinct, but did not fit into any particular syndrome. Sometimes they were manifested in more distinct vegetative disturbances than during the second period. Microsymptoms of cranial-nerve functional disturbances and symptoms of oral automatism were detected. The enhanced tendon reflexes with broadened reflexogenic zones were at times somewhat asymmetrical. Paresthesias and twitching of the legs were common.

The EEG's showed slow brain biopotential activity and effects of moderate dysrhythmia or depression of brain electrical activity in some of the patients. These reports are confirmed by the studies of D.A. Ginzburg and M.N. Sadchikova (1964).

These disorders were observed in persons who had worked for long periods with higher-output microwave sources. These clinical disturbances lowered the efficiency of the patients substantially, and hospital treatment was required during periods of poor health (N.V. Tyagin, 1966, and others). The general condition of the patients indicated the need for reassignment to work not involving exposure to radio waves.

The nervous-system changes were encountered even less frequently during the fourth stage. They have been reported only in persons who have spent 10 or more years in work involving exposure to intense microwave fields with frequent violations of safety rules. The medical histories of these patients record conditions resembling acute microwave sickness. During this period, /146
the clinical abnormalities indicate organic injury to the brain and symptoms of neuropsychic disturbances appear. The frequent somatic complaints (injury to the cardiovascular system) are frequently accompanied by cardiovascular insufficiency and phenomena of paroxysmal tachycardia.

By themselves, these disorders can affect the patient's ability to work. At the same time, the neuropsychic disturbances are strongly manifested, often dominate the picture, and take a severe course. The diencephalic crises are more profound, with impaired consciousness, and occur more frequently. The headaches and sensopathic disturbances to perception become more severe. The mood background is unsteady. A somewhat lighter, more cheerful mood sometimes approaches the euphoric level and often alternates with depression, anxiety and uneasiness, or dysphoria. Thought disturbances sometimes arise during this period, with the thinking becoming less mobile and more plodding and punctilious. Impairment of memory is noted, and in some cases the symptoms resemble the clinical picture observed on injury to the frontal lobes. The neurological microsymptoms then become more manifest. Brain bioelectric activity appears in pathological variants. As a rule, therapeutic measures produce only a slight improvement.

The pathological disturbances enumerated above may result in loss of ability to work and make disability arrangements necessary (disability group III or even II).

These stages in the course of the neuropsychic disturbances indicate the development in the brain of a process that depends on the time of subjection to this hazard. This pathological picture develops especially rapidly in persons who have sustained brain injuries or one of the neuropsychic disorders, and in persons who exhibit pronounced peculiarities of character (psychopathic personalities). These facts point to a need for careful screening of specialists for work with microwave generators and for constant monitoring of their health during this activity, as has been recommended by many authors (A.A. Kevork'yan, 1948; V.N. Gur'yev, 1962; N.V. Tyagin, 1966, and others).

Chapter 10

EFFECTS OF MICROWAVE RADIATION ON THE VISUAL ORGAN

About twenty years ago, a cataractogenic effect of microwave radiation was established in the experimental studies of Richardson (1951) and others. Later, numerous investigators reported various types of ophthalmological complaints, including lowered sharpness of vision, from persons working with microwave generators.

Hence it is understandable why studies devoted to the effects of microwave radiation on the eyes have occupied a prominent position among the other aspects of research on the biological effects of microwaves. In addition to this factor, the influence of the microwave field on the eye has also been widely studied because the visual organ is a convenient experimental object in view of its lack of protection by overlying tissues and the transparency of its media. When he irradiates the eye, the experimentor knows that the incident energy is not being absorbed by shielding tissues and that the changes produced will be accessible to in vivo macro- and microscopic observation. A number of important premises have been established as a result of experimental study of the action of the microwave field on the visual organ.

Under microwave irradiation at thermal intensities (PFD's above 10 mW/cm^2), a number of changes take place in the eye, due chiefly to the thermal effect (hyperemia and hemosis of the conjunctiva, dulling of the cornea, contraction of the pupil, clouding of the lens, changes in the vascular membrane and retina). Here, the changes in the anterior segment of the eye vanish without a trace within a few days after the irradiation is discontinued, while the changes in the lens and the internal membranes are more persistent and sometimes irreversible (P.I. Galeyev, 1957; Williams, Monahan, 1956, and many others).

A single radiation exposure at threshold thermal and subthermal microwave intensities (8-12 mW/cm^2) does not lead to the appearance of clinically definable changes, but repeated exposures to the same intensity may cause changes in the lens (S.F. Belova, 1960; A.P. Balutina, 1966; Carpenter et al., 1960; and others). Thus, the microwave field has cumulative properties with respect to the organ of sight.

With increasing frequency (shortening of the wavelength) at a given PFD, the superficial thermal effect becomes stronger and the deep effect weaker, with the result that the danger of injury

to the internal media and membranes of the eye is reduced (N.N. Bokhon, 1960). The very shortest (millimetric) radio waves in the microwave band, while they do not influence the internal media, have an extremely unfavorable effect on the capillary net- /148
work of the ocular mucosa, sharply increasing the permeability of the vessels (A.P. Balutina, 1966).

A pulsed microwave field has a stronger cataractogenic action than a continuous field at the same average power flux density. Clouding in the lens as a result of exposure to weak microwave intensities is characterized by the following features: it appears preferentially in areas where there are existing congenital clouding defects, and their development may be partially or even completely reversed (A.P. Balutina, 1966). Clouding defects that appear in the lens as a result of more intensive exposure interfere with vision (P.I. Gapeyev, 1957; Williams, Monahan, 1956, and others).

Histomorphological changes occur in the lens under exposure to low microwave-field intensities (5 mW/cm^2), intensities that produce no clinical signs of damage even on multiple repetition. Irradiation by a rotating antenna is no practical threat to eyesight at rather high radiated powers (above 100 mW/cm^2).

The question as to the pathogenesis of changes in the visual organ and, in particular, clouding of the lens, remains unclarified to this day. There is no doubt, however, that the original hypothesis that the damage was purely thermal in nature was far from complete. The authors of many papers point to the unfavorable influence of the microwave field on tissue metabolism and tissue respiration (P.I. Gapeyev, 1957; Carpenter et al., 1960; Merola, Kinoshita, 1961, and many others). Another hypothesis that has been advanced (Carpenter et al., 1960) is that the microwave field disturbs primarily the cell-differentiation process in the mesenchymal epithelium in the normal lens fibers.

The basic results of experimental study of the action of microwaves on the visual organ that have been cited above suggest a potential occupational-disease hazard and the possibility of eye damage in personnel exposed to microwave radiation. The popular, but not always rigorously scientific treatment given this information in general publications has led many radar and electronics-industry workers to associate a wide variety of eye diseases with exposure to the microwave field. This circumstance may give rise to certain difficulties in medical-occupational expertise and have a unfavorable psychological effect on persons working with microwave sources.

It must not be forgotten that under normal working conditions, the personnel are irradiated at levels representing tenths and hundredths of the level with which the various changes in the visual organ are produced in experiments. As of this writing, a /149 great deal of material has been accumulated from study of the visual organ in radar and electronics-industry workers (S.F. Belova, 1960; V.G. Shilyayev, 1960; B.L. Polyak, V.V. Volkov, V.G. Shilyayev, 1962; Zaret, 1960, and others). This material is already sufficient for development of a general picture of the changes actually encountered in these specialists.

It appears that severe damage to the eyes under exposure to microwave radiation occurs very seldom (if at all), and then only in breakdown situations. Analysis of the few available descriptions of cases of "microwave cataract" (S.V. Kudryavtseva and Yu.A. Osipov, 1954; P.I. Gapeyev, 1957; I.S. Shimkhovich and V.G. Shilyayev, 1959; Hirsch, Parker, 1952, and others) permits the conclusion that, as a rule, the development or detection of cataract coincided only accidentally in time with the exposure to microwave radiation and was actually due to other causes (uveitis, congenital clouding). On the basis of our present knowledge of the conditions under which experimental "microwave cataract" arises and of its diagnosis and treatment, it must be acknowledged that none of the cases described in the literature is fully verified, since the irradiation of the patients was not accompanied by painful sensation or even mild searing of the anterior segment of the eye.

The nonexistence or, more accurately, the extreme improbability of serious single-factor damage to the eye by the microwave field by no means suggests that it has no detrimental influence on the eyes of humans who work routinely under conditions of relatively weak microwave irradiation. In an examination of large groups of persons engaged in the adjustment and tuning of microwave generators and coming under exposure to comparatively high microwave PFD's, Zaret (1960) and A.P. Balutina (1966) found that minor lens clouding defects are encountered more frequently among these people than in control groups working under similar conditions but not coming into contact with the microwave generators. This difference in the incidence of lens clouding was found to be statistically significant. Clouding defects also appear to develop at the positions of existing microscopic congenital changes and, on reaching a certain magnitude, progress no further (when there is no change in occupational conditions).

However, S.F. Belova (1960) takes the view that some further enlargement of these clouding defects is possible in some of the cases. The appearance of clouding might possibly lead to accelerated aging of the lens and to the earlier development of senile cataract, although they do not by themselves lower visual acuity. Unfortunately, no differential-diagnostic criteria that would make it possible to distinguish these clouding defects from congenital ones are as yet known.

Prolonged occupational exposure to microwaves also has a /150
detrimental effect on the condition of the anterior segment of

the eye and may lead to the development of a unique form of chronic conjunctivitis. As in any other chronic conjunctivitis (a poly-etiological disorder), the subjective sensations again predominate over objectively discernible changes.

The complaints are diverse but not very characteristic in the conjunctivitis that appears under exposure to microwaves: dryness in the eyes, the sensation that a foreign body is present, heavy eyelids, eyestrain, etc. The unpleasant sensations become stronger during the latter half of the working day. Objectively, the conjunctiva is found to be slightly hyperemic and velvety. A characteristic feature of this conjunctivitis is the total absence of pathological secretum.

Another peculiarity of this occupational disorder, and one that simultaneously demonstrates the specificity of its origin, is the fact that it vanishes without a trace some time after contact with the microwave generators is terminated. During the actual course of the disease, there may be remissions and relapses that depend on the exposure to the microwave field during the course of the working day. The only reliable method of treating conjunctivitis due to microwave exposure is to exclude or minimize microwave irradiation of the eyes.

It must be stressed that the above clouding defects of the lens, like the phenomena of the chronic conjunctivitis without secretum, have been found almost exclusively among individuals who have occasionally, for one reason or another, been obliged to work under conditions in which the USSR's maximum microwave dose levels were exceeded by a substantial margin. Such disorders of the eye were not detected in many thousands of specialists who were examined by ophthalmologists. In these cases, the specialists examined were engaged in the operation of radars and the irradiation levels at their workstations were for the most part within the acceptable limits.

However, we may not omit mention of the fact that numerous ophthalmological complaints are submitted by radar specialists, sometimes involving eye disorders that the sufferers quite frequently attribute to unfavorable effects of the microwave field.

B.L. Polyak and V.V. Volkov (1956); N.F. Galanin, B.L. Polyak et al. (1956), V.G. Shilyayev (1960) and other authors have demonstrated both the error of this view and the true causes of the appearance of such complaints. It was found that the largest number of complaints, chiefly asthenopic in nature, comes from the operators, i.e., specialists who are irradiated less than the others. It was also found that these complaints and certain changes in the visual organ (for example, a tendency to spasm, /151
accomodation) were by no means caused by the microwave field, but were due to the severe eyestrain involved in work at the radarscope.

The best preventive measures in this case are careful occupational screening, mandatory correction of farsightedness and astigmatism, rational rotation of staff to permit work at different types of displays, improvement of work, rest, and nutrition patterns, etc. It is necessary to explain to radar workers the true origin of the unpleasant sensations in their eyes to avoid prejudice against the microwave field as the cause of these sensations and possible serious consequences for their eyesight.

Chapter 11

PROBLEMS OF THE ETIOLOGY AND PATHOGENESIS OF THE PATHOLOGICAL PROCESSES CAUSED BY MICROWAVE RADIATION

As is evident from the material given above, a variety of pathological processes may arise as a result of failure to observe safety rules in work with microwave electromagnetic generators: asthenovegetative syndrome, neurocirculatory dystonia with depressed or elevated arterial pressure, sexual weakness, burns, etc. Experiments have convincingly demonstrated the development, under exposure to microwave radiation, of functional disturbances to the CNS, endocrine glands, cardiovascular system, and gastrointestinal tract, changes in metabolism and enzymatic activity, morphological changes in the blood and various organs (cataract, atrophy of the gonads, etc.). It should be noted that certain investigators (Brown et al., 1954) hold that even high microwave powers cause no damage, although the possibility of the appearance of pathological changes has been demonstrated convincingly as a result of experimental studies and clinical observations.

The etiology and pathogenesis of the pathological processes arising under exposure to radio waves in the microwave band have not yet been adequately studied; at the same time, correct conceptions in this respect are important for the organization of rational prophylaxis and treatment of such patients.

ETIOLOGY

In discussing the etiology of the pathological processes caused by microwave electromagnetic radiation, it is necessary to consider not only the peculiarities of the etiological factor, /152 but also the significance of the concrete working conditions of the specialists and the role of the organism itself — its reactivity. In characterizing the role of microwaves, it must be recognized that their influence on the organism depends on a) wavelength (the frequency of the oscillations); b) the intensity of the radiated energy (PFD); c) the duration of exposure; and d) the type of modulation and the pattern of exposure (intermittent, continuous, from 1 or more generators).

As we know, a substantial fraction of the energy of microwaves (40-50%) is absorbed by the tissues of the organism, while the rest is reflected. Some of the absorbed energy is converted into heat in the tissues, as a result, in the view of some investigators, of vibrations of ions and dipolar water molecules in the tissues. The most efficient absorption of microwave energy is observed in tissues with high water contents (blood, muscle, gastric and intenstinal mucosa) and sparse vascularization (crystalline lens, testes, etc.).

In setting forth the mechanism by which microwaves act on the organism, it is important to recognize that the penetration depth of electromagnetic microwaves is a function of their wavelength. It is considered established that the depth of penetration of microwaves into the tissues of the organism is approximately 1/10 wave; as a result, millimetric waves penetrate only through the skin, while decimetric waves, e.g., 50-cm waves, may reach internal organs. This makes it understandable why decimetric waves have a stronger effect on the organism than millimetric waves.

Needless to say, the duration of the exposure is of significant importance for the consequences. When the generator operates periodically, the influence of the microwave energy on the organism is determined, other irradiation conditions the same, by the ratio of the exposure and intermission times.

Considerable importance attaches to the organism itself, to its reactivity as related to past illnesses and constitutional factors. In N.V. Tyagin's experiments (1957), animals with previously weakened cardiac activity fared more poorly than healthy ones under exposure to microwaves. The sensitivity of the animal organism to microwaves is related to the size of the animal. Thus, under irradiation at λ = 10-12 cm and PFD = 100 mW/cm^2, white mice perish within 5-10 minutes, rabbits and cats within 20-40 minutes; dogs survive radiation exposure for as long as six hours.

We have noted that the changes become less pronounced when the intermissions are lengthened in periodic exposure of the organism to the microwave field. Thus, Deichmann's rat experiments (1961) showed that the animals perished after 15 minutes of intermittent irradiation (60-second exposures separated by 60-second /153 intermissions for a 1:1 ratio), while all of them survived under irradiation at the same level but with 15-second exposures alternating with 60-second intermissions (ratio 1:4).

Simultaneously with the microwaves, the human organism may also be acted upon by other factors (soft x-rays, noise, high temperature, noxious gases — CO and others). It is also important to take account of climatic factors in establishing the influence of microwaves on the human organism.

As we have noted, establishment of the importance of factors acting on the organism simultaneously with the microwaves is important for the elaboration of preventive measures on the one hand and, on the other, proper understanding of the etiology of microwave injury. However, the combined action of microwaves and other environmental factors has not yet been adequately studied.

Although references to combined microwave-field effects are encountered in the literature, the etiological roles of the microwaves and the other factors often remain unclear.

It is important to stress that in studying the etiology of microwave damage, it is necessary to evaluate properly the importance of factors acting on the organism simultaneously with the microwaves in the development of the disorders. Factors operating simultaneously with the microwaves also have an important role in pathogenesis, since they may lower the resistance of the organism and create conditions under which even a microwave field not exceeding the permissible dosage level may cause pathological changes. Conversely, certain conditions that increase the resistance of the organism prevent the appearance of pathological changes under microwave exposure; an example is regular muscular exercise.

As we know, only that factor which determines the basic pathological changes characteristic for it is recognized as the cause of an illness. All other factors acting on the organism simultaneously with the cause are conditions whose role in the development of the sickness is not decisive.

If a physician arrives at microwave injury as a diagnosis, he has thereby recognized microwave irradiation as the basic cause of the injury. On familiarization with the literature, however, the impression is gained that medical specialists do not always take account of the basic pathological and etiological premises enumerated above. From this viewpoint, the concept of "combined microwave injury" would hardly be correct without an evaluation of the role of individual factors and without establishment of the cause and conditions of the specific complaint, and this, in /154 turn, as we noted above, is necessary for proper organization of preventive measures and therapy.

We know that x-rays increase the organism's sensitivity to thermal microwave intensities, but the importance of this factor in nonthermal-intensity microwave irradiation of the organism requires further study. It has been established that microwave-generator workers complain more frequently of deteriorating health under the conditions of a hot climate than personnel operating the same generators under temperate-climate conditions.

There is reason to assume that when low-intensity microwaves combine with various degrees of ambient-temperature elevation, the two factors may "take turns" in dominating the development of pathological changes. A similar phenomenon has also been observed under the combined action of microwaves and a thin atmosphere (I.R. Petrov, N.Ya. Yarokhno, 1967). Indeed, the inhibition of certain important adaptive reactions, e.g., inhibition of hematopoiesis instead of the intensification that is characteristic under rarefied-atmosphere conditions, was observed as a combined effect of microwaves (PFD's of 10 mW/cm^2 or 1 mW/cm^2) and breathing of a gaseous mixture with 11.2% oxygen (which corresponds to an altitude of 5000 meters).

The most pronounced inhibition of this adaptive reaction was observed when microwaves (λ = 12.6 cm, PFD 30 mW/cm^2) were combined with breathing of a gaseous mixture containing 8.5% oxygen. In the examples given here, therefore, the microwaves were recognized as the prime factor in the development of the changes under combined subjection to microwaves and a rarefied atmosphere.

In contrast, no suppression of the adaptive responses to oxygen insufficiency was observed when microwave exposure (PFD = = 10 mW/cm^2) was combined with a substantial reduction of the oxygen content in the inspired air (to 8.5%). Under microwave exposure combined with breathing of an 11.2% oxygen mixture, rabbits that had breathed this mixture one hour per day for 20 days and were adapted to this low oxygen content also showed no inhibition of bone-marrow blood production.

Thus, in these combinations of microwaves and oxygen deficiency, the latter factor (the lowered oxygen content in the inspired air) exerted the dominant influence on the organism.

Almost no study has been given to the problem of the role of the organism itself in the development of pathological changes under exposure to microwave radiation, although we know that the /155 reactivity of the organism is recognized as important in pathology. It is also known that the organism's reactivity is determined primarily by the functional state of its central nervous system and endocrine glands. Under the influence of various pathogenic factors, as we have noted, changes are observed in central nervous system functions and in the functions of some of the endocrine glands, which regulate the organism's capacities for adaptation to changes in environmental factors. Hence the functional state of these systems may be of great importance in the development of pathological disorders under the influence of microwaves.

In fact, animals that react to other extraordinary stimuli by CNS excitation have also been found more sensitive to microwaves than animals in which the inhibitory process predominated in the CNS under subjection to strong stimuli (I.R. Petrov and V.A. Pukhov, 1966). The resistance of white rats to microwaves increased sharply on artificially induced CNS inhibition, as by administration of soporofic doses of a narcotic.

Adrenectomized white rats were found to be more sensitive to microwaves. In experiments conducted 1-2 weeks after adrenal autotransplantation, white rats also fared worse under microwave irradiation than intact animals.

The higher microwave sensitivity of white rats two weeks after adrenal autotransplantation can be explained as due for the most part to insufficient glucocorticoid activity of the adrenal cortex.

The experimental results of A.G. Subbota (1966) showed that castrated dogs are also more sensitive to microwave irradiation and that microwave sensitivity should probably increase in hyperthyroidism, which is accompanied by manifest excitation of the central nervous system. It is also known that the gonads are highly sensitive to microwaves, and that degenerative changes are quick to appear in the epithelium of the seminiferous tubules with the associated weakening of the sex function. The sick are often more sensitive to microwave irradiation.

The aftereffects of microwave exposure depend on the localization of the irradiated region of the body. Thus, Deichmann (1961) showed that at a given intensity (300 mW/cm^2), irradiation of the abdonimal region produced more severe changes than irradiation of the head. In these experiments, the animals perished within 12 minutes after irradiation of the abdomen, but 18 minutes after irradiation of the head.

Z.P. Svetlova (1963) reported more pronounced conditioned-reflex changes in dogs after irradiation of the torso as compared with irradiation of the head alone. In the opinion of N.S. Bychkov (1962), however, isolated irradiation of the head of an animal causes more severe changes than irradiation of the torso. Weaker changes following irradiation of the head would be understandable if the shielding properties of the bones are considered. When the abdominal region is irradiated, death may occur as a result of shock of the type seen in burns (Hines, Randall, 1952). It has also been established that irradiation of the abdomen in rabbits (I.V. Pitenin, A.G. Subbota, 1965) leads to the development of gastric ulcer. /156

When animals are irradiated, their weights are quite important. Under a given set of irradiation conditions, e.g., at thermal intensities, small animals perished much earlier than large ones.

Thus, while acknowledging that the microwave radiation is the cause of pathological changes in personnel working with microwave generators, it is necessary to establish the role of contributory factors acting on the organism simultaneously with the microwaves, namely, noise, soft x-rays, microclimate factors, etc. Along with the above factors, peculiarities of climate (high and low temperatures, etc.) and the reactivity of the worker's organism may be highly important.

The various conditions may act in different ways: some of them may tend to produce the sickness by lowering the resistance of the human organism, while others may help improve it.

PATHOGENESIS

Most investigators now recognize the possibility that microwave radiation may be harmful to the human organism when safety rules are violated, but no definite sickness specific for the action of this factor has as yet been identified. Under the influence of microwaves, a variety of functional changes take place and various complaints characteristic of the asthenic nervous system and complicated by vegetative disturbances are submitted. In arriving at the pathogenesis of the pathological process, it is of prime importance to start from correct notions as to the mechanism by which the etiological factor acts on the organism.

It is known that some etiological factors cause such sharp changes that the entire course of the disease is determined by them. In such cases, it is sufficient to ascertain the action mechanism of the etiological factor in order to understand the pathogenesis of the process, and we may speak of etiopathogenesis of the pathological process. In the case of etiological factors /157
that do not have such a striking effect, importance attaches not only to the initial changes that arise under the influence of the etiological factor, but also to subsequent changes, and the process develops with features of a chain reaction. When the organism is acted upon by such etiological factors, secondary factors may be of great importance; we refer here to the conditions under which this etiological factor acts on the organism, and to the reactivity of the organism, which depends on constitutional peculiarities, past illnesses, etc.

To this day, however, little study has been given to the mechanism by which microwaves act on the organism of animals and man. As we have noted, a distinction is drawn between two types of microwave effect: the thermal effect observed at PFD's above 10 mW/cm^2 and a nonthermal effect under exposure to PFD's below 10 mW/cm^2; thus, this etiological factor acts through a complex mechanism. It should be noted that the concepts of thermal and nonthermal effects are highly conditional; a combined effect invariably prevails. A rise in body temperature is characteristic for the first type of microwave effect, and it is this overheating which is linked with the effects of high microwave intensities on the organism of man and animals.

Under exposure to microwaves at high PFD's that are accompanied by the development of acute hyperthermia (t = 42-43-44°C) and are lethal to the organism, the effect of the elevated temperature on organs and tissues is of decisive importance in the development of the changes. In this case, the effect of the microwave electromagnetic energy on the organism is mediated by the influence of the thermal energy formed in the human or animal organism. In such cases, of course, there is also the so-called specific effect of the microwaves. However, it is not decisive, since the increased body temperature is the prime factor in the rapid intervention of death.

When the organism is acted upon by high microwave intensities that cause a substantial rise in body temperature, the changes are the same as those observed on overheating of the organism and during any fever (Kalant, 1959). It is important to stress that when the organism is acted upon by high microwave intensities, the factors acting simultaneously with the microwaves are sometimes less important than they are at nonthermal intensities. Under the influence of a sharp rise in body temperature on local microwave irradiation, tissue necroses occur as a consequence of thermal coagulation of the tissues and are explained solely in terms of the high-temperature effect.

The functional and morphological changes that arise under /158 exposure to microwave radiation and lead to acute hyperthermia are essentially no different from the changes that occur at high ambient temperatures; they are of two types, namely, adaptive reactions and pathological changes, as has already been pointed out (I.R. Petrov, A.G. Subbota, 1964). The former include dyspnea, tachycardia, increased circulation velocity, increased sweating, hyperthermia of the skin and other tissues. These reactions prevent the rapid development of acute hyperthermia when the heat is not released too rapidly in the organism and is formed in amounts small enough so that much of it can be rejected by the organism through increased heat exchange.

It is important to note one peculiarity of the microwave effect. While these adaptive reactions come into play quickly under the action of high ambient temperature owing to stimulation of thermoreceptors in the skin, they are triggered later in response to microwaves, which penetrate deep into the tissues (e.g., decimetric waves), i.e., after the skin temperature has been raised.

In the opinion of Hubelbank (1960), the danger to the organism from exposure to high microwave powers consists in the fact that body temperature may rise abruptly before the brain receives the "alarm signal," since the electromagnetic energy penetrates deep into the tissues, where there are fewer receptors than there are in the skin. This statement is especially applicable to experiments in which small animals are exposed to microwaves.

According to Richardson et al. (1950), such an adaptive reaction as a substantial increase in blood flow in the femoral artery in experiments in which the rear extremities of animals were irradiated were noted when the temperature of the thigh tissues had risen to 42° and above at a depth of 1 cm. We can therefore understand why high-intensity exposure to microwaves that penetrate comparatively deep into the organism's tissues may result in a rapid rise in body temperature and, in experiments on small animals, in their death. Thus, white mice exposed to centimetric microwaves survive for 45 minutes at a PFD of 45 mW/cm^2, 30.2 ± 1.5 minutes at 68.5 mW/cm^2, 24.0 ± 2.1 minutes at 72.6 mW/cm^2, and 6.5 ± 0.7 minutes at 122 mW/cm^2, since their adaptive reactions appear relatively late and are insufficient under these irradiation conditions. As we have already noted, the survival times of animals of different sizes under microwave irradiation (PFD 100 mW/cm^2) also differ, namely: 4-10 minutes for white mice, 10-20 minutes for white rats, and 45-60 minutes for rabbits, while dogs survive these experimental conditions. /159

It is known that no manifest changes are observed in man and animals in response to a slight body-temperature rise (+1°C) in a fever or under the influence of elevated ambient temperature, while functional shifts are noted at the same small elevation of body temperature under the influence of electromagnetic microwaves. These changes cannot be explained solely in terms of the temperature factor; they are also a consequence of the nonthermal, specific influence of the microwaves. Thus, microwave exposure at λ = 12.6 cm and a PFD of 50 mW/cm^2 was accompanied by more pronounced changes in arterial pressure than exposure to infrared rays that caused the same body-temperature rise (by +2-3°C) (A.G. Subbota, 1966).

In the context of our discussion of the complex problem of the basic pathogenetic mechanisms in the development of pathological processes under exposure to microwave energy, it is necessary to dwell briefly on certain previously cited data on the influence of microwaves on proteins, glycogen, and single-celled organisms; this is important for consideration of the possibility of pathological changes occurring under the influence of direct exposure of human cells and tissues to microwaves.

It goes without saying that in examining such literature data, it is necessary to remember the incomparably more complex pathogenetic mechanisms of the pathological processes in the intact animal organism and the intact human organism in particular.

It has been established that microbes are sensitive to microwave exposure and perish at intensities at which the temperature settles at a level of 37-39°, i.e., the optimum level for their growth (Schliephake, 1960; Boiteau, 1960); this indicates a specific (nonthermal) microwave action. Stimulation of cell growth in tissue cultures has been observed under the action of microwaves (λ = 21 cm) when the medium was at a temperature that in itself does not accelerate the growth of cells in tissue cultures.

Heller's studies (1963) showed that at a certain electric-field frequency that does not raise the temperature of the medium, the direction in which paramecia move when they are placed between two flat electrodes may be influenced: at frequencies below 25 MHz, the paramecia move along the lines of force, but when the frequency is increased they turn through 90° and move across lines of force.

The results of these observations, like the appearance of chromosome aberrations when plants are irradiated and the mutagenic effect of a pulsed electric field that does not raise temperature (Heller, Mickey, 1961) led to the conclusion that there is a nonthermal, specific action of microwaves. As noted, changes in embryogenesis appear as a nonthermal effect of microwave exposure; embryonal cells that are in the stage of differentiation are found to be more sensitive. It is important to remember this in explaining the pathogenesis of cataract, gastric ulcer, and changes in sex-gland function. /160

Biophysical data are naturally of great importance in explaining the influence of microwaves on the organism; this applies in particular to their interaction with individual molecules and constituent ions of these molecules (Schwan, Piersol, 1954; Schliephake, 1962). According to the suggestions of these authors, absorption of electromagnetic energy by the tissues first intensifies the vibrations of ions. The ions transfer some of their energy to atoms, which are also set in motion, with the result that the microwave-field energy is converted to thermal energy, with an accompanying rise in body temperature. According to the Debye theory (1932), absorption of microwave energy results in vibration of dipolar water molecules present in the tissues. These processes lead to a temperature increase.

An attempt has been made to explain the action of microwaves on the cells by considering DNA as a kind of signal generator and RNA as an amplifier; the enzymes and proteins are effectors. Pulse-modulated signals at various frequencies from the DNA pass to the RNA and thence to the effectors (enzymes and proteins). The cell membranes are regarded as noise filters. When the organism is microwave-irradiated, the energy overcomes the capacitive reactance of the cell membranes and may interfere with the intracellular signals, thereby disturbing transmission of information from DNA to RNA and the effectors.

Some idea of the complexity of the direct effect of microwaves on tissues can be gained from the results of a study of the influence of microwaves on a solution of glycogen and gamma-globulin. The experimental results of Van Everdinger (1946) showed that microwaves (λ = 10 cm, 300 MHz) change the optical and colloid properties of glycogen solutions, producing a flocculent precipitate.

From a study of electrophoregrams of a gamma-globulin solution that he irradiated in vitro, Bach (1965) concluded that the electric field causes the protein spiral to unwind (molecular changes).

In attempting to explain the mechanism of the microwave effect, certain authors have proceeded from a detection hypothesis and ascribed detector properties to various nervous-system formations (Kaczynski et al., 1965), regarding certain nerve-cell struc- /161
tures as microscopic radio sets — detectors that respond to induced currents. Frey (1961) confirmed that a pulse-modulated microwave field is sensed by the human auditory analyzer as a hum or buzz, depending on the frequency and repetition rate of the pulses and their duration. The sound stops when the head is shielded.

As proof of the specific microwave effect, we might cite the results of studies in which it was found that atrophy of the seminiferous tubules occurs under microwave exposure at a temperature of 35°C, although similar changes arose under exposure to infrared light only when the temperature had risen to 40°C.

Paff et al. (1963) came to the conclusion that the lengthening of the St interval and distinct inversion of the T wave of an embryonic heart under microwave exposure with a mild thermal effect were due to metabolic changes caused by the nonthermal effect. Thus, the results of experiments on microbes, protozoa, and other objects indicate convincingly a direct action of nonthermal microwave intensities on these entities.

As we have already noted, there is sufficient basis for recognizing a direct action of microwaves of high thermal intensity on human tissue as well; here the microwave effect is mediated by high temperature. Needless to say, the factual data given above must be taken into account in explaining the influence of microwaves on human tissues. However, the mechanism by which intensities that do not cause a general body-temperature rise act on the human and animal organism is more complex.

This is demonstrated convincingly by the results of comparative experiments (A.I. Ivanov, B.A. Chukhlovin, 1966) performed to study the phagocytic activity of cat blood neutrophils after irradiation of the blood in vitro with nonthermal-intensity microwaves and that of neutrophils taken from an irradiated cat. The phagocytic activity of the blood neutrophils irradiated in vitro showed practically no change. In contrast, the phagocytic activity of blood from the cat, which had been irradiated at about the same intensity as was used in the in vitro experiments, was subject to change, showing an increase or slight decrease, depending on the experimental conditions. These changes cannot be explained by the direct action of microwaves on the blood cells. They occur in the intact organism under the influence of another, probably neurohumoral, mechanism.

In examining the diverse experimental materials characterizing the biological activity of electromagnetic fields (EMF), A.S. /162
Presman (1968) concluded quite correctly that attempts to find

the cause of the biological activity of EMF at the molecular level alone would be fruitless. This reflects most realistically the results of research on the effect of external EMF's on biological objects. It was established that the intact organism is most sensitive to the EMF, isolated organs and cells less sensitive, and molecules still less sensitive. Substantial differences in the response to the EMF are observed in the same biological system (molecular, cellular, organic or systemic) depending on the conditions under which it is applied – with the system in the intact organism or isolated. In such cases, differences are noted in the manner in which the system reaction depends on the EMF parameters. As we pointed out above, these considerations pertain equally to the mechanism by which microwaves act on the human and animal organisms.

Two types of changes occur when the organism of a man or animal is acted upon by microwaves: adaptive reactions (Diagram 1) and pathological changes (Diagram 2). It must be stressed that the pathological changes and adaptive reactions observed under exposure to microwave irradiation in the intact organism are more diverse as compared to the single-cell case, and that the mechanisms by which they arise in man and highly organized organisms are highly complex and accessible only through study of the influence of microwaves on them.

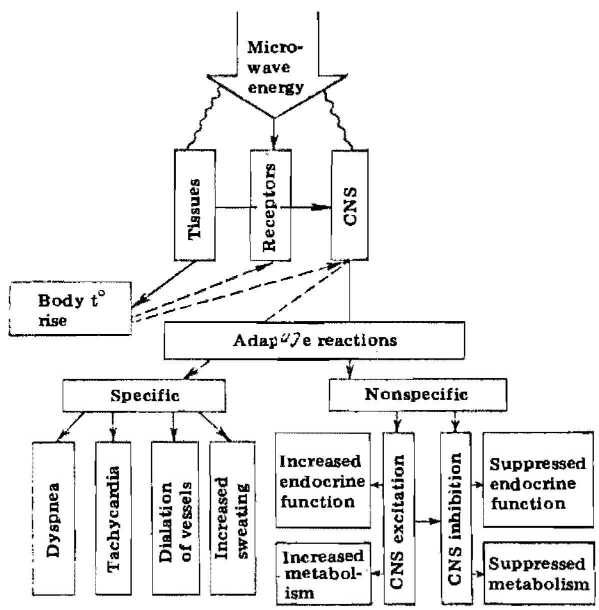

Diagram 1. Adaptive Reactions Arising when the Organism is Exposed to Microwave Electromagnetic Energy.

An important property of the human organism and of highly organized animals is that they have quite sophisticated and diversified adaptive reactions that have made their appearance during the evolutionary process.

As noted earlier, there is a distinct adaptation of the animal organism even to rather high thermal microwave intensities when the exposures are repeated. The organism's adaptive reactions are developed by the mechanisms of physiological regulation of functions. Although the basis for the adaptive reactions is a reflex mechanism, this does not, of course, exclude humoral mechanisms of adaptation. The reflex mechanism of development of such an adaptive reaction as arterial hyperemia on local

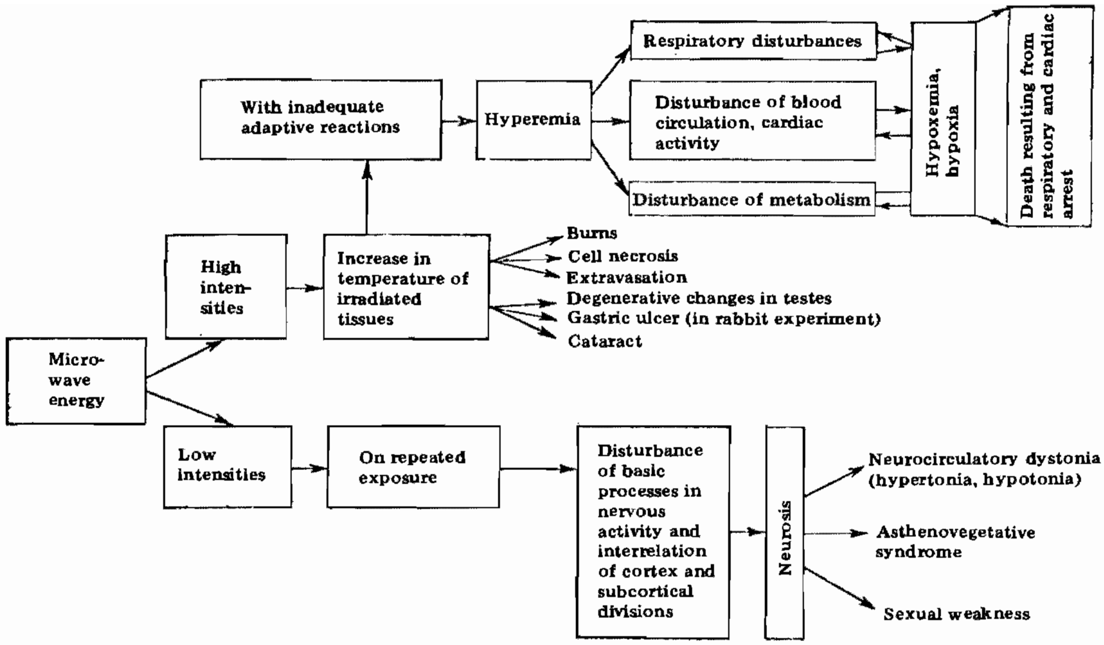

Diagram 2. Pathological Changes Arising Under the Influence of Microwave Radiation.

exposure to thermal intensities can be regarded as definitely proven. The influence of elevated temperature on temperature receptors emerges as the basic factor in such cases.

Under the influence of elevated body temperature, such adaptive reactions as dyspnea, dilation of blood vessels, tachycardia, /163 and increased perspiration (see Diagram 1) also arise by reflex. The reflex dilation of blood vessels has been demonstrated quite convincingly by A.I. Semenov (1965), I.M. Mishina (1965), and others who observed dilation of vessels in an animal's right paw after irradiation of the left paw, but found it to be absent in the paw opposite a denervated extremity. However, when the denervated extremity of a rabbit was irradiated repeatedly, a certain decrease in the tissue-temperature rise was noted in it (A.I. Semenov, 1965), something that may be explained by stimulation of tissue adaptive reactions.

In a study of the activity of oxidative enzymes (succindehydrase and cytochrome oxidase) under exposure to centimetric microwaves accompanied by a slight increase in tissue temperature (0.7-1.2°), A.I. Moskalyuk (1957) and V.A. Syngayevskaya (1964) detected a slight decrease, while irradiation that did not produce a temperature rise increased the activity of these enzymes.

Exposure of animals to high microwave intensities (λ = 3 cm, PFD = 150-170 mW/cm^2) caused a sharp decrease in oxidative-enzyme /165 activity. It is probable that the tissue adaptive reactions under exposure to microwaves are also related to a change in oxidative-enzyme activity. When body temperature rises, the products of the abnormal metabolism may also act on the receptor apparatus (on interoceptors in particular) and adaptive reactions – inhibition of metabolism and heat production – may arise; however, this question requires study.

Adaptive reactions are also observed on irradiation in a microwave field of nonthermal intensity; in these cases, the low irradiation intensities often cause only stimulation of the adaptive reactions. Under the action of various stimuli, general nonspecific adaptive reactions are observed. These include excitation of the CNS, enhancement of anterior pituitary and adrenal-cortex function, and increased metabolic rate (I.R. Petrov, 1960).

General nonspecific adaptive reactions are also observed under exposure to microwaves (see Diagram 1). Central nervous system excitation should be counted among the earliest and most general nonspecific adaptive reactions. In fact, enhancement of food conditioned reflexes was observed in dogs after the first few irradiations, but then the reflexes remained practically unchanged as the exposures were repeated. An increase in the precision of movements was observed in humans exposed to microwaves at a PFD of 1 mW/cm^2 (M.A. Pivovarov, 1962, 1963).

Enhancement of the anterior pituitary and adrenal cortex functions is associated with central nervous system excitation; as we know, this is now recognized as an adaptive reaction. Many investigators have observed this reaction under exposure to microwaves. In humans irradiated at low intensities, the anterior pituitary and adrenal cortex functions were enhanced and, as we have reported, the content of 17-ketosteroids in the urine increased, while potassium decreased and sodium increased in the blood.

Low-intensity microwaves also stimulate metabolism, since CNS and endocrine-gland functions, the activities of certain enzyme systems, and redox processes in a number of organs and tissues are enhanced. Increased oxygen demand has been noted under low-intensity irradiation in humans; it was also noted in animal experiments and was an adaptive reaction.

Enhancement of CNS function results in such adaptive reactions as stimulation of antibody production and an increase in the bactericidal properties of the blood. Increased phagocytic activity was also noted for leucocytes and cells of the reticulo- /166
endothelial system.

In experiments in which a suspension of paramecia was irradiated with decimetric waves, their phagocytic activity increased. It might be hazarded that these adaptive reactions occur both as a result of enhancement of CNS functions and also apparently as a direct effect of microwaves on reticuloendothelial cells and leucocytes.

Various factual data confirm the occurrence of adaptive reactions (see Diagram 1) under microwave exposure: 1) the decrease in the temperature rise on subsequent exposures; 2) the less pronounced temperature rise in the unirradiated paw of a rabbit after a series of exposures of the other paw as compared with the temperature rise in response to the first irradiation of the repeatedly irradiated paw; 3) the appearance of dyspnea and tachycardia, which help lower body temperature under exposure to thermal-intensity microwaves; 4) the smoothing of conditioned-reflex changes under repeated exposures; 5) augmented functioning of the pituitary-adrenal system; 6) smoothing of changes in the secretory-motor function of the stomach and intestine under repeated irradiations, etc.

Thus, the organism's adaptive reactions under exposure to high and low microwave intensities arise by the physiological mechanisms of neurohumoral regulation of organ and system functions.

At the same time, it should be noted that the mechanism by which the receptor apparatus is directly stimulated by microwaves is more complex and as yet little studied. It can be regarded as established by the results of Z.P. Svetlova (1962) and others that excitation of the CNS under exposure at nonthermal intensities occurs as a result of stimulation of the receptor apparatus at the point of irradiation [and] a flow of afferent pulses to the CNS. The author's experiments indicated enhancement of salivary conditioned reflexes when the head of a dog was shielded and only its torso was irradiated.

M.S. Bychkov (1962) also regards the reflex mechanism of functional changes under exposure to the microwave field as a demonstrated fact that has been brought out clearly in experiments in which one extremity was irradiated. Novocaine blocking of the tissues of the extremity prevented neurodynamic shifts when it was irradiated. In addition to the influence of microwaves on the receptor apparatus, their direct action on the CNS is also recognized.

Stimulation of other general adaptive reactions is also associated with CNS excitation: enhancement of endocrine functions, especially in the case of the anterior pituitary and adrenal cor- /167
tex, and stepped-up metabolism. The latter also occurs when the functions of other endocrine glands are enhanced. Note should be taken of the hypothesis that microwaves have a direct action on the cells of the brain if the head is in the microwave field during irradiation.

In view of the importance of the CNS in supporting the organism's adaptive reactions under exposure to microwaves, note should be taken of the high sensitivity of the CNS to microwaves and of the dependence of various functional changes on the functional state of the CNS. The latter is of great importance for the development of pathological changes that arise under microwave exposure.

As we have noted, animals with the weak type of nervous activity (with internal-inhibition inadequacy) are more sensitive to microwave exposure than animals with nervous activity of the strong type. It has also been shown in special experiments (I.R. Petrov and V.A. Pukhov, 1966) that after injection of caffeine, white rats with the strong nervous-activity type (with an inhibitory response to acoustic stimuli) were found to be just as sensitive to microwaves as animals with weakened internal-inhibition processes.

Experimental results have shown that the resistance of white rats with internal-inhibition insufficiency (with a strong excitation reaction to acoustic stimuli) can be increased by using a soporofic dose of a narcotic, i.e., by inhibiting the CNS. Thus, by varying the functional state of the CNS, it is possible to control the reactivity of white rats to microwaves.

The mechanism of the pathological changes is complex and still inadequately explored. However, certain considerations can be advanced as to the mechanism by which the pathological changes develop on the basis of available literature data.

A number of pathological changes arise under the direct action of microwaves at high PFD's (see Diagram 2). Necrotic changes in the tissues may be included among them. Admittedly, elevated temperature is the decisive factor in the development of these changes, i.e., the microwave effect is mediated by the effects of high temperature.

In the development of cataract (see Diagram 2), great importance attaches to the structural peculiarities of the lens, which, lacking a vascular network, may be heated rapidly under exposure to microwaves. However, the development of cataract does not appear to be determined solely by the temperature factor, since even after exposure to high intensities that cause a temperature increase (to above 48°C) in the lens, cataract does not appear immediately after the radiation exposure, but 1-6 days later (P.I. /168
Gapeyev, 1957; Carpenter et al., 1960).

The same authors and Merola and Kinoshita (1961) observed cataract after repeated exposure to low microwave intensities. Thus, metabolic changes in the lens occurring prior to the appearance of the cataract and manifested in lowered contents of ascorbic acid and glutathione are essential to the development of the cataract.

Certain authors (Daily et al., 1950) have reported lowered activity of the enzymes adenosine triphosphatase and pyrophosphatase. Finally, the high microwave sensitivity of differentiating cells (Van Ummersen, 1961) from which the lens fibers are formed is another major factor in the mechanism of cataract development. It appears that the above-noted metabolic disturbances that are the root cause of the cataract take place in these cells. Other mechanisms of cataract development are also possible in addition to the influence of high temperature and tissue-metabolism disturbances.

It was established by I.V. Pitenin and A.G. Subbota (1965) that the direct action of microwaves is also important in the development of gastric ulcer in rabbits after exposure of the abdominal region to thermal intensities. The thermal factor is, of course, important in the development of gastric ulcer (see Diagram 2). The gastric mucosa is more strongly heated than other tissues of the abdominal wall (skin, subcutaneous fatty layer, muscles), because it has many folds and crypts filled with gastric juice and mucus where most of the energy of the electromagnetic waves is absorbed and cooling of the mucosa is difficult.

Nevertheless, it is impossible to explain the development of gastric ulcer solely in terms of the temperature factor. In fact, it was shown in experiments performed by I.V. Pitenin and A.G. Subbota (1965) that although gastric ulcers form when the temperature in the mucosa is raised to 42° by microwave irradiation, they appear only at temperatures above 60°C in experiments with contact heating of hot water run into a balloon introduced into the stomach. It is also important to note that gastric ulcers appear not immediately after irradiation, but some time later. These factual materials negate McLaughlin's assumption (1957) that the ulcers can be explained solely in terms of the thermal microwave-field effect.

Along with damage to the mucosa due to the thermal action of the microwaves, the development of gastric ulcer also involves lowered stability of the mucosal cells to the digestive action of gastric juice and various disturbances to blood circulation /169
in the mucosa (stagnation effects), as well as disturbances to tissue metabolism, which are particularly likely to arise in rapidly multiplying cells.

The possibility that a pathological reflex may arise under these conditions as a result of strong stimulation of interoceptors cannot be excluded. This may be accompanied by a disturbance to the secretory and motor functions of the stomach, tissue metabolism, and circulation, with subsequent development of gastric ulcer. Disturbances to nerve trophics may also be a factor in this process.

Atrophy of the seminiferous tubules also occurs as a result of the direct action of microwaves, even with very small temperature elevations or with none at all. It has in fact been established that microwaves cause degenerative changes in the epithelium of the testes in animals when the temperature is raised to 30-35°C. At the same time, similar changes are observed under the action of infrared rays only when the temperature rises to 40°C (Imig, Tomson, 1948). Consequently, the pathological changes in the testes arise chiefly under the influence of the nonthermal, specific action of the microwaves (see Diagram 2).

Morphological examination of the testes shows necrobiotic changes in the spermatogenic epithelium; ovaries have been found to be less sensitive than testes, but various advanced necrobiotic processes have also been detected in them, both in the follicular epithelium and in the egg cells. Studies of the nucleic acids (DNA and RNA) in the tubules of the testes indicated full correlation between the degree of nucleic-acid depletion and the degree of the necrobiotic changes in the cells (I.V. Toroptsev, 1968). It may be that the disturbances of gonad function that arise under the influence of microwaves is related to a change in enzyme activity. In fact, after irradiating the testes of white rats with microwaves in the 3000-MHz band, Ciecura and Mineck (1964) noted lowered activity of a number of enzymes: alkaline phosphatase, acid phosphatase, adenosine triphosphatase, and 5-nucleotidase in the germ cells that form spermatozoa.

As we noted above, the CNS is highly sensitive to microwave energy. Changes in cerebral-cortex function occur both under the influence of a flow of afferent pulses from receptors in the irradiated zone and as a result of direct action of the microwaves on brain tissue.

Experiments have convincingly demonstrated the emergence of neurotic states under repeated radiation exposure (see Diagram 2). The neurosis is characterized by the appearance of inhibition in /170
the cerebral cortex, weakening of conditioned reflexes, phase changes in the reflexes, and disturbance of the interrelationships between the cortex and subcortical divisions; excitation centers (dominants) may appears in the CNS subcortical divisions. Naturally, an excitation center will be supported and strengthened by afferent pulses from the receptor apparatus of the irradiated region, e.g., from the region of the stomach, with the result that the secretory changes and circulatory disturbances that occur will be sustained, a factor of importance in the appearance of gastric ulcer.

Quite possibly, a number of vegetative disorders and the development of syndromes such as the asthenovegetative syndrome with phenomena of hypotonia or hypertonia under the action of the microwave field are to be explained by such disturbances in the interrelationships between the cortex and subcortical divisions.

Thus, the importance of the direct microwave action on tissues and organs in the development of certain pathological changes, namely cataract, necrosis, gastric ulcer, and atrophy of the testes, can now be regarded as established (see Diagram 2). However, the mechanism of the direct microwave effect on organs and tissues has not yet been adequately studied.

It is known that much of the energy of the microwaves is converted into thermal energy. The excess heat then becomes one of the factors stimulating adaptive reactions and causing damage in the tissues (necrosis, etc.). At the same time, the microwave field may exert a direct influence on the receptor apparatus and nerve centers. Thus, a pathological reflex that may result in disturbance of nerve trophics, blood circulation, and the secretory and motor functions of the stomach may be of great improtance in the development and maintenance of local changes.

Thus, repeated exposures to microwaves that do not raise temperature may give rise to neurosis and the associated disturbance of the interrelationships between the cerebral cortex and the subcortical divisions, as indicated by the phased development of conditioned reflexes. This pathogenetic mechanism is a major factor in the development of the various pathological changes (neurocirculatory dystonia, hypotonia, hypertonia). Oxygen insufficiency, which may arise as a result of circulatory disturbances and changes in the activities of certain enzyme systems, is probably an important factor in the development of the various changes.

The possibility of oxygen insufficiency is confirmed by the results of our own studies, which indicated a substantial increase in the resistance of the animal organism to microwave radiation under the influence of antihypoxic drugs (gutimine [guanylthio- /171
urea], sodium hydroxybutyrate). At the same time, the question as to the role of oxygen insufficiency requires further study.

On the basis of presently available data, therefore, local and general pathological changes under exposure to microwaves may arise as a result of: a) the thermal effect; b) the specific effect; c) a combination of the two.

The pathogenetic mechanisms of the pathological changes that occur when the organism is subjected to microwave exposure are: a) the direct action on the tissues; b) primary development of CNS functional changes, especially neurosis and the associated disturbance of neurohumoral regulation; c) reflex changes in neurohumoral regulation.

It is important to stress that the pathological changes frequently arise as a result of a combination of the basic pathogenetic mechanisms enumerated above. Metabolic and enzyme-activity disturbances resulting both from the disturbances to neurohumoral regulation and the direct action of the microwaves are probably also important in the development of the pathological changes.

Chapter 12

THERAPEUTIC USES OF MICROWAVES

Establishment of the influence of the microwave field on the living organism and study of its biological action have formed a basis for the use of microwaves as a therapeutic factor (L.A. Skurikhina, 1961; A.N. Obrosov et al., 1963). Microwave therapy has come into increasingly widespread use in our country during recent years. The irradiation intensities usually used are comparatively high, producing manifest changes in temperature in organs and tissues (N.M. Liventsev, 1964).

A distinctive feature of the method is the substantially higher frequency of the electromagnetic waves as compared with the frequencies used for diathermy, d'Arsonvalism, shortwave, and ultrashortwave therapy; this is responsible for certain differences in its effect on the organism as compared with the other electrotherapeutic methods (L.A. Skurikhina, 1961; R.I. Mikhaylova, 1966; Schwan, Piersol, 1954, and others).

The successful introduction of microwave therapy into medical practice has been due to the penetration of the energy of the microwave field through the skin and subcutaneous cellular tissue without significant losses and its absorption by deep tissues (muscles, etc.), which gives the method high therapeutic effectiveness and makes it possible to treat circumscribed areas of the /172
body (especially in contact irradiation), as well as to the relative simplicity of the equipment. That there is great interest in the physiotherapeutic use of microwave energy is confirmed by Soviet and foreign researchers and by the development of special apparatus for implementation of microwave therapeutic procedures.

The first Soviet unit of this type placed in production was the Luch-58, which was designed for remote administration of procedures. Although this apparatus has been in production for some time and the physiotherapy rooms of many medical agencies have been equipped with it, certain problems of its therapeutic use require further study.

The high power generated and the scattering of the electromagnetic energy into the surrounding space in the minor and back lobes, together with reflection from the patient's body, require not only the development of techniques for design of the therapeutic procedures, but also measures to protect personnel from the detrimental effects of the microwaves during operation of the Luch-58 apparatus. An investigation of the radiation characteristics of the unit (A.R. Livenson, 1964; V.V. Sevast'yanov and A.I.

Semenov, 1967) and the energy distribution of the microwave field around it (O.N. Karelin and I.M. Mishina, 1966) made it possible to determine the extent of the hazard that it presents for the patient and attending personnel. These characteristics have made it possible to develop measures to be taken in work with the Luch-58 and recommendations for its proper installation in the treatment rooms.

However, the material that has been published on this subject does not include exhaustive data for final resolution of these questions. Thus, the directional patterns are not sufficiently comprehensive, covering only certain radiators used with the Luch-58 apparatus.

The most detailed directional diagrams (in two mutually perpendicular planes) were obtained by V.V. Sevast'yanov (Fig. 21) with a stock PO-1 measuring instrument. These diagrams permit analysis of the microwave distribution pattern in the far zone of the radiation, which is necessary to determine the extent to which attendant personnel are irradiated and for rational use of protective devices.

Nevertheless, even diagrams of this type are not adequate for proper threapeutic use of the apparatus, since they do not show features of radiation-beam shaping in the immediate vicinity of the radiators, i.e., at the distances used in practical physiotherapy. As a result, characteristics needed for the develop- /173
ment of optimum procedure design are lacking: the size of the area irradiated on the patient's body and the distribution of the microwave field energy in it when the various radiators are used. This matter is so urgent that searches for ways to obtain these data merit serious attention.

This problem has been solved by visual registration of traces of the microwave field that reflect the true distribution of the radiant energy in the region (plane) of space under study (V.V. Sevast'yanov, 1967). Special temperature-sensitive indicator paper was used to investigate the distribution of the microwave field in the cross sections of the beams at distances of 0 to 1.0λ from the radiators (Figs. 22 and 23), both under free-space conditions and in the presence of a special phantom that reproduced fully the dielectric properties of muscle tissue. Thermometer measurements made on the phantom showed that the structures of the temperature and electromagnetic fields are identical.

Comparison of the visualized microwave-field traces shown in Figs. 22 and 23 with the directional patterns recorded in the far zone (Fig. 21) shows that the distribution of the microwave-field energy over the cross sections of the beams near the Luch-58 radiators is the same as that in the lobes of the directional patterns: the pattern of the bunches ("hot spots"), i.e., the highest concentrations of electromagnetic energy, on the traces

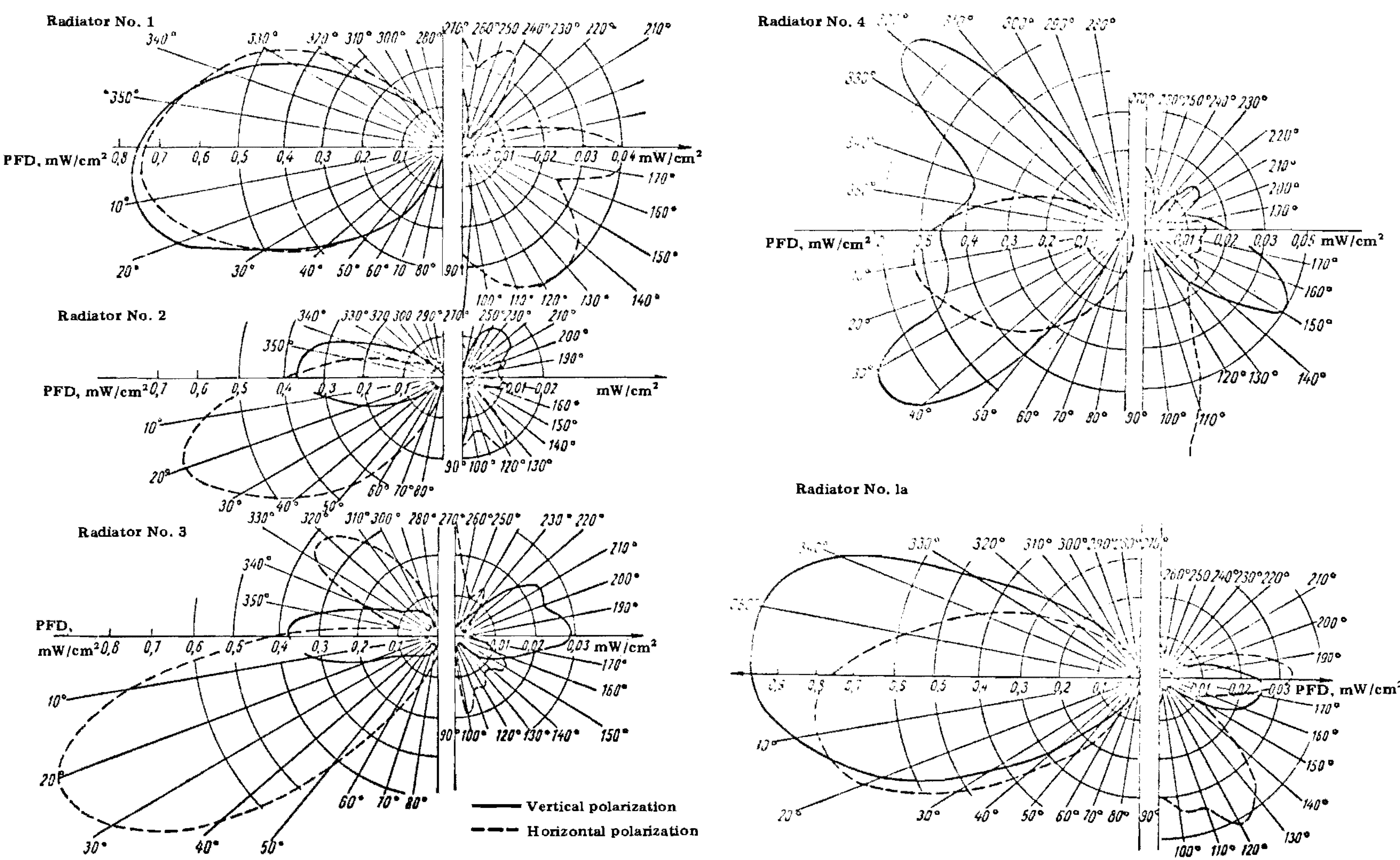

Figure 21. Directional Patterns (in Two Mutually Perpendicular Planes) of the Radiation from the Luch-58 Apparatus. Radiators Nos. 1, 1a, 2, and 3 are cylindrical with diameters of 90, 110, 140, and 180 mm, respectively; radiator No. 4 is rectangular, with dimensions 300 × 90 mm.

governs the configuration, magnitude, and spatial orientation of the directional-pattern lobes.

Since different areas of the patient's body are irradiated at different intensities by the various radiators of the Luch-58, undesirable effects may result unless the microwave procedures are properly carried out. It is therefore advisable to familiarize medical personnel operating the microwave apparatus with the data obtained on the structure of the field near the Luch-58 radiators.

The above shape features of the electromagnetic field in the near radiation zone and the dependence of the microwave-field structure on radiator size and distance from the radiator must be taken into account in elaborating therapeutic procedures.

The shortcomings of the Luch-58 unit, which consist in considerable scattering of the radiated energy into the surrounding space, the impossibility of strictly local application and sufficiently precise dosimetry under remote-controlled irradiation conditions, and the cumbersomeness of the apparatus led to the development of a new, portable unit designated Luch-2.

As concerns the Luch-2 apparatus, it produces no "stray" /176
radiation with the accompanying hazard to operating personnel
in virtue of the contact application of the radiators; these
dielectric-filled units transfer the microwave energy to the
target tissues of the organism with minimal losses. As a result,
the conventional instrumental method of investigation (using /177
the PO-1 instrument) of the radiation characteristics is excluded
where the Luch 2 apparatus is concerned. This explains the lack
of scientifically sound data pertaining to techniques for therapeutic use of this unit. Under these conditions, the only method that yields information on the structure of the radiation field is the above-described method of visual registration of microwave-field traces.

The results of studies of the field structure (V.V. Sevast'yanov, 1967) indicate that the electromagnetic energy is not uniformly distributed at the outputs of the contact electrodes (including the intracavitary rectal and vaginal electrodes) (Fig. 24). Just as in the case of the Luch-58 radiators, "hot spots," which result in nonuniform-intensity action on the target organ, are detected. The fact that the "hot spots" are observed even on the surfaces of the protective sheaths on the intracavitary electrodes merits special attention.

These beam-shaping peculiarities must be taken into account
both in prescribing microwave threapeutic procedures and in the
development of techniques for therapeutic use of the Luch-2 ap- /179
paratus. The structural nonuniformity of the microwave field at
the outputs of various radiators indicates the advisability of

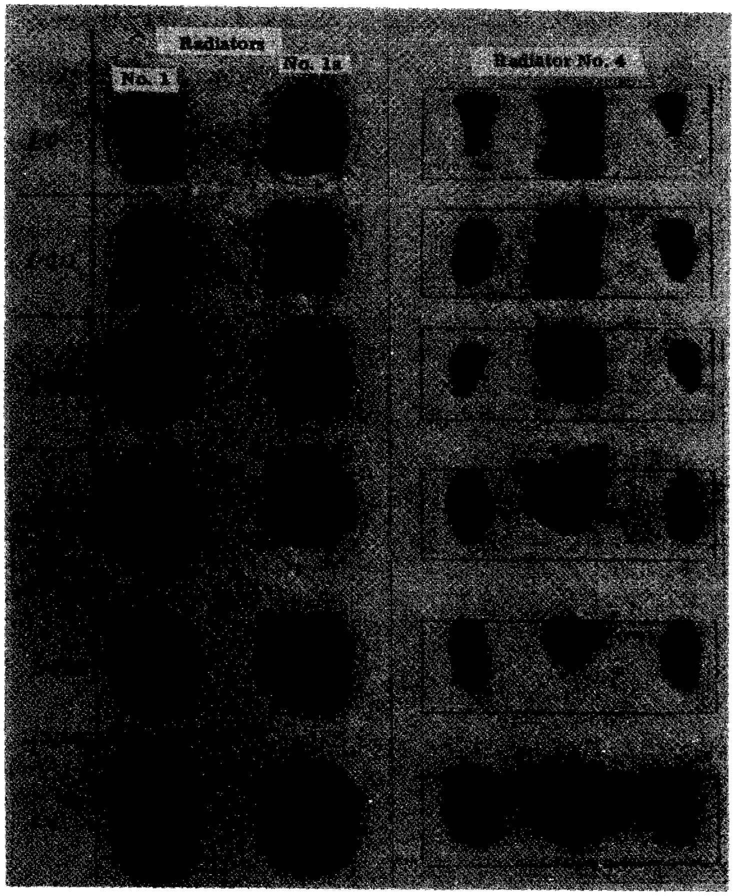

Figure 22. Distribution of Microwave Field Energy in Cross Sections of Radiation Beams (in Near Zone) at Various Distances (in Fractions of the Wavelength) from the No. 1 (d = 90 mm) and No. 1a (d = 110) Cylindrical Radiators and the No. 4 (S = 300 × 90 mm) Rectangular Radiator of the Luch-58 Apparatus. L is the distance from the radiator aperture.

considering design improvements directed at improving the radiation energy distribution characteristics of these radiators.

Since the method of dosimetry frequently used in physiotherapeutic practice, which is based on the subjective perceptions of the patient (nonthermal, weakly thermal, and thermal doses), is highly imperfect and not a reliable criterion of treatment intensity, the need for objective dosimetry in the administration of therapeutic microwave procedures is quite obvious.

A certain amount of progress in this direction has been recorded in the development of a physiotherapeutic microwave apparatus. However, the indirect dosimetric method used in the Luch-58, which is based on the plate current of the magnetron, is subject to large errors owing to the dependence of energy absorption by the tissues and energy reflection and scattering on the distance between the radiator and the patient's body.

Thus, the development of standardized conditions for irradiation of specific areas of the patient's body acquires great importance for the improvement of dosimetry precision; they should clearly define in advance the type of radiator, its distance from the surface of the body, and the optimum irradiation settings (output power and exposure time). Correction factors that establish relationships between the radiated power and the power absorbed by the organism's tissues could be used for such standard schemes.

Use of the Luch-2 apparatus for contact treatment ensures more precise dosimetry, since there are practically no energy losses to scattering into the surrounding space and no variation in the reflections as a result of differences in the distances from the radiator to the surface of the patient's body.

Since the generated power is absorbed only in the target tissues of the body in the contact method, it permits dosimetry based on measurement of the power that passes through the high-frequency strip of the apparatus. However, an indirect method of power measurement based on magnetron plate current is used in the Luch-2 apparatus; it is less accurate, since it does not take account of the influence of the patient's body on the performance of the device and variations of magnetron efficiency.

A new decimetric-wave physiotherapy unit designated Volna-1 (A.R.

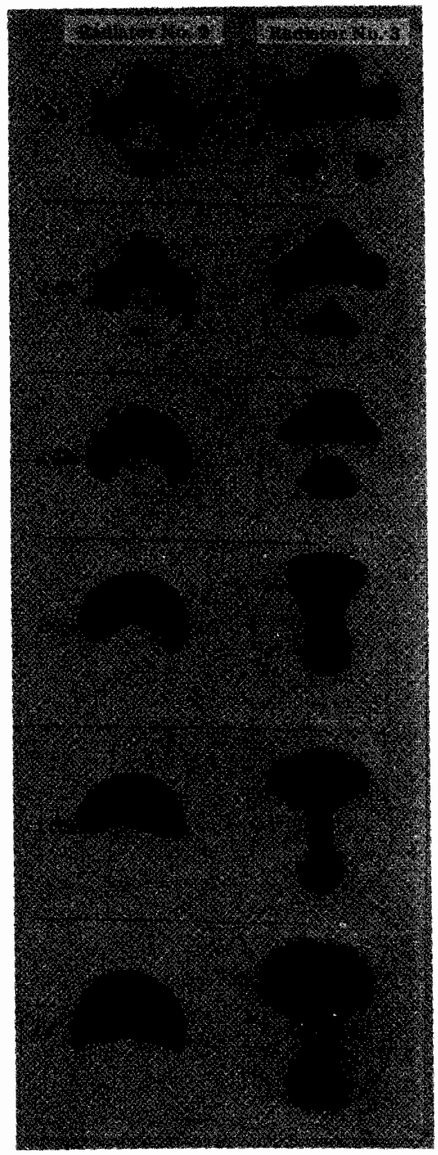

Figure 23. Distribution of Microwave Field Energy in Cross Sections of Radiation Beams (in the Near Zone) at Various Distances (in Fractions of the Wavelength) from the No. 2 (d = 140 mm) and No. 3 (d = 180 mm) Cylindrical Radiators of the Luch-58 Apparatus. /180

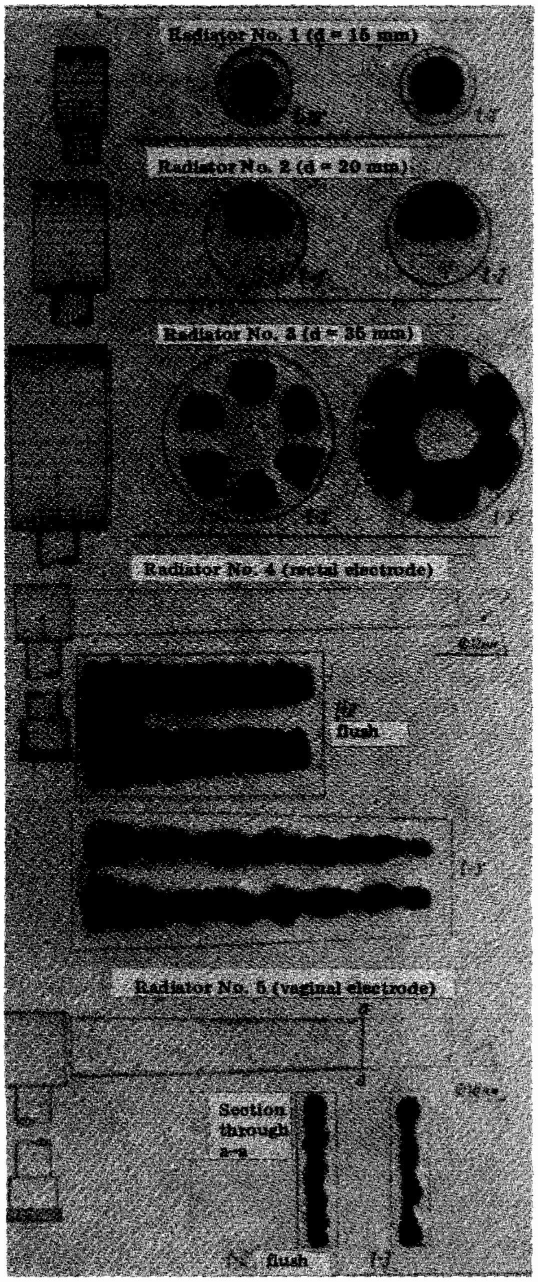

Figure 24. Distribution of Microwave Field Energy in Cross Sections of Radiation Beams (at Output of Contact-Type Cylindrical and Intracavitary Rectal and Vaginal Electrodes) of Luch-2 Apparatus. t is the time of exposure at P_{out} = 15 W; ø is the inside diameter of the radiator; a is its cross section.

Livenson, 1963) ensures the most accurate dosimetry of the treatment (15-20%) with a special measuring device for the amount of power absorbed in the organism. Use of the contact method in the wavelength band from 50 to 70 cm excludes strong standing waves inside the tissues, and this makes possible more accurate evaluation of the depthwise electromagnetic-energy distribution in the tissues.

Basically, the therapeutic use of microwaves makes use of the thermal effect of the microwave electromagnetic energy (Schwan, Piersol, 1954). In recent years, however, it has been suggested that the therapeutic effect of microwaves consists not only in the thermal action, but also in specific (nonthermal) effects on the particular pathological process involved (R. I. Mikhaylova, 1966; S.I. Dobromyslova, 1967; L.B. Shenfil' and M.I. Peylet, 1967, and others). A large amount of experimental and clinical material indicating that local microwave exposure not only has various effects directly on the target organs and tissues, but may also cause a variety of reflex and neurohumoral changes in the organism has now been accumulated (A.I. Semenov, 1965; I.M. Mishina, 1965; A.D. Golendberg et al., 1965; S.I. Dobromyslova, 1967, and others).

However, in spite of the steadily broadening use of microwave therapy, there are as yet no sufficiently clear directives regarding indications and contraindications for the therapeutic application of microwaves.

In microwave therapy, the temperature of the irradiated tissues is raised; this becomes noticeable during the first few minutes of exposure, and the heating continues until the local and general mechanisms that counter the microwave thermal effect are "switched on." Most important among these mechanisms is the augmentation of local blood circulation, which reduces the degree of tissue heating and protects them from injury by the microwaves (A.S. Presman, 1956; A.I. Semenov, 1963; Schwan, Piersol, 1954, and others).

It has been established experimentally that microwave irradiation of nonvascular organs (the crystalline lens) and of organs and tissues in which the cooling action of the local blood flow is limited may injure them. It is basically this fact that has predetermined contraindications for the therapeutic use of microwaves.

During the early years of use of microwaves for therapeutic purposes, the overwhelming majority of authors recommended that they be used extensively only in diseases of the supporting and /181
motor apparatus with various etiologies. Later, however, the range of indications for therapeutic use of microwaves was broadened substantially. Most authors now take the view that microwaves can be used in a wide variety of diseases, including the acute stage of the inflammatory process, local circulatory insufficiency, atherosclerotic changes in blood vessels, etc.

Microwaves are used more or less successfully in treating diseases of the supporting and motor apparatus (myositis, bursitis, periarthritis, injuries to joints, muscles, ligaments, etc.), of the nervous system (plexitis, neuritis, radiculitis, etc.), of internal organs (pleurisy, sequelae of myocardial infarct, cystitis, etc.), of organs of the pelvis minor (inflammation of the adnexae and body of the uterus, inflammatory disorders of the prostate), etc. In the view of most investigators, microwave therapy cannot replace other forms of high-frequency and UHF therapy, but is merely an addition to the arsenal of therapeutic weapons of this type.

Regarding the diagnosis and treatment of acute trauma to the supporting and motor apparatus (bruised muscles and joints, ruptured tendons, ligaments, articular capsules, etc.), it was recommended during the first few years of use of microwave therapy that it be prescribed only after the acute reaction to the injury had passed; swelling of the tissues and an acute inflammatory reaction were regarded as contraindications for microwave therapy (Schwan, Piersol, 1954). However, microwaves are now used quite extensively even in the acute phases of affection of the supporting and motor apparatus (A.D. Golendberg et al., 1965; M.I. Yatsenko, 1966, and others).

At the same time, emphasis is placed on the need for careful matching of the irradiation parameters to each specific case, including power, exposure time, and distance from the radiator to the target surface), to exclude the injurious effects of the microwaves.

There is a rather large body of clinical material indicating the advisability of using microwaves in the treatment of patients with the following diseases: bursitis of the shoulder and elbow, periarthritis of the shoulder, epicondylitis, tendovaginitis, stenosing tendinitis in the forearm region, and other disorders of the same character (A.D. Golendberg et al., 1965; I.M. Mishina, 1965, and others).

Treatment was administered with the Luch-58 apparatus. The exposed skin area in the region of the complaint was irradiated. The shoulder and elbow joints were irradiated successively from both sides. The distance from the radiator to the body surface was about 10 cm. When the morbid process can be localized at a shallow depth (tendinitis and myalgia in the forearm region, arthrosoarthritis of the small joints of the foot and hand, especially in the acutely painful stage), the authors recommend the following irradiation procedure: power 25-30 W, exposure time no longer than 10 minutes, followed after 2-3 procedures by an increase in power to 40-45 W and extension of the exposure time to 15 minutes. /182

In periarthritis and bursitis of the shoulder, and in calcaneal spur, irradiation is performed at intensities of 50-60 W for 10 minutes; after two or three procedures, the power is increased to 70-80 W and the exposure time to 15 minutes. The course of treatment consists of 10-15 procedures. The treatments are given daily, especially when the pain is severe, or every other day.

The authors report that a distinct analgesic effect usually appeared under this treatment after 2-3 procedures, and persisted for several hours. Subsequently, the pain was, as a rule, substantially reduced, and by the end of the therapy it had often disappeared entirely. Simultaneously, the range of movements in the shoulder or elbow joint (in periarthritis) had been fully recovered or restored almost to normal. It is noted here that all patients sustain the procedure well. Even among aged patients with pronounced signs of atherosclerosis, the microwave irradiation had no marked effect on the way the patients felt, or on their arterial pressure and pulse rates.

A number of reports have stressed the particularly striking effectiveness of microwave therapy in calcaneal spur. In the opinion of A.D. Golendberg, combination of microwave irradiation with other physiotherapeutic measures (baths, massage, therapeutic exercising) is advisable in diseases of the supporting and motor apparatus, and especially in the treatment of patients with periarthritic shoulder (A.D. Golendberg et al., 1965).

Experimental studies indicated that microwave irradiation can greatly accelerate the resorption of infiltrates and edemas of various etiologies (I.M. Mishina, 1965; M.I. Yatsenko, 1966, and others). However, it must be noted that the presence of infiltrate or local tissue edema tends to raise temperature when these tissues are subjected to microwaves. As a result, relatively intense irradiation (long exposures or high powers) may be harmful; the temperature rise may aggravate not only the infiltrate or edema itself, but also the local blood-circulation disturbance that they cause.

In this light, the design of procedures must be guided by the statement put forth by Schiephake (1962) that the more acute the process, the smaller is the permissible radiation dose. Schiephake (1961) takes note of the good therapeutic effect obtained from local irradiation of patients suffering from furuncle, carbuncle, hydroadenitis, osteomyelitis, etc. He stresses the need for combining the microwave treatment with surgical and medical therapy.

L. Nikolova-Troyeva (1964) reports a beneficial effect of microwaves in the treatment of postoperative infiltrates (following appendectomy, strumectomy, herniotomy, and other operations). /183 The author recommends the contact irradiation method, noting particularly dramatic results in patients with acute suppurative highmoritis and acute inflammation of the middle ear: the treatment was administered simultaneously with antibiotics. In these cases, a low power, 2-4 watts, was used with an exposure time of 5 minutes daily; the course of treatment consisted of 8-10 irradiations. Under the combined therapy, the subsidence of the complaints and objective abnormalities was found to be more rapid than when antibiotics were used alone.

The microwave-therapy technique is extensively used in the treatment of otorhinolaryngological, stomatological, gynecological, and other diseases. Thus, Spiegel (1956) indicates microwave therapy in cases of sinus and tonsil inflammations. Schliephake (1960) reports the effective application of microwaves in acute angina, paratonsillitis, inflammations of the sinuses, otitis, and laryngitis. Other authors have also reported good results of microwave therapy in the treatment of eye, ear, and throat diseases.

V.P. Nikolayevskaya (1966) reports good therapeutic effects obtained by use of the contact microwave method in simple forms of chronic tonsillitis.

The therapy was given with the Luch-2 apparatus. An electrode 3.5 cm in diameter was applied to the soft tissues on the side of the neck near the angle of the mandible (over the projection of the tonsil). The treatments were given daily with an exposure time of 6-7 minutes per side (radiated power 5-6 W, 10 treatments in all). A positive therapeutic effect was noted for all patients.

The literature also notes positive results from the contact method in treating a number of stomatological diseases: acute periostitis of the jaw, exacerbation of chronic periodontitis, alveolar pain, and acute odontogenic circumscribed osteomyelitis of the jaw, arthrosoarthritis of the temporomandibular articulation (R.I. Mikhaylova, 1966).

The Luch-2 apparatus was used for the most part to treat the patients. The 2-cm-diameter radiator was applied to the skin in the region of the projection of the pain. The radiated power was 5 W, and a procedure lasted 7 minutes. The radiation treatments were given daily. In addition to the Luch-2, the Volna unit, which operates in the decimetric band (65 cm) was used to treat a number of patients.

R.I. Mikhaylova reports that no appreciable differences could be discerned between these machines in the treatment of the above disorders; the author stresses the advantage of microwaves over UHF.

Microwaves have also come into widespread use for the treatment of various diseases of the peripheral nervous system. They are used successfully to treat radiculitis, neuritis, etc. (A.D. /184
Golendberg, 1965; Ye.I. Sorokina, 1965; S.I. Dobromyslova, 1967, and others). Microwaves were found to be particularly helpful in the treatment of radiculitides of varying etiology. According to Ye.I. Sorokina (1965), microwave irradiation of the spinal region in rheumatoid-spondylitis patients with secondary radiculitis (without involvement of the sympathetic nervous system) reduced not only the pain (including the pains in the heart region), but also the objective symptoms of secondary radiculitis of the cervicothoracic division. However, when the sympathetic nervous system had become involved in the pathological process of the same form of disorder (sympathicoganglionitis), the therapeutic use of microwaves was ineffective for most patients and often aggravated the disease.

A.D. Golendberg (1965) and others have reported good effects from the therapeutic use of microwave energy in lumbosacral radiculitis in various etiologies. The authors noted a significant and stable improvement in 34 patients, deterioration in 17, and no effect at all in only 5 of the 56 patients treated.

The group that recorded significant improvement included persons whose pains vanished completely after microwave treatment and whose objective symptoms were reduced to a major degree.

Encouraging results were also obtained in treatment of patients with secondary lumbosacral radiculitis due to intravertebral pathology: intervertebral osteochondrosis, rheumatoid spondylitis, etc. (S.I. Dobromyslova, 1957).

The Luch-58 apparatus was used in all cases to treat the above disorders of the peripheral nervous system in conjunction with various drugs. During the acute stage, radiation treatments were given at low powers (up to 40 W) for 8-10 minutes daily or every other day, with a subsequent increase of both the radiated power (to 60 W) and the exposure time (to 15 minutes). The course of treatment consisted of 10-15 procedures.

Microwave therapy has also been recommended for the treatment of certain local vascular-vegetative disturbances (L.B. Shenfil' and M.I. Peylet, 1967). The authors emphasize that microwave therapy alleviates pain, causes neurohumoral shifts, and improves calcium metabolism. In view of these facts, the treatment was given to patients with vasomotoralgic symptom complexes of the upper extremities. Characteristically, these patients complained of sudden attacks of pain and numbness in the hands, often accompanied by impairment of the function of their arms. The trouble was recurrent. Onsets of the disease lowered /185 working efficiency, sometimes to the point at which some of the patients were obliged to leave work altogether. Microwave treatments were given to 38 patients. Stable good results were obtained in 33, and full recovery was observed in a number of patients when the course of microwave treatment was repeated.

Experimental studies have established that the secretory function of the stomach is normalized and its absorptive function improved as a result of microwave therapy (V.R. Faytel'berg-Blank, 1964, Ye.L. Revutskiy, 1963, and others). In view of the positive effects of microwaves, certain authors have begun using them to treat a number of disorders of the gastrointestinal tract.

Ye.L. Revutskiy (1963) reported good results from microwave treatment of gastrointestinal patients, including some with gastric and duodenal ulcers. Other authors (Ye.B. Vygodner, 1966; I.G. Glushkova, 1966; N.S. Chistyakova, 1967, and others) have also reported good results in certain diseases of the gastrointestinal tract. They combined microwave therapy with other therapeutic factors.

N.S. Chistyakova (1967) used microwave therapy in combination with medication and dietetics in the treatment of gastric- and duodenal-ulcer patients. Thirty-eight persons came under observation (35 with duodenal ulcers and 3 with gastric ulcers).

Most of these patients (21) has previously received ambulatory and hospital treatment with various medical and physiotherapeutic agents (electrophoresis of various medications, inductothermy, paraffin applications, etc.) with short-lived results. Ulcer had been confirmed in all patients by the presence of "niches" and clinical symptoms. The patients were treated during the acutely painful stage. Some of the patients had complicating disorders: sclerosis of brain vessels, chronic coronary insufficiency, gallstones, colitis.

Treatment was given with the Luch-58 apparatus. The 14-cm radiator was mounted above the epigastric region and the projection of the duodenum; the radiator-to-skin distance was 5-7 cm, the exposure time 15 to 20 minutes, the power 30-40 W; the procedures were given daily until 20 had been administered.

The authors reported a faster improvement under microwave therapy than under treatment involving diet and medication alone. The "niche" symptom disappeared in 26 of 38 patients, became much /186
smaller in 11, and remained unchanged only in one. Stomach tone and evacuation normalized and the perigastric and periduodenal phenomena diminished; there were no undesirable side effects or complications, even in patients with manifest attendant disorders of the cardiovascular system.

It is concluded on the basis of the research results that the use of microwave therapy as part of the treatment given stomach- and duodenal-ulcer patients is quite justified. Without disputing the possibility in principle of using microwaves to treat certain diseases of the gastrointestinal tract, an extremely cautious approach must nevertheless be recommended in prescription of this method of treatment, since damage to the gastric and intestinal mucosa resembling ulcer appeared in rabbit experiments after irradiation of the epigastric region (I.V. Pitenin and A.G. Subbota, 1965). The authors conclude that the injurious effect of microwaves on the stomach is obviously due not only to the thermal factor, but also to the nonthermal effect of the microwaves. A pathological reflex that aggravates the course of the disease may appear in ulcer patients (I.R. Petrov, 1966).

We have already noted that microwave irradiation of the eyes may damage the organ of sight, especially the lens. At the same time, there are published reports of a beneficial therapeutic effect of microwaves in certain diseases of the visual organ. L.Ya. Shereshevskaya (1966) reports on the use of microwaves to treat dystrophy of the yellow spot and uveitis.

The procedure of treatment was as follows. Luch-58 apparatus, power 20 W, radiator diameter 20 cm, distance from radiator to eye 10 cm, treatment time 15 minutes. The procedures were given with the patient supine, eyes half-closed, daily or every other day. The course of treatment consisted of 15-20 procedures. Seventy-six patients were treated. Good results were reported following microwave therapy in all patients with ordinary senile dystrophy of the retina, circiform rhinitis [sic], disciform dystrophy, and central myopic chorioreniitis [sic].

Reports of beneficial effects of microwaves in the treatment of other diseases, including infectious polyarthritis, can also be found in the literature (P.I. Pokutsa, 1965; V.S. Cheredova, 1967), in inflammations of the gallbladder and in hepatocholecystitis (I.G. Glushkova, 1966; V.G. Gogibedashvili et al., 1965), in cardiovascular diseases (L.A. Skurikhina, 1961; I.R. Chepikova, 1965), and in diseases of the female sex organs (A.I. Batsak and Ya. N. Degtyareva, 1965; S.M. Malysheva et al., 1966; A.G. Uvarov, 1966).

Thus, from analysis of the literature data pertaining to the therapeutic use of microwaves, especially those published in recent years, we may conclude that the microwave-therapy method is now firmly established among the other methods of physiotherapy and is being used successfully in treatment of a wide variety of diseases. It is stressed in most of the reports that the optimum results are obtained when microwaves are used in combination with other forms of treatment. /187

At the same time, numerous papers are correct in stressing the need for an individualized approach to selection of the optimum microwave doses for each case, also with recognition of the fact that certain physiotherapeutic machines (for example, the Luch-58) may generate quite substantial radiant intensities that may have detrimental effects extending even to damage of the irradiated tissues. It must be emphasized once again that the potential danger of microwave injury is especially great in irradiation of tissues or organs with disturbed or insufficient local blood circulation and in all other cases in which various conditions intensify the microwave thermal effect (edemas, inflammation, etc.). Caution must therefore be exercised in prescribing microwave procedures in such cases.

Finally, it should be noted that the time is not yet ripe for the routine use of microwaves to treat diseases of the gastrointestinal tract and especially diseases of the visual organ. These problems require further study. It is also important to remember that certain microwave-therapy machines, such as the Luch-58, create conditions under which the operating personnel may be subjected to microwave irradiation in excess of the permissible amount per working day. In the design of therapeutic procedures, therefore (and especially in work with the Luch-58 machine), rules and recommendations that exclude injurious effects of microwaves on the patient and the operating personnel must be observed. These recommendations and safety measures are set forth in a number of papers (A.R. Livenson, 1964; A.I. Semenov, 1965; I.M. Mishina, 1965; V.V. Sevast'yanov, 1967).

Chapter 13

PROBLEMS OF PROPHYLAXIS AND PROTECTION FROM THE HARMFUL EFFECTS OF MICROWAVES

Recent years have witnessed a steady increase in the use of devices working with microwave electromagnetic energy. Present-day units radiate microwaves at intensities considerably higher than those encountered earlier. These facts point to the need for augmented protective measures to ensure the safety of personnel coming into contact with radiation from microwave apparatus.

At the same time, the development of preventive measures against injurious effects of microwaves on the human organism is a very urgent problem, since brief irradiation at powers exceeding the maximum permissible level is sometimes inevitable in the course of operations.

The organization and implementation of protective and preventive measures requires, first of all, scientifically sound hygienic irradiation norms and special radiometric apparatus that can be used to determine the extent of the hazard presented by microwaves at the workstations and the need for taking various protective measures.

In this chapter, we shall examine:

a) maximum permissible levels for the irradiation of humans by microwaves,

b) protection of personnel from exposure to microwave radiation and

c) prevention of its detrimental effects.

Maximum permissible levels. It has been established in numerous studies that radio waves in the microwave band have a biological effect that manifests to a degree dependent on their intensity, the time of exposure, wavelength, and irradiation conditions.

It is generally assumed in the USSR that a power flux density of 10 $\mu W/cm^2$ is perfectly safe for a man microwave-irradiated throughout an eight-hour working day.

Irradiation by electromagnetic waves with a PFD not above 100 $\mu W/cm^2$ may not exceed 2 hours per working day, and the exposure time at a PFD of 1000 $\mu W/cm^2$ must not exceed 15-20 minutes per working day, with wearing of protective goggles mandatory. (Provisional Sanitary Rules for Work with Centimetric-Wave Generators. USSR Ministry of Health, 1959). An intermittency correction factor of 10 has been proposed for intermittent irradiation occurring when the radiating devices are used in circular- and sector-scanning modes. This means that the irradiation norms are increased by one order for these conditions. The expediency of this coefficient has been justified by experiment. /189

Adherence to the hygienic norms is monitored with the radiometric instruments listed below:

1. The PO-1 power flux density meter — an instrument for measuring the PFD's of sinusoidal oscillations in the frequency range from 0.15 to 16.7 GHz under field and operations conditions with a measurement error not exceeding 30% of the measured value without adjustment of the high-frequency elements.

2. The P2-2, which indicates dangerous electromagnetic field strength levels, measures PFD's of continuous amplitude-modulated, frequency-modulated, and pulse-modulated microwaves. It covers the frequency range from 300 to 16,000 MHz. The range of PFD measurement is 10-1000 $\mu W/cm^2$. The measurement error is 3 dB.

PROTECTION OF PERSONNEL FROM EXPOSURE TO MICROWAVE RADIATION

The operating conditions of modern radioelectronic apparatus are such that the microwave-irradiation intensities at the workstations of the specialists operating powerful radioelectronic devices or engaged in their repair and adjustment may in some cases exceed the above maximum permissible levels and thereby create a hazard to the health of personnel. Many researchers, both Soviet and foreign, have been engaged extensively in the development of prophylactic and protective measures against the detrimental effects of microwaves. A number of scientists (A.S. Presman, 1958; Vosburgh, 1956; Egan, 1957, Marek, 1959; Hübner, 1960; Mumford, 1961) have submitted proposals for protection and prevention of the harmful effects of microwaves involving either the establishment of irradiation danger zones not to be entered by personnel or changes in the direction of the radiation, or other principles. Detailed instructions recommending various practical methods of protection from microwaves have now been elaborated in the USA. For example, to ensure the safety of operating personnel at the powerful radar stations set up to detect intercontinental ballistic missiles in flight, the sites are equipped with metal-screened passageways, corridors, and shelters joining the various areas of the site with one another.

Much attention is given to the development and production of individual protective devices (Bovill, 1960; Hübner, 1960), and testing to determine the protective properties of various materials: glasses for goggles, screens, films, etc. (Egan, 1957).

Classification of protective measures. All protective measures can be classed into two basic groups: a) group protective measures and b) individual protective measures. /190

The former provide group protection from microwave exposure for operating personnel and other persons entering the effective zones of the radiating microwave apparatus. The latter provide protection directly to each specialist subject to the radiation hazard.

The group protective measures may be either primarily organizational or primarily technical. Organizational measures include rational placement of the radiating devices on the operations area with observance of the necessary spatial separations between them and residential buildings, elevation of antenna systems above the surrounding terrain, establishment of safe sectors in azimuth and elevation around the radiating units, etc. The technical protective measures include various forms of shielding.

Protective shielding materials. Electromagnetic shielding is one of the basic methods of providing protection from microwaves. It reduces to the use of various materials and devices that stop the propagation of electromagnetic energy by reflection or absorption. Shielding may be complete, in which case the shielded object or microwave source is surrounded by shielding surfaces on all sides, or partial.

All shielding materials can be classified as absorbing or reflecting; the choice of the type used in practice is dictated by the purpose and objective of the shielding. Thus, materials with reflecting properties are used to advantage to protect personnel from stray microwaves and from radiation from antennas at points where there is no conflict with the operating efficiency of these devices. Preferential use of absorbing materials is recommended in the zone of the main lobe from the antenna. Usually, the following materials are used in shielding practice: sheet metal in various thicknesses, metallic screens, metallized cloth, and metallized glass. Metal sheets have high attenuation (Table 31), far in excess of that necessary for biological protection. They may therefore be of the minimal thickness that provides adequate strength. Of the four materials listed in the table, steel may be recommended as the cheapest and strongest and as having shielding properties on a par with those of the others. It is only necessary to galvanize or paint it in order to prevent corrosion. However, there are many cases in which continuous metal sheets cannot be used.

Metal-wire screens are even more extensively used for shielding. Their comparatively light weight, transparency, and flexibility, together with a high attenuation factor, make them a highly valuable shielding material. The attenuation factor of a screen is determined by its reflecting properties, and, for a /191

TABLE 31. EFFICIENCY (E) OF SHIELDING PROVIDED BY METAL SHEETS
(Ye.A. Yermolayev, A.I. Senkevich, 1966)

Frequency in MHz	E (dB) with 0.1-mm screen			
	Aluminum	Zinc	Brass	Steel
3 000	$5,2\cdot10^2$	$3,6\cdot10^2$	$3,3\cdot10^2$	$1,5\cdot10^3$
10 000	$9,4\cdot10^2$	$6,5\cdot10^2$	$6,0\cdot10^2$	$1,7\cdot10^3$

TABLE 32. ATTENUATING PROPERTIES OF SQUARE-MESH SCREENS
(Ye.A. Yermolayev, A.I. Senkevich, 1966)

Material	Wire diameter in mm	mesh side length, mm	Attenuation in dB at frequency [MHz] of	
			10 000	3 000
Steel	0,42	2,0	25	36
Brass	0,42	2,0	25	38
Steel	0,28	1,0	30	39
Brass	0,34	1,0	30	40
	0,25	0,63	34	40

given wavelength, is larger the larger the diameter of the wire and the smaller the mesh size (Table 32).

The data of Table 32 indicate that metal screens can give attenuations of 25-40 dB in the microwave band. In most cases, this satisfies biological-protection requirements. The material of the wire and anticorrosion paints applied to it have practically no influence on shielding properties.

There is a great demand for a transparent shielding material on the part of various planning and construction organizations. Ordinary glass has low attenuating properties, of the order of a few decibels. Glass is metallized by application of a thin conductive film in order to improve these properties. Although it loses 10-15% of its transparency, the glass acquires an attenuation coefficient of the order of 20 dB (Table 33). The film is chemically stable and mechanically strong. Although such glass has not yet come into widespread use, it is highly promising.

Metallized protective cloth has come into extensive use during recent years as a shielding material; it is used to make both individual and collective protection items. All known protective fabrics can be classed into two groups: fabrics with open metallization, in which the threads that reflect the radio waves consist of a cotton base with wound-on metal ribbons, and fabrics with closed metallization, in which the shielding network is /192

TABLE 33. ATTENUATING PROPERTIES OF SPECIALLY COATED GLASSES (Egan, 1957)

Coating material	Microwave transparency in % transmission	Optical transparency, %	Microwave attenuation, dB
Gold film about 11 mμ thick (surface resistance 300 ohms)	10	49	10
Gold film 30 mμ thick (surface resistance 12 ohms)	0.1	24	30
Gold film 75 mμ thick (surface resistance 1.5 ohms)	0.01	3.2	40
Lead glass (for x-ray protection) 6 mm thick	25	85	6
Glass with conductive coating 300 mμ thick, resistance 70 ohms	10	80	10
Glass with conductive coating 1.5 mμ thick, resistance 15 ohms	1.2	45	19.2

formed by microscopic wires woven into the fabric. The fabric exhibits good hygienic properties and attenuates microwave intensities on the order of 25-30 dB. This cloth is acknowledged to be the most commonly used material for the manufacture of individual items of protection.

Radioabsorbent materials, whose effect is based on total absorption of incident electromagnetic waves, form the second major group of shielding materials. They can be subdivided into two groups on the basis of working principle. In one group, absorption or, more precisely, the absence of reflection is obtained as a result of addition of waves reflected in antiphase. Materials of this type form dielectric layers one-quarter of a wavelength thick and are bonded to a conductive base - a metal film or screen. Radio waves incident on the surface of this material are partly reflected from the dielectric and partly transmitted through to the conducting base, where they undergo secondary reflection and are extinguished on the surface of the material by the primarily reflected waves, which have the same amplitude but /193 the opposite phase. Use of such materials is limited because, as a rule, they are extremely narrow-band, i.e., can be used only at one wavelength.

In the other group of radioabsorbent materials, the energy of the radio waves is attenuated by progressive absorption of the waves within the material and conversion to thermal energy. Such materials are made in the form of solid, uniform sheets of a dielectric with patterned surface relief resembling pyramidal or conical projections, which create conditions for progressive incidence of the radio waves on the surface. These materials are broad-band, but rather clumsy and heavy. However, they are still used more extensively in practice than materials of the first group. Disadvantages of radioabsorbent mateials include their high cost and structural complexity. However, the use of these materials for protection is mandatory when reflecting screens may interfere with equipment performance.

Protective properties of various structural materials. Knowledge of the protective properties of various structural materials and other factors such as terrain relief, vegetation cover, etc., is necessary for both medical and engineering personnel, since it permits more realistic organization of practical personnel protection at the various radio-engineering installations.

The walls of buildings provide varying degrees of protection, depending on their thickness and material. As a rule, the effectiveness of the shielding that they provide in the microwave band increases with shorter wavelengths. Thus, for example, a brick retaining wall 70 cm thick has attenuation coefficients from 12 dB in the metric band to 20 dB in the centimetric band. A plastic interior partition 15 cm thick gives from 2.5 dB in the metric band to 10-12 dB in the centimetric band. A wooden partition consisting of a single layer of pine boards 30 mm thick attenuates microwave energy on the order of 1 to 2.5 dB. Ordinary 3-mm-thick window glass has a theoretical attenuation coefficient of 1-3 dB in the centimetric band, owing to reflection. On the whole, a window with a single frame gives protection ranging from 3 dB in the metric band to 4.5 dB in the centimetric band; for a double frame, the figures are 3.5 and 7 dB, respectively. The figures for doors are similar.

Various terrain relief shapes and lines may also be highly important from the protection standpoint. Elevated terrain features — cones, embankments, hills — and the crests of ridges and edges of gullies may form serious obstacles to the propagation of microwave energy, creating shadow zones whose extent depends on /194 obstacle height, the position of the obstacle relative to the radiation source, and the character of the terrain beyond the obstable. In such cases it is mandatory to consider the frequency-dependent diffraction effects at the peak of the obstacle.

In practice, it is most expedient to evaluate the role of relief in the distribution of the electromagnetic field on the terrain by measuring the PFD at as many points as are necessary. Tree cover should be regarded as a semitransparent obstacle for microwaves. The thicker the woods, the lower its transparency.

Individual protective measures against microwave exposure. Where collective protective measures do not achieve the desired result or cannot be used, recourse is taken to protective clothing. For example, this is necessary under repair-shop conditions, where the work is done with the equipment unshielded and the microwave-field strengths are high. The idea of designing protective clothing for specialists working on radiating electronic equipment dates from the discovery of the microwave hazard. The early models were sandwich-fabric coveralls in which brass screening was used as the sandwiched layer. Metal screening was also used to protect the eyes. However, these suits were inconvenient to work in and did not come into widespread use.

Several varieties of protective fabric (with microscopic wire networks woven into the fabric) have made their appearance in recent years; they have been found more desirable as regards their protective and hygienic properties than the materials previously used. A protective glass has also been developed.

The contemporary protective suit is a coverall-and-hood made from the protective fabric described above. Special goggles whose lenses are coated on the inside with a thin semiconductive film are provided in the head (hood) of the suit to provide protection for the eyes. Despite the fact that the modern protective suit has the required protective and hygienic properties, its use is not always desirable, since it makes it difficult to perform repair and servicing jobs and may generate resentment on the part of personnel.

Whenever possible, personnel protection is provided by certain organizational-and-technical measures. If the irradiation originates from radiators mounted in enclosed areas or out in the open, radiation protection is obtained:

a) indoors: by pointing the radiators at windows or at places where there are no people; by the use of absorbing loads (antenna /195
equivalents); by metal-panel or metal-screen shielding of work-stations; and by limiting the radiating operating time of the device or shortening the working time of the specialist;

b) in the open: by maintaining the necessary distances between the radiators and personnel areas (the distances are determined under specific conditions after measuring the intensity of the microwave radiation and with consideration of the permissible irradiation levels); by rational placement of the electronic devices and use of terrain features in siting various structures and areas to be occupied by personnel; by using reflecting materials to shield windows and walls facing radiating devices in nearby personnel areas; by building earthworks and terraces, digging trenches, and planting trees around personnel areas; by marking dangerous areas.

In addition to the above measures for protection against the harmful effects of microwaves, which ensure the safety of personnel servicing the electronic equipment, it is necessary to recognize the need for protection against other environmental factors as well — such as noise, the physical and chemical properties of the air breathed, work-area lighting, soft x-rays, etc., which may aggravate the harmful effects of the microwaves and help lower the efficiency of personnel. Thus, in elaborating combined protective measures with the object of preventing occupational disease, it is necessary to evaluate the microwave hazard with consideration of all prevailing environmental factors encountered in operation of the electronic facilities. For this reason, the Soviet legislature has established preliminary and periodic medical-examination requirements.

These require the participation of a neuropathologist, a therapist, and an oculist and, if necessary, other specialists.

PREVENTION OF HARMFUL CONSEQUENCES OF EXPOSURE TO HIGH-POWER MICROWAVES

As we know, persons working with microwave generators may, in virtue of the nature of their work (tuning the generators, making repairs, accidents), be subject to exposure to high microwave powers for short periods of time. For this reason, the search /196
for medicines that have prophylactic effects is an exceedingly urgent problem.

Before turning to experimental material on the practical effectiveness of certain drugs that we have very recently tested, let us dwell briefly on the improvement of microwave resistance that occurs under the influence of an ancient and time-tested measure — one that is useful against the widest variety of unfavorable factors acting on the human organism. We are concerned here with improving the microwave resistance of the human organism by means of systematic muscular activity.

In man, muscular activity is of extremely great importance in raising the organism's resistance to noxious pathogenic factors. The influence of muscular activity on the endurance of the organism under various extreme stimuli is now an urgent problem and one that requires further study. It is conceivable that the resistance of the organism to microwaves might also be increased by physical exercise.

Certain indirect observations pertaining to individuals' state of health confirm this possibility. However, it was necessary to have experimental results for a definite answer to the question as to whether physical exercising improves the organism's resistance to the effects of microwaves. For this reason, we made a comparative study of the sensitivities of conditioned and unconditioned white mice to microwave radiation (λ = 12.6 cm) that is lethal to a majority of animals in control experiments.

Three series, each consisting of 20 experiments, were organized (the first series was the control). In all experiments, the mice were irradiated with the Luch-58 machine (PFD 34 mW/cm^2) for 20 minutes. Over 15 days in the second series of experiments, the mice were forced to tread water, at first for 30 minutes at a time (5 days), and then for 45 minutes (10 days).

In the third series of experiments, the mice put forth a static effort each day for 18 days. They were made to sit on a pole for 5 minutes at a time during the morning and afternoon of the first day, and then, for the next six days, the time on the pole was increased by 5 minutes at each session; on the last 11 days, the mice pole-sat for 45 minutes at a time. The day after conditioning was complete, the animals of the second and third experimental series were irradiated under conditions the same as for the animals of the control series.

The results of the investigation showed that 16 out of 20 animals in the control series perished after irradiation, leaving only four survivors. In contrast, only three of the 20 mice that had been made to tread water (second series of experiments) perished after 20 minutes of irradiation. The differences between the control and experimental series were found to be statistically significant ($P < 0.001$).

Thus, under the influence of daily swimming exercise, the resistance of the mice to microwaves had increased substantially; in some of them, it persisted for as long as 10 days after the end of conditioning. Of the 10 mice subjected to repeated irradiation, only four perished. When irradiation was repeated 20-25 days after the end of the swimming exercises, three of 15 mice survived and 12 perished, i.e., mortality was about the same as in the control series. /197

In the experiments of the third series, in which the mice were made to perform static work, an increase in microwave stability was again observed. Twelve, i.e., 60%, of the 20 irradiated mice survived, while the rest perished. In the control series, which was run simultaneously, only 25% survived after irradiation. The differences between the results of the third and control series of experiments were found to be reliable ($P < 0.05$).

The increase in resistance to various harmful factors (hypoxemia, overheating, infection, microwave radiation, etc.) under the influence of physical exercising can be explained as due chiefly to stimulation of the organism's general nonspecific adaptive reactions.

According to literature data, performance of physical exercises is accompanied by hyperfine coordination processes in the central nervous system, enhancement of the functions of certain endocrine glands and especially an increase in the weight of the adrenals, increased activity of muscle enzyme systems, and increased production of macroergic phosphorus compounds, glycogen, structural proteins, etc. (N.V. Zimkin, 1963); all of this helps increase the organism's endurance under various pathogenic factors.

Thus, on the basis of the literature data and the research results of I.R. Petrov and N.Ya. Yarokhno (1967), persons working with microwave generators should be reminded repeatedly to engage systematically in gymnastic exercises.

It was shown in Chapter IV that in work with microwave generators at high elevations, the rarefied atmosphere, through the oxygen insufficiency that it causes, creates conditions for a more pronounced reaction to microwave radiation. Prior acclimatization to life in the thin atmosphere increases the organism's stability to microwave exposure (I.R. Petrov and N.Ya. Yarokhno, 1967); it has therefore been proposed that when radar installations are built at moderate elevations (2500-3000 m), their crews be assigned to work at them after preliminary (one-month) acclimatization to the conditions of life and work at the particular altitude.

As we have noted, interest attaches to the testing of drugs to determine their prophylactic effectiveness; this applies particularly to drugs with an antihypoxic action, since oxygen insufficiency is a major factor in the development of changes under the influence of thermal microwave intensities.

Our own results from tests of gutimine (guanylthiourea), which increases the resistance of the organism, indicate that it /198 is definitely helpful under microwave exposure.

In fact, as we see from the results given in Table 34, all white mice that had been given 150 mg/kg of gutimine subcutaneously one hour before exposure to thermal-power microwaves survived, while of the 10 animals irradiated with the same dose in the control series of experiments, all but four perished. The differences between the two groups cited are significant.

It is important to stress the fact that the good preventive effect of gutimine was also in evidence in experiments on mice who were given the drug orally one hour before exposure to the microwaves. In the control series, 17 mice perished under microwave irradiation and 13 survived. In contrast, 22 mice survived and 8 perished under exposure to the same microwave power in the 30-animal experimental series, in which gutimine was administered (Table 35).

TABLE 34. DATA ON PROPHYLACTIC EFFECT OF GUTIMINE IN WHITE MICE UNDER MICROWAVE IRRADIATION
(λ = 12.6 cm, PFD = 48 mW/cm^2, exposure time 20 min)

Experimental series	Number of animals in experiment	Survived	Perished	Statistical Certainty
Control	10	4	6	$P < 0.05$
Experimental	10	10	0	

TABLE 35. DATA ON PROPHYLACTIC EFFECT OF ORALLY ADMINISTERED GUTIMINE UNDER MICROWAVE IRRADIATION
(λ = 12.6 cm, PFD = 48 mW/cm^2, exposure time 20 min)

Experimental series	Number of mice	Survived	Perished	Statistical Certainty
Experimental	30	22	8	$X^2 = 0.05$
Control	30	13	17	

The difference between the experimental and control series was found to be statistically significant. The survival times of the white mice that perished in the experimental series were longer than in the control series. While all 17 control mice perished during irradiation, only three of the eight mice that perished did so during irradiation, two expired 20 minutes after the end of irradiation, and three lived for more than 24 hours in the experimental series (gutimine per os one hour before irradiation).

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TABLE 36. DATA ON PROPHYLACTIC ACTION OF SODIUM HYDROXYBUTYRATE UNDER MICROWAVE IRRADIATION
(λ = 12.6 cm, PFD = 48 mW/cm^2, exposure time 20 min)

Experimental series	Number of animals	Survived	Perished	% Perished	Certainty
Control	20	7	13	65%	$P < 0.5$
Experimental	30	21	9	30%	

Note. In the experimental series (250 mg/kg of sodium hydroxybutyrate injected subcutaneously 30 minutes before the microwave exposure, 2 mg of 10% glucose solution given 1 hour before exposure).

The positive preventive effect of gutimine can be explained by the fact that, according to literature data (L.V. Pastushenko, V.M. Vinogradov, 1966), it causes a marked decrease in oxygen demand without an accompanying drop in efficiency (muscular activity); this is also confirmed by the research results of I.R. Petrov and N.Ya. Yarokhno. According to the studies of I.P. Shcherbachev (1968) this preparation increases the stability of the animal organism to high ambient temperature (40°C).

The enhanced prophylactic effect against the harmful effects of microwaves in experiments with subcutaneous injection of gutimine is probably also partly due to the combined effect of the lower oxygen demand and a decrease in body temperature, since a more pronounced body-temperature decrease (by 2-2.4°C) has been observed in experiments with subcutaneous injection of thd drug as compared with oral administration. Thus, gutimine can be recommended for testing as a preventive in humans who may from time to time be subjected to brief exposure to high microwave powers.

The prophylactic action of sodium hydroxybutyrate (the sodium salt of gamma-hydroxybutanoic acid) was tested in a special series of experiments in which animals were irradiated with thermal microwaves; according to studies made at the USSR Academy of Medicine Institute of Pharmacology and Chemotherapy, where it was synthesized, this compound has a sedative action by which it prolongs the "survivability" of the brain and cardiac activity during experimental anoxia.

It was felt that tests to determine the effectiveness of this drug would be worthwhile, since pronounced CNS changes occur under the influence of thermal microwave intensities.

The results of our experiments with white mice indicate that this drug was effective when the animals were irradiated in a microwave field with PFD = 98 mW/cm^2. While 65% of the mice in /200
control experiments perished under exposure to microwaves of the parameters indicated, only 30% perished in the experimental series (Table 36).

Consequently, the survivability of the animals was doubled under the influence of sodium hydroxybutyrate in combination with glucose; the increase was found to be statistically reliable.

The positive prophylactic effect of sodium hydroxybutyrate under thermal-microwave exposure can be explained by its sedative and antihypoxic action.

Thus, more attention should be given to the organization of systematic physical exercises (isometrics, gymnastics, games, etc.) to increase the resistance of the organism to microwaves.

Antihypoxic drugs can be recommended for further testing against the effects of brief exposure to high microwave intensities that raise body temperature.

CONCLUSION

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This monograph has been devoted to an important problem of contemporary medicine and occupational pathology: the effects of microwaves, which are used widely in radiocommunications, 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 ultrashortwave 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 /202 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 to 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 /203
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 convined 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, $\lambda = 10$ 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 /204
in study of lethal effects; for example, centimetric waves ($\lambda = 10$ 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 (ε) and conductivities (σ), 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. /205

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 as under 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 ($E = h\nu$). 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 (λ 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 (λ 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 nonthermal 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 /207 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 nosological 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 /208
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 /209 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 λ = 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 μW/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 /210 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 ef ects 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 λ = 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 constitute 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 extremal 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 /211 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 /212
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.

REFERENCES

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1. Abrikosov, A.I. Impul'snoye elektricheskoye pole ul'travysokoy chastoty (The Pulsed UHF Electric Field), Moscow, 1958.
2. Aleksandrov, L.N., and Zolotashko, M.I. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 81.
3. Aleksandrova, A.P. and Luk'yanov, V.S. Voprosy kliniki, profilaktiki i lecheniya gipotonicheskoy bolezni (Problems in the Clinical Medicine, Prevention, and Treatment of Hypotonia), Moscow, 1960.
4. Aleksandrovskaya, M.M. and Kruglikov, R.I. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitiykh voln radiochastot (Industrial Hygiene and Biological Effects of Radio-Frequency Electromagnetic Waves), Moscow, 1968, 5.
5. Al'pern, D.Ye. Kholinergicheskiye protsessy v patologii (Cholinergic Processes in Pathology), Moscow, 1963.
6. Anichkov, S.V. Fiziol. zhurn. SSSR, 1954, 40, 4, 420.
7. Asanova, T.P., Osipov, Yu.A. and Uspenskaya, N.V. In book entitled: Materialy nauchnoy sessii, posvyashchennoy 40-letiyu Len. NII gigiyeny truda i profzabolevaniy (Materials of Scientific Session Dedicated to the 40th Anniversary of the Leningrad Scientific Research Institute of Industrial Hygiene and Occupational Diseases), Leningrad, 1964, 67.
8. Babkin, B.P. Sekretornyy mekhanizm pishchevaritel'nykh zhelez (The Secretory Mechanism of the Digestive Glands), Moscow, 1960.
9. Babskiy, Ye.B. and Minayev, P.F. Fiziol. zhurn. SSSR, 1947, 33, 6, 773.
10. Balutina, A.P. Byull. eksper. biol., 1965, 12, 41.
11. Balutina, A.P. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 174.
12. Batunina, V.Ya. In collection entitled: Nekotoryye dannyye o biologicheskoy kharakteristike ul'travysokoy chastoty (Certain Data on the Biological Characteristics of UHF), Gor'kiy, 1938, 39.
13. Batunina, V.Ya. and Gernet, Ye.V. In collection entitled: Tr. Gor'kovskogo fizioterapevticheskogo instituta (Transactions of the Gor'kiy Physiotherapeutic Institute), Gor'kiy, 1938, 36.
14. Batsak, A.I. and Degtyareva Ya.N. Dokl. 23-y nauchn. sessii, posvyashchennoy 20-letiyu Kishinevskogo Gos. med. in-ta (Papers at 23rd Scientific Session Devoted to the 20th Anniversary of the Kishinev State Medical Institute), Kishinev, 1965, 246.
15. Beletskiy, G.Yu. Ionnyy mekhanizm osnovnykh nervnykh protsessov (The Ionic Mechanism of the Fundamental Nervous Processes), Leningrad, 1958.

16. Belova, S.F. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR (Transactions of the USSR Academy of Medical Sciences Institute of Industrial Hygiene and Occupational Diseases), No. 1, Moscow, 1960, 41.
17. Belokrinitskiy, V.S. Nekotoryye posledstviya vozmushcheniy, nanesennykh na nervnuyu sistemy zhivotnykh deystviyem bol'shikh doz elektromagnitnogo polya. Biofizicheskiye zakonomernosti deystviya fizicheskikh agentov na organizm (Certain Consequences of Disturbances Applied to the Animal Nervous System by Large Electromagnetic-Field Doses. Biophysical Laws Governing the Action of Physical Agents on the Organism), Abstracts of Papers, Kiev, 1966.
18. Bessonova, A.F. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya (Problems in the Biological Effect of Superhigh-Frequency (Microwave) Electromagnetic Fields), Abstracts. Leningrad, 1962, 4.
19. Boyenko, I.D. Materialy po fiziologii termoretseptsii (Materials on the Physiology of Thermoreception), Author's abstract of dissertation. Sverdlovsk, 1950.
20. Bokhon, N.N. Tr. VMA im. S.M. Kirova, Vol. 109, Leningrad, 1960, 163.
21. Bychkov, M.S. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 58.
22. Bychkov, M.S. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 8.
23. Bychkov, M.S. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnikh poley radiochastot, Abstracts of papers. Moscow, 1963, 9.
24. Bychkov, M.S. and Syngayevskaya, V.A. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts. Leningrad, 1962.
25. Vartanov, S.A. Materialy itogovoy nauchnoy konferentsii slu- /215
shateley VMA im. S.M. Kirova (Materials of Review Scientific Conference of Auditors at the S.M. Kirov Military Medical Academy), Leningrad, 1966, 1, 60.
26. Vasil'yev, N.V., Garganeyev, G.P. and Vasil'yeva, O.A. Tr. Tomskogo NIIVS i TMI, 1965, 16, 228.
27. Vasil'yev, L.L. Tainstvennyye yavleniya chelovecheskoy psikhiki (Mysterious Phenomena of the Human Psyche), Moscow, 1964.
28. Vernadskiy, V.I. Biosfera (The Biosphere), Leningrad, 1926.
29. Volkova, A.P. and Smurova, Ye.I. Gig. i san., 1967, 9, 107.
30. Vol'fovskaya, R.N. et al. Gig. i san., 1961, 5.
31. Vygodner, Ye.B. Materialy nauchnoy konferentsii Kirgizskogo NII i instituta kurortologii i fizioterapii (Materials of Scientific Conference of the Kirgiz Scientific Research Institute and the Institute of Balneology and Physiotherapy), Frunze, 1966, 131.
32. Gavrilova, O.Ye. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromag-

nitnogo polya, Abstracts. Leningrad, 1962, 13.
33. Galanin, N.F. et al. Voyenno-med. zhurn., 1956, 9, 28.
34. Gapeyev, P.I. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 152.
35. Gvozdikova, Z.M., Anan'yev, V.M., Zenina, I.N., and Zak, V.I. Tr. laboratorii elektromagnitiykh poley radiochastot instituta gigiyeny truda i profzabolevaniy AMN SSSR (Transactions of the Radiofrequency Electromagnetic Field Laboratory of the USSR Academy of Medicine Institute of Industrial Hygiene and Occupational Diseases), No. 2, Moscow, 1964, 20.
36. Gel'fon, I.A. and Sadchikova, M.N. Tr. instituta gigiyeny truda i profzabolevaniy ANM SSSR, No. 1, Moscow, 1960, 46.
37. Gembitskiy. Ye.V. Klin. med., 1953, 7, 35.
38. Gembitskiy, Ye.V. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 14.
39. Gembitskiy, Ye.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitiykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 15.
40. Gembitskiy, Ye.V. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 121.
41. Gembitskiy, Ye.V. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 139.
42. Gembitskiy, Ye.V. and Gavrilova, O.Ye. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 27.
43. Gersamiya, G.K. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnetnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 46.
44. Gershanovich, M.L. In collection entitled: Nauchnyye raboty vrachey Krasnoznamennogo Baltiyskogo Flota (Collected Scientific Papers of Physicians of the Red Banner Baltic Fleet), Tallin, 1959.
45. Ginzburg, D.A. and Sadchikova, M.N. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 17.
46. Ginzburg, D.A. and Sadchikova, M.N. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, Vol. 2, Moscow, 1964, 126.
47. Glezer, D.Ya. Materialy Leningradskoy konferentsii po UVCh (Materials of a Leningrad Conference on UHF), Leningrad, 1937, 5.
48. Glezer, D.Ya. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine (Problems in the Use of Short and Ultrashort Waves in Medicine), Moscow, 1940, 44.
49. Glibin, V.F. Gig. i san., 1952, 11, 41.
50. Glushkova, I.G. In book entitled: Voprosy kurortologii i fizioterapii (Problems of Balneology and Physiotherapy), Tomsk, 1966, 3, 187.

51. Gogibedashvili V.G. et al. Doklady 8-y konferentsii institutov kurortologii i fizioter. metodov lecheniya Azerbaydzhana, Gruzii i Armenii (Papers at 8th Conference of the Institutes of Balneology and Physiotherapeutic Treatment Methods of Azerbaydzhan, Georgia, and Armenia), Baku, 1965, 81.
52. Golendberg, A.D. et al. Vopr. kurortol., 1965, 1, 45.
53. Golysheva, K.P. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 55.
54. Goncharuk, E.N. and Pivovarov, M.A. Tr. VMA im. S.M. Kirova, Vol. 166,Leningrad, 1966, 7.
55. Gordon, Z.V., Lobanova, Ye.A. and Tolgskaya, M.G. San. i gig., 1955, 12, 16.
56. Gordon, Z.V. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 1, Moscow, 1960, 5.
57. Gordon, Z.V. and Lobanova, Ye.A. Tr. instituta gigiyeny truda i profzabolenaniy AMN SSSR, No. 1, Moscow, 1960, 59.
58. Gordon, Z.V., Lobanova, Ye.A., Nikogosyan, S.V., Kitsovskaya, /215
I.A., and Tolgskaya, M.S. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 15.
59. Gordon, Z.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 20.
60. Gordon, Z.V., Drogichina, E.A., Lobanova, Ye.A., Sadchikova, M.N., and Tolgskaya, M.S. Materialy sessii, posvyashchennoy 20-letiyu AMN SSSR i 40-letiyu instituta gigiyeny truda i profzabolenaniy (Materials of Session Devoted to the 20-th Anniversary of the USSR Academy of Medicine and the 40-th Anniversary of the Institute of Industrial Hygiene and Occupational Diseases), Moscow, 1964.
61. Gordon, Z.V. Tr. laboratorii elektromagnitnykh poley radiochastot instituta gigiyeny truda i profzabolenaniy AMN SSSR, No. 2, Moscow, 1964, 57.
62. Gordon, Z.V. In collection entitled: Voprosy gigiyeny truda i biologicheskogo deystviya elektromagnitnhkh poley sverkhvysokikh chastot, Moscow, 1966.
63. Gorizontov, P.D. Zhurn. pat. fiziol. i eksper. ter., 1967, 4, 1.
64. Gorkin, Ye.N. and Suchkova, K.I. In: sb. trudov Gor'kovskogo fizioterapevticheskogo instituta (Collected Transactions of the Gor'kiy Physiotherapeutic Institute), Gor'kiy, 1938, 50.
65. Gorodetskaya, S.F. Fiziol. zhurn. SSSR, 1960, 6, 5, 622.
66. Gorodetskaya, S.F. Fiziol. zhurn. SSSR, 1961, 7, 672.
67. Gorodetskaya, S.F. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 16.
68. Gorodetskaya, S.F. Vliyaniye sverkhvysokochastotnogo elektromagnitnogo polya na razmnozheniye, sostav perifericheskoy krovi, uslovnoreflektornyyu deyatel'nost' i morfologiyu vnutrennikh organov belykh myshey (Influence of Microwave

Electromagnetic Fields on the Multiplication, Peripheral-Blood Composition, Conditioned-Reflex Activity, and Visceral Morphology of White Mice), Author's Abstract of Dissertation, Kiev, 1963.
69. Gorodetskaya, S.F. In book entitled: Biologicheskoye deystviye ul'trazvuka i sverkhvysokochastotnykh elektromagnitnykh kolebaniy (Biological Effects of Ultrasound and Electromagnetic Microwaves), Kiev, 1964, 80.
70. Grebeshechnikova, A.M. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 17.
71. Grebeshechnikova, A.M. In collection entitled Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 26.
72. Grebeshechnikova, A.M. Tr. VMA im. S.M. Kirova, Vol. 166, 1966, 47.
73. Grigor'yan, D.G. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 27.
74. Gur'yev, V.N. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 18.
75. Gur'yev, V.N. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 28.
76. Gusarov, D.V. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 145.
77. Debay, P. Polyarnyye molekuly (Polar Molecules), Leningrad, 1963.
78. Danilevskiy, V.Ya. Issledovaniya nad fiziologicheskim deystviyem elektrichestva na rasstoyanii (Studies of the Physiological Effects of Electricity at a Distance), Part 1, Khar'kov, 1900; Part 2, Khar'kov, 1901.
79. Derevyagin, M.P. Fizioterapiya, 1939, 6, 50.
80. Dobromyslova, S.I. Vopr. kurortol., 1967, 1, 22.
81. Dolina, L.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1959, 44.
82. Drogichina, E.A. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, 1960, 29.
83. Drogichina, E.A., Sadchikova, M.N., Ginzburg, D.A., and Chulina, N.A. Gig. truda, 1962, 1, 28.
84. Drogichina, E.A., Sadchikova, M.N., and Ginzburg, D.A. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 22.
85. Drogichina, E.A. and Sadchikova, M.N. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 29.
86. Drogichina, E.A. and Sadchikova, M.N. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 2, Moscow, 1964, 105. /217

87. Drogichina, E.A. and Sadchikova, M.N. Gig. truda, 1965, 1, 17.
88. Drogichina, E.A. and Sadchikova, M.N. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 42.
89. Yermolayev, Ye.A. and Senkevich, A.I. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy (Medicobiological Problems of Microwave Radiation), Leningrad, 1966, 27.
90. Zherdin, I.V. In collection entitled "Nekotoryye dannyye o biologicheskoy kharakteristike ul'travysokoy chastoty, Gor'kiy, 1938, 33.
91. Zakrzhevskiy, Ye.B. and Malyshev, V.M. Voyenno-med. zhurn., 1964, 10, 15.
92. Zakharov, L.V. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 122.
93. Zakharov, L.V. Arterial'naya gemodinamika pri normal'noy i narushennoy regulyatsii krovoobrashcheniya (Arterial Hemodynamics in Normal and Disturbed Regulation of Blood Circulation), Author's Abstract of Dissertation, Leningrad, 1967.
94. Zelenskiy, A.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963.
95. Zenina, I.N. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 32.
96. Zenina, I.N. Tr. laboratorii elektromagnitnikh poley radiochastot instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 2, Moscow, 1964, 26.
97. Ibragimov, I.M. and Mironov, G.S. Materialy itogovoy nauchnoy konferentsii slushateley VMA im. S.M. Kirova, Leningrad, 1966, 1, 132.
98. Ivanov, A.I. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Leningrad, 1962, 24.
99. Ivanov, A.I. Tr. VMA im. S.M. Kirova, No. 166, Leningrad, 1966, 153.
100. Ivanov, A.I. and Chukhlovin, B.A. Cited from book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy (Medicobiological Problems of Microwave Radiation), Edited by Prof. I.R. Petrov, Leningrad, 1966, 105.
101. Ivanov, A.I. and Chukhlovin, B.A. Labor. delo, 1967, 10, 610.
102. Ivanov, A.I. and Chukhlovin, B.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 62.
103. Kalyada, T.V. Materialy nauchnoy sessii, posvyashchennoy 40-letiyu Leningradskogo NII gigiyeny truda i profzabolevaniy, 24-26 noyabrya 1964 (Materials of Scientific Session dedicated to the 40-th Anniversary of the Leningrad Scientific Research Institute of Industrial Hygiene and Occupational

Diseases, November 24-26, 1964), Leningrad, 66.
104. Karaseva, A.N., Mikhel'son, G.A., and Subbotin, A.A. Zhurn. mikrobiol., 1956, 1, 88.
105. Karelin, O.N. and Mishina, I.M. Gig. i san., 1966, 5, 46.
106. Kevork'yan, A.A. Gig. i san., 1948, 4, 26.
107. Kerova, N.I. Biologicheskoye deystviye ul'trazvuka i SVCh EM kolebaniy (Biological Effects of Ultrasound and Microwave Electromagnetic Vibrations), Kiev, 1964.
108. Kitsovskaya, I.A. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 1, Moscow, 1960.
109. Kitsovskaya, I.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 40.
110. Kitsovskaya, I.A. Gig. truda, 1964, 6, 14.
111. Klyachina, K.N. et al. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 41.
112. Kovach, R.I. et al. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 160.
113. Kolesnik, F.A. Klinika khronicheskogo vozdeystviya elektromagnitnykh voln sverkhvysokoy chastoty (Diagnosis and Treatment of Chronic Exposure to Electromagnetic Microwaves), Leningrad, 1961.
114. Kolesnik, F.A. and Malyshev, V.M. Voyenno-med. zhurn., 1967, 2, 27; 1967, 4, 21.
115. Kolesnik, F.A., Malyshev, V.M., and Murashev, B.F. Voyenno-med. zhurn., 1967, 7, 39.
116. Kondrat'yeva, V.F. and Chistyakova, Ye.N. Tr. Leningr. khim.-farm. in-ta, Leningrad, 1967, 20, 1, 83.
117. Komarov, F.I., Zakharov, L.V. and Kolesnik, F.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 44. /218
118. Konko, A.I., Navrotskiy, V.V., and Dubrovina, R.M. Vrach. delo, 1966, 7, 126.
119. Korsun, G.S. and Mikhaylova, G.V. Voyenno-med. zhurn., 1956, 9, 32.
120. Koton, Ye.A. and Danilova, T.N. Materialy nauchoy sessii, posvyashchennoy itogam raboty instituta za 1961/62 g. (Len. Gos. NII gigiyeny truda i profzabolevaniy) (Materials of Scientific Session Dedicated to the Work Progress of the Institute for 1961/62 (Leningrad State Scientific Research Institute of Industrial Hygiene and Occupational Diseases)), Leningrad, 1963, 83.
121. Koshtoyants, Kh.S. Dokl. Akad. Nauk SSSR, 1938, 19, 4, 317; 1944, 43, 8, 376.
122. Kruglikov, R.I. Materialy VIII Vsesoyuzn. konf. po vozrastnoy fiziologii, biokhimii, morfologii (Materials of 8th All-Union Conference on Age-Group Physiology, Biochemistry, and Morphology), Moscow, 1967, 203.
123. Kugushev, A.M. In collection entitled: Biologicheskoye deystviye ul'travysokoy chastoty (ul'trakorotkikh voln)

(Biological Effects of Ultrahigh Frequency (Ultrashort Waves)), Leningrad, 1937, 19.
124. Kudryavtseva, S.V. and Osipov, Yu.A. Referaty nauchnykh rabot Leningradskogo NII gigiyeny truda i profzabolevaniy za 1953 god (Abstracts of Scientific Papers of the Leningrad Scientific Research Institute of Industrial Hygiene and Occupational Diseases for 1953), Informats. byull., 1954, 65.
125. Kulakova, V.V. Tr. laboratorii elektromagnitnykh poley radiochastot instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 2, Moscow, 1964, 70.
126. Kulin, Ye.T. and Morozov, Ye.I. Vestn. Akad. Nauk Belorusskoy SSR, 1965, 4, 91.
127. Lebedeva, V.A. Mekhanizmy khemoretseptsii (Mechanisms of Chemoreception), Leningrad, 1965.
128. Lebedinskiy, A.V. In collection entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 121.
129. Levitina, I.A. and Presman, A.S. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 51.
130. Levitina, I.A. Byull. eksper. biol., 1966, 12, 64.
131. Leytes, F.L. and Skurikhina, L.A. Byull. eksper. biol., 1961, 52, 12, 47.
132. Lekakh, A.B. Materialy 7-go Vsesoyuzn. s"yezda fiziologov, biokhimikov, farmakologov (Materials of 7th All-Union Conference of Physiologists, Biochemists, and Pharmacologists), Moscow, 1947, 332.
133. Libezni, P., Korotkiye i ul'trakorotkiye volny (Short and Ultrashort Waves), Moscow-Leningrad, 1936.
134. Libikh, S.F. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 30.
135. Livenson, A.R. Med. prom. SSSR, 1963, 11, 10.
136. Livenson, A.R. Voprosy kurortol., 1964, 5, 450.
137. Liventsev, N.M. In book entitled: Elektromeditsinskaya apparatura (Electromedical Apparatus), 1964, 188, 297.
138. Livshits, N.N. Biofizika, 1957, 3, 2, 378.
139. Liozner, L.D. Vosstanovleniye utrachennykh organov (Regeneration of Lost Organs), Leningrad, 1962.
140. Listova, N.M. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 31.
141. Listova, N.M. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 54.
142. Lobanova, Ye.A. and Gordon, Z.V. Tr. Instituta gigiyeny truda i profzabolevaniya AMN SSSR, No. 1, Moscow, 1960, 52.
143. Lobanova, Ye.A. and Tolgskaya, M.S. Tr. instituta gigiyeny truda i profzabolevaniya AMN SSSR, No. 1, Moscow, 1960, 69.
144. Lobanova, Ye.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot,

Abstracts of Papers, Moscow, 1963, 55.
145. Lobanova, Ye.A. Tr. laboratorii elektromagnitnykh poley radiochastot instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 2, Moscow, 1964, 13.
146. Lobanova, Ye.A. Gig. truda, 1966, 10, 7.
147. Lystsov, V.N., Frank-Kamenetskiy, and Shchedrina, M.V. Biofizika, 1965, 10, 105.
148. Mayster, A. Biokhimiya aminokislot (Biochemistry of Amino Acids), Moscow, 1961.
149. Malov, N.N. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 120. /219
150. Malysheva, S.M. et al. Materialy 4-y nauchn. konf. Kirgizskogo NII i instituta kurortologii i fizioterapii, Frunze, 1966, 175.
151. Matuzov, N.I. Byull. eksper. biol., 1959, 48, 7, 27.
152. Medvedev, B.A. Byull. eksper. biol., 1957, 4, 68.
153. Meshalova, A.N. Zhurn. mikrobiol., 1961, 7.
154. Mirutenko, V.I. Teplovoy effekt deystviya i nekotoryye voprosy dozimetrii sverkhvysokochastotnogo impul'snogo elektromagnitnogo (SVCh) polya (The Thermal Effect and Certain Problems in the Dosimetry of the Pulsed Superhigh-Frequency (Microwave) Electromagnetic Field), Author's Abstract of Dissertation, Kiev, 1963.
155. Mirutenko, V.I. In collection entitled: Biologicheskoye deystviye ul'trazvuka i sverkhvysokochastotnykh elektromagnitnykh kolebaniy, Kiev, 1964, 62.
156. Mikhaylova, R.I. Stomatologiya, 1966, 1, 49.
157. Mishina, I.M. Issledovaniya rassasyvayushchego deystviya SVCh-izlucheniy apparatom Luch-58 (Effects of Microwave Radiation from the Luch-58 Apparatus on Resorption), Leningrad, Author's Abstract of Dissertation, 1965.
158. Molchanov, N.S. Gipotonicheskiye sostoyaniya (Hypotonic States), Leningrad, 1962.
159. Molchanov, N.S. Vestn. AMN SSSR, 1965, 6.
160. Moskalyuk, A.I. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 133.
161. Moshkin, Ye.A. Tr. VMA im. S.M. Kirova, Vol. 82, Leningrad, 1958, 50.
162. Mukhina, N.A. Fizioterapiya, 1940, 1, 5.
163. Nikogosyan, S.V. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, Moscow, 1960, 81.
164. Nikogosyan, S.V. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 33.
165. Nikogosyan, S.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963.
166. Nikogosyan, S.V. Gig. truda i profzabol., 1964, 9, 56.
167. Nikolayevskaya, V.P. Vestn. otorinolar., 1966, 31.
168. Nikolova-Troyeva, L. Vopr. kurortol., 1964, 3, 239.
169. Obraztsova, M.S. Klin. med., 1953, 7, 42.
170. Obrosov, A.N. et al. Vopr. kurortol., 1963, 3, 232.

171. Orlov, S.M. Vopr. med. khim., 1953, 5, 138.
172. Orlova, A.A. In collection entitled: Yubileynaya nauchnaya sessiya instituta gigiyeny truda i profzabolevaniy AMN SSSR, posvyashch. 40-letiyu Velikoy Oktyabr'skoy sotsialisticheskoy revolyutsii (Anniversary Scientific Session of the USSR Academy of Medical Sciences Institute of Industrial Hygiene and Occupational Diseases Dedicated to the 40th Anniversary of the Great October Socialist Revolution), Part 2, Abstracts, Moscow, 1957.
173. Orlova, A.A. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, Moscow, 1960, 36.
174. Orlova, A.A. In book entitled: Fizicheskiye faktory vneshney sredy (Physical Factors in the Environment), Moscow, 1960, 171.
175. Osipov, Yu.A. In book entitled: Promyshlennoye primeneniye tokov vysokoy chastoty (Industrial Use of High-Frequency Currents), Leningrad, 1952.
176. Osipov, Yu.A., Kalyada, T.V., and Kulikovskaya, Ye.L. Materialy nauchnoy sessii, posvyashchennoy itogam raboty instituta za 1959/60 g. (Len. Gos. NII gigiyeny truda i profzabolevaniy) (Materials of Scientific Session Dedicated to the Work Progress of the Institute for 1959/60 (Leningrad State Scientific Research Institute of Industrial Hygiene and Occupational Diseases)), Leningrad, 1961, 25.
177. Osipov, Yu.A. and Kalyada, T.V. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 34.
178. Osipov. Yu.A. and Kalyada, T.V. Gig. i san., 1963, 10, 73.
179. Osipov, Yu.A. and Kalyada, T.V. Materialy nauchnoy sessii, posvyashchennoy itogam raboty instituta za 1961/62 g. (Len. Gos. NII gigiyeny truda i profzabolevaniy), Leningrad, 1963, 54, 56.
180. Osipov, Yu.A. In book entitled: Materialy nauchnoy sessii, posvyashchennoy 40-letiyu Leningradskogo instituta gigiyeny truda i profzabolevaniy, Leningrad, 1964, 57.
181. Osipov, Yu.A. In collection entitled: Gigiyena truda i vliyaniye na rabotayushchikh elektromagnitnykh poley radiochastot (Industrial Hygiene and the Effects of Radio-Frequency Electromagnetic Fields on Operating Personnel), Leningrad, 1965.
182. Panov, A.G. and Tyagin, N.V. Voyenno-med. zhurn., 1966, 9, 13.
183. Parfenov, A.P. and Molchanov, Ye.V. Klin. Med., 1950, 28, 4, 84.
184. Pastushenko, L.V. and Vinogradov, V.M. Patol. fiziol. i eksper. ter., 1966, 6, 31.
185. Pervushin, V.Yu. Byull. eksper. biol., 1957, 43, 6. /220
186. Pervushin, V.Yu. and Triumfov, A.V. Tr. VMA im. S.M. Kirova, Vol. 73, 1957, 141.
187. Petrov, I.R. Fiziol. zhurn. SSSR, 1958, 44, 10, 1224.

188. Petrov, I.R. Fiziol. zhurn. SSSR, 1960, 46, 10, 82.
189. Petrov, I.R. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy (Medicobiological Problems of Microwave Radiation), Leningrad, 1966, 114.
190. Petrov, I.R. and Subbota, A.G. Voyenno-med. zhurn., 1964, 9, 26.
191. Petrov, I.R. and Subbota, A.G. Voyenno-med. zhurn., 1964, 9.
192. Petrov. I.R. and Pukhov, V.A. Tr. VMA im. S.M. Kirova, Vol. 666, Leningrad, 1966.
193. Petrov, I.R. and Syngayevskaya, V.A. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy, Leningrad, 1966, 72.
194. Petrov, I.R. and Yarokhno, N.Ya. Voyenno-med. zhurn., 1967, 4, 20.
195. Petrov, I.R. and Yarokhno, N.Ya. Voyenno-med. zhurn., 1967, 7, 21.
196. Pivovarov, M.A. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Leningrad, 1962, 35.
197. Pivovarov, M.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963.
198. Pitenin, I.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts, Moscow, 1959, 54.
199. Pitenin, I.V. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 36.
200. Pitenin, I.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 69.
201. Pitenin, I.V. and Subbota, A.G. Byull. eksper. biol., 1965, 9, 55.
202. Pitenin, I.V. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 76.
203. Pokutsa, P.I. Vopr. kurortol., 1965, 1, 77.
204. Polyak, B.L., Volkov, V.V., and Shilyayev, V.G. Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 38.
205. Ponomarev, A.V. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 90.
206. Presman, A.S. Usp. sovr. biol., 1956, 41, 1, 40.
207. Presman, A.S. Byull. eksper. biol., 1957, 43, 2, 51.
208. Presman, A.S. Gig. i san., 1958, 1, 21.
209. Presman, A.S. and Levitina, N.A. Byull. eksper. biol., 1960, 53, 4, 39.
210. Presman, A.S., Kamenskiy, Yu.I., and Levitina, N.A. Usp. sovr. biol., 1961, 51, 1, 84.
211. Presman, A.S. Usp. sovr. biol., 1963, 56, 2 (5), 161.
212. Presman, A.S. Usp. fiz. nauk, 1965, 86, 2.
213. Presman, A.S. and Rappoport, S.M. Byull. eksper. biol., 1965, 59, 4, 48.

214. Presman, A.S. Elektromagnitnyye polya i zhivaya priroda (Electromagnetic Fields and Living Nature), Moscow, 1968.
215. Pushkarev, A.D. Klin. med., 1956, 34, 5, 80.
216. Revutskiy, Ye.L. Vrach. delo, 1963, 11, 59.
217. Romanov, V.I. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 3.
218. Romanov, Yu.D. Materialy k klinike gipotonicheskikh sostoyaniy i rezul'tat dinamicheskogo nablyudeniya za litsami molodogo vozrasta s arterial'noy gipotoniyey (Clinical Materials on Hypertonic States and the Results of Dynamic Observations of Young People with Arterial Hypotonia), Author's Abstract of Dissertation, Leningrad, 1957.
219. Ryzhkova, M.N. and Smirnova, M.N. Gig. truda, 1961, 6, 34.
220. Savitskiy, N.N. Biofizicheskiye osnovy krovoobrashcheniya i klinicheskiye metody izucheniya gemodinamiki (Biophysical Foundations of Blood Circulation and Clinical Methods for the Study of Hemodynamics), Moscow, 1963.
221. Sadchikova, M.N. and Orlova, A.A. Gig. truda, 1958, 6, 16.
222. Sadchikova, M.N. In book entitled: Fizicheskiye faktory vneshney sredy, Moscow, 1960, 177.
223. Sadchikova, M.N. In collection entitled: Gigiyena truda i /221
biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 75.
224. Sverdlina, N.T. Materialy k nauchnoy sessii, posvyashchennoy 40-letiyu NII gigiyeny truda i profzabolevaniy (Leningrad), 24-26 noyabrya 1964 g., Leningrad, 1964, 64.
225. Svetlova, Z.P. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 43.
226. Svetlova, Z.P. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 81.
227. Svetlova, Z.P. Tr. VMA im. S.M. Kirova, Vol. 166, 1966, 38.
228. Svetlova, Z.P. and Subbota, A.G. Tezisy dokladov XVI Ukrainskoy respubl. nauchno-tekhnicheskoy konf., posvyashchennoy Dnyu radio (Abstracts of Papers at Sixteenth Ukrainian Republic Scientific-Technical Conference Dedicated to Radio Day), Kiev, 1966, 151.
229. Sviridov, L.P. Materialy itogovoy nauchnoy konferentsii slushateley fakul'teta usovershenstvovaniya vrachey (Materials of Review Scientific Conference of Auditors in the Physicians' Improvement Faculty), Leningrad, 1967, 131.
230. Sevast'yanov, V.V. and Sedel'nikov, Yu.N. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 82.
231. Sevast'yanov, V.V. Tezisy dokladov XXII oblastnoy konferentsii NTO im. A.S. Popova (Abstracts of Papers at 22nd Regional Conference of the A.S. Popov Scientific-Technical Society), Leningrad, 1967.
232. Sevast'yanov, V.V. and Semenov, A.I. Vopr. kurortol., 1967, 1, 25.

233. Severin, S.Ye. et al. Dokl. Akad. Nauk SSSR, 1960, 131, 1447.
234. Severin, S.Ye. Zhurn. kardiol., 1961, 2, 1.
235. Sel'ye, G. Ocherki ob adaptatsionnom sindrome (Outlines of the Adaptation Syndrome), Moscow, 1960.
236. Semdomskaya, D.V. Vopr. pitaniya, 1956, 15, 2, 37.
237. Semenov, A.I. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 83.
238. Semenov, A.I. O vliyanii SVCh elektromagnitnogo polya na temperaturu tkaney bedra krolika (Effects of Electromagnetic Microwave Fields on Tissue Temperature in the Thigh of the Rabbit), Author's Abstract of Dissertation, Leningrad, 1965.
239. Semenov, A.I. Byull. eksper. biol., 1965, 7, 64.
240. Sil'vestrov, V. P. Ter. arkh., 1956, 2, 9.
241. Skurikhina, L.A. Vopr. kurortol., 1961, 4, 338.
242. Slabospitskiy, A.A. In collection entitled: Biologicheskoye deystviye ul'trazvuka i sverkhvysokochastotnykh elektromagnitnykh kolebaniy, Kiev, 1964, 92.
243. Smirnova, M.I. and Sadchikova, M.N. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, Moscow, 1960, 50.
244. Smit, A. Radioastronomiya (Radio Astronomy), Moscow, 1961.
245. Smurova, Ye.I. et al. Gig. truda, 1962, 5, 22-27.
246. Smurova, Ye.I. In book entitled: Voprosy gigiyeny truda i profzabolevaniy, Gor'kiy, 1966, 86.
247. Sokolov, V.V., Ariyevich, M.N., and Chulina, N.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Abstracts, Moscow, 1959, 32.
248. Sokolov, V.V. and Ariyevich, M.N. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, Moscow, 1960, 43.
249. Sokolov, V.V., Kitsovskaya, I.A., and Chulina, N.A. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 48.
250. Sokolov, V.V. and Chulina, N.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963.
251. Solov'yev, N.A. Novosti med. tekhniki, 1962, 5, 86.
252. Spasskiy, V.A. Voyenno-med. zhurn., 1956, 9, 25.
253. Sorokina, Ye.I. Vopr. Kurortol., 1965, 1, 40.
254. Stroykova, K.V. and Belyayeva, T.I. Tr. laboratorii elektrobezopasnosti. Zashchita ot deystviya elektricheskikh poley i elektricheskogo toka v promyshlennosti (Transactions of Electrical Safety Laboratory. Protection from Electric Fields and Electric Current in Industry), All-Union Scientific Research Institute of Industrial Safety, Leningrad, 1958, 76.
255. Subbota, A.G. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 35.
256. Subbota, A.G. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 78.

257. Subbota, A.G. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 127. /222
258. Subbota, A.G. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 165.
259. Subbota, A.G. Byull. eksper. biol., 1958, 10, 55.
260. Subbota, A.G. 18-e soveshchaniye po problemam vysshey nervnoy deyatel'nosti (18th Conference on Problems of Higher Nervous Activity), No. 3, Leningrad, 1958, 148.
261. Subbota, A.G. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) polya. Abstracts, Leningrad, 1962, 49.
262. Subbota, A.G. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 92.
263. Subbota, A.G. Lektsii po probleme SVCh-izlucheniy (Lectures on the Problem of Microwave Radiation), Leningrad, 1964.
264. Subbota, A.G. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy, Edited by Prof. I.P. Petrov, Leningrad, 1966, IV, 38.
265. Subbota, A.G. Tezisy dokl. XVI Ukrainskoy resp. nauchno-tekhnicheskoy konferentsii, posvyashchennoy Dnyu radio, Kiev, 1966, 148.
266. Subbota, A.G. and Sverlova, Z.P. 21-e soveshchaniye po probl. vysshey nervn. deyatel'nosti (21st Conference on the Problems of Higher Nervous Activity), Moscow, 1966, 284.
267. Subbota, A.G. et al. Tezisy dokl. XXII nauchno-tekhnicheskoy konferentsii, posvyashchennoy 50-letiyu Sovetskoy vlasti (Abstracts of Papers at 22nd Scientific-Technical Conference Dedicated to the 50th Anniversary of the Soviet Regime), Leningrad, 1967, 57.
268. Subbota, A.G. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 148.
269. Subbota, A.G. and Chukhlovin, B.A. Biologicheskoye deystviye sverkhvysokochastotnykh (SVCh) izlucheniy (Bibliographic Index), Leningrad, 1968.
270. Suponitskaya, F.M. Byulleten' Gos. NII fiz. metodov lecheniya im. Sechenova (Bulletin of the Sechenov State Scientific Research Institute of Physical Methods of Therapy), Sevastopol', 1933, 6, 244.
271. Suponitskaya, F.M. Arkh. patol. anat., 1937, 3, 2, 118.
272. Suponitskaya, F.M. V. sb. trudov Gor'kovskogo fizioterapevticheskogo instituta (In collected Transactions of the Gor'kiy Physiotherapeutic Institute), 1938, 3, 4.
273. Suponitskaya, F.M. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 58.
274. Schastnaya, P.I. Tr. Khar'kovskogo gos. med. instituta, 1958, 15, 36, 239.
275. Syngayevskaya, V.A., Ignat'yeva, O.S., and Pliskina, T.P. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya,

Abstracts, Leningrad, 1962, 52.
276. Syngayevskaya, V.A., Ignat'yeva, O.S., and Sinenko, G.F. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 51.
277. Syngayevskaya, V.A., Ignat'yeva, O.S., and Pliskina, T.P. Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot. Abstracts of Papers, Moscow, 1963, 94.
278. Syngayevskaya, V.A. and Sinenko, G.F. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 95.
279. Syngayevskaya, V.A. and Pliskina, T.P. In collection entitled: Gigiyena trudy i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 96.
280. Syngayevskaya, V.A. Lektsii po probleme SVCh-izlucheniy (Lectures on the Problem of Microwave Radiation), Leningrad, 1964.
281. Syngayevskaya, V.A. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy, Leningrad, 1966, 67 and 93.
282. Syngayevskaya, V.A. Tezisy dokl. XVI Ukrainskoy resp. nauchno-tekhnich. konferentsii, posvyashchennoy Dnyu radio, Kiev, 1966, 152.
283. Syngayevskaya, V.A. and Sinenko, G.F. Trudy VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 57.
284. Syngayevskaya, V.A. and Ignat'yeva, O.S. Trudy VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 71.
285. Syngayevskaya, V.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 150.
286. Talayeva, Yu.G. Gig. i san., 1956, 9, 69.
287. Tatarinov, V.V. In collection entitled: Biologicheskoye deystviye ul'travysokoy chastoty (ul'trakorotkikh voln), Moscow, 1937. /223
288. Timeskova, G.F. Influence of Microwave Radiation on the Human and Animal Organism, Trudy VMA im S.M. Kirova, Vol. 166, Leningrad, 1966, 100.
289. Tkachenko, Ye.G. and Padalka, V.S. In book entitled: metody fiziko-khimicheskikh analizov (Methods of Physicochemical Analysis), Rostov-on-Don, 1965, 222.
290. Tolgskaya, M.S. and Gordon, Z.V. In collection entitled: Gigiyena trudy i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Abstracts, Moscow, 1959, 55.
291. Tolgskaya, M.S., Lobanova, Ye.A., and Gordon, Z.V. Vopr. kurortol., 1959, 1, 21.
292. Tolgskaya, M.S., Gordon, Z.V., and Lobanova, Ye.A. Tr. Instituta gigiyeny truda i profzabolevaniy AMN SSSR, Moscow, 1960, 90.
293. Tolgskaya, M.S. and Gordon, Z.V. Tr. instituta gigiyeny truda i profzabolevaniy AMN SSSR, Moscow, 1960, 99.

294. Tolgskaya, M.S., Gordon, Z.V., and Lobanova, Ye.A. In book entitled: Fizicheskiye faktory vneshney sredy, Moscow, 1960, 188.
295. Tolgskaya, M.S. and Gordon, Z.V. Tr. laboratorii elektromagnitnykh poley radiochastot Instituta gigiyeny truda i profzabolevaniy AMN SSSR, No. 2, Moscow, 1964, 80.
296. Tonkikh, A.V. In book entitled: Voprosy primeneniya korotkikh i ul'trakorotkikh voln v meditsine, Moscow, 1940, 67.
297. Toroptsev, I.V. Arkh. pat., 1968, 30, 3, 3.
298. Treskunova, A.S. and Slizskiy, G.N. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 53.
299. Troshina, Ye.D. Materialy Vsesoyuznogo s"yezda fizioter. i kurort. (Materials of All-Union Conference of Physiotherapists and Balneologists), Baku, 1965, 351.
300. Turlygin, S.Ya. and Kobozev, N.I. Dokl. Akad. Nauk SSSR, 1937, 17, 1-11, 77.
301. Turlayev, T.M. Biokhimiya, 1958, 1, 23.
302. Tyagin, N.V. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 9.
303. Tyagin, N.V. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 84.
304. Tyagin, N.V. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 102.
305. Tyagin, N.V. Tr. VMA im. S.M. Kirova, Vol. 73, Leningrad, 1957, 116.
306. Tyagin, N.V. Byull. eksper. biol., 1958, 46, 8, 67.
307. Tyagin, N.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Abstracts, Moscow, 1959, 24.
308. Tyagin, N.V. Voyenno-med. zhurn., 1960, 9, 14.
309. Tyagin, N.V. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 54.
310. Tyagin, N.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963.
311. Tyagin, N.V. Voyenno-med. zhurn., 1965, 2, 36.
312. Tyagin, N.V. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy (Medicobiological Problems of Microwave Radiation), Leningrad, 1966, 155.
313. Tyagin, N.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 158.
314. Uvarov, A.G. In book entitled: Aktual'nyye voprosy teoreticheskoy i klinicheskoy meditsiny (Urgent Problems in Theoretical and Clinical Medicine) Kiev, 1966, 249.
315. Uspenskaya, N.V. Tr. nauchnoy sessii Leningradskogo NII gigiyeny truda i profzabolevaniy, posvyashchennoy itogam raboty za 1957 g. (Transactions of Scientific Session of the Leningrad Scientific Research Institute of Industrial

Hygiene and Occupational Diseases Devoted to the Progress of Work in 1957), Leningrad, 1959, 63.
316. Uspenskaya, N.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Abstracts, Moscow, 1959, 28.
317. Uspenskaya, N.V. Vrach. delo, 1961, 3, 124.
318. Uspenskaya, N.V. Materialy Nauchnoy sessii, posvyashchennoy itogam raboty instituta za 1961/1962 gg. (Len. Gos. NII gigiyeny truda i profzabolevaniy), Leningrad, 1963, 61.
319. Uspenskaya, N.V. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963, 101. /224
320. Uspenskaya, N.V. Klinika khronicheskogo vozdeystviya elektromagnitnykh voln maloy intensivnosti (Diagnosis and Treatment of Chronic Exposure to Low-Intensity Electromagnetic Radiation), Author's Abstract of Dissertation, Leningrad, 1963.
321. Faytel'berg-Blank, V.R. Byull. eksper. biol., 1964, 57, 45.
322. Faytel'berg-Blank, V.R. Fiziologicheskiy zhurn. SSSR, 1965, 51, 3, 372.
323. Fofanov, P.N. Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 56.
324. Fofanov, P.N. Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 129.
325. Frenkel',G.L. Biologicheskoye deystviye ul'travysokikh chastot (ul'trakorotkikh voln), Moscow, 1937, 115.
326. Frenkel', G.L. Deystviye UVCh na infektsiyu i immunitet (Effects of UHF on Infection and Immunity), No. 4, Edited by A.V. Ponomarev, Leningrad, 1940.
327. Frolova, L.T. K gigiyenicheskoy otsenke usloviy truda pri rabote s tokami sverkhvysokoy chastoty (Hygienic Evaluation of Working Conditions in Work with Superhigh-Freuency Currents), 1963, 2, 27-29.
328. Fukui, Ref. zhurn. Biologiya, 1961, 13, Abstract 11, 98.
329. Khazen, I.M. In collection entitled: Teoriya i praktika fizioterapii. Trudy Moskovskoy obl. klin. fizich. metodov lecheniya (Theory and Practice of Physiotherapy. Transactions of Moscow Regional Physiological-Therapy Clinic), Moscow, 1940, 4, 25.
330. Kholodov, Yu.A. In collection entitled: Voprosy biologicheskogo deystviya sverkhvysokochastotnogo (SVCh) elektromagnitnogo polya, Abstracts, Leningrad, 1962, 59.
331. Kholodov, Yu.A. Priroda, 1962, 4, 105.
332. Kholodov, Yu.A. Vliyaniye elektromagnitnykh i magnitnykh poley na tsentral'nuyu nervnuyu sistemu (Influence of Electromagnetic and Magnetic Fields on the Central Nervous System), Moscow, 1966.
333. Kholodov, Yu.A. Tezisy dokladov 2-go zonal'nogo simpoznuma po bionike (Abstracts of Papers at Second Zonal Symposium on Bionics), Minsk, 1967, 98.
334. Kholodnyy, A.Ya., Ivanov, A.I., and Chukhlovin, B.A. In

collection entitled: Gigiyena truda i biologich. deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 165.
335. Chepikova, I.R. Materialy nauchnoy konferentsii po eksperim. kurortologii i fizioterapii (Materials of Scientific Conference on Experimental Balneology and Physiotherapy), Moscow, 1962.
336. Chepikova, I.R. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh poley radiochastot, Abstracts of Papers, Moscow, 1963.
337. Chepikova, I.R. Materialy Vsesoyuznogo s"ezda fizioter. i kurort. (Materials of All-Union Conference on Physiotherapy and Balneology), Baku, 1965, 158.
338. Cheredova, V.S. Zdravookhr. Belorussii, 1967, 4, 65.
339. Chernigovskiy, V.N. Fiziol. zhurn. SSSR, 1940, 29, 526.
340. Chernigovskiy, V.N. Interoretseptory (Interoceptors), Leningrad, 1961.
341. Chizhenkova, R.I. Zhurn. vysshey nervn. deyatel'nosti, 1967, 17,666, 1083.
342. Chistyakova, N.S. Vopr. kurortol., 1967, 1, 16.
343. Chukhlovin, B.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnogo polya radiochastot, Abstracts of Papers, Moscow, 1963, 13.
344. Chukhlovin, B.A. Voyenno-med. zhurn., 1965, 7, 25.
345. Chukhlovin, B.A. Tezisy dokladov XVI Ukrainskoy resp. nauchn.-tekhn. konferentsii, posvyashchennoy Dnyu radio, Kiev, 1966, 149.
346. Chukhlovin, B.A.Tr. VMA im. S.M. Kirova, Vol. 166, Leningrad, 1966, 64.
347. Chukhlovin, B.A. In book entitled: Mediko-biologicheskiye problemy SVCh-izlucheniy, Leningrad, 1966, 105.
348. Chukhlovin, B.A., Grachev, B.N., and Likina, I.V. Byull. eksper. biol., 1966, 6, 53.
349. Chukhlovin, B.A. In collection entitled: Gigiyena truda i biologicheskoye deystviye elektromagnitnykh voln radiochastot, Moscow, 1968, 172.
350. Shemyakov, S.I. Voyenno-med. zhurn., 1955, 5, 79.
351. Shenfil', L.L. and Peylet, M.I. Vopr. kurortol., 1967, 1, 19.
352. Shereshevskaya, L.Ya. Vestn. oftal'mol., 1966, 3, 5.
353. Shilyayev, V.G. Tr. VMA im. S.M. Kirova, 1960, Vol. 109, 169.
354. Shimkhovich, I.S. and Shilyayev, V.G. Vestn. oftal'mol., 1959, 4, 12.
355. Shcherbachev, I.I. Farmakol. i toksikol., 1968, 31, 1, 107. /225
356. Shchipkova, V.A. In collection entitled: Nauchnyye raboty vrachey Krasnoznamennogo Baltiyskogo Flota, Tallin, 1959.
357. Yudayev, N.A. Opredeleniye steroidnykh gormonov v biologicheskikh zhidkostyakh (Determination of Steroid Hormones in Biological Fluids), Moscow, 1961.
358. Yakovleva, M.I. Tr. instituta eksperimental'noy meditsiny AMN SSSR, Yezhegodnik (Transactions of the USSR Academy of Medicine Institute of Experimental Medicine. Yearbook), 1966, 9, 2, 135.

359. Yanushkevich, R.I. and Rogovaya, T.Z. V sb. Gor'kovskogo NII gigiyeny truda i profzabolevaniy (In collection of Gor'kiy Scientific Research Institute of Industrial Hygiene and Occupational Diseases), Gor'kiy, 1956, 32.
360. Yatsenko, M.I. Vopr. kurortol., 1966, 5, 446.
361. Addington, C., Osborn, C. et al., Biol. Eff. Microwave Rad., 1961, 1, 17.
362. Amadou, R. La parapsichologia, Paris, 1954.
363. Austin, G. Am. J. Phys. Med., 1954, 33, 141, 149.
364. Bach, S. Feder. Proc., 1965, 24, Suppl. 14, 22.
365. Bach, S.A., Luzzio, A.S. et al. Biol. Eff. Microwave Radiation, 1961, 1, 117.
366. Baranski, S. Rev. Med. Aeronaut., 1963, 6, 2, 108.
367. Barber, D.E. Digest of the Intern. Conf. on Medical Electronics, New York, 1961, 157.
368. Barber, D. IRE Trans. Biomed. Electr., 1962, 9, 77.
369. Barron, C., Love, A., and Baraff, A. J. Aviat. Med., 1956, 26, 6, 442.
370. Barron, C., Love, A., and Baraff, A. Trans. IRE Med. Electr., 1956.
371. Barron, Ch. and Baraff, A. JAMA, 1958, 168, 9, 1194.
372. Beily, P. Aviation Week, 1959, 70, 29.
373. Boiteau, H. Rev. Corps Sante Armees, 1960, 1, 637.
374. Bovill, Ch. Brit. Commun. Electr., 1960, 7, 363.
375. Boysen, J.E. Arch. Ind. Hyg. Occup. Med., 1953, 7, 6, 516.
376. Brody, S.J. Aviat. Med., 1953, 24, 516.
377. Brody, S. Trans. IRE Med. Elect., 1956, 89.
378. Brown, G.L. and Gray, J.A. J. Physiol., 1948, 107, 306.
379. Brown, G. and Morrison, W. Tomberg. Food Technol., 1954, 8, 361.
380. Carpenter, R. Medford Mass. Tufts Univ., 1957.
381. Carpenter, R. et al. Am. J. Ophthal., 1959, 47, 94.
382. Carpenter, R. et al. Proc. Third Intern. Conf. Med. Electr., New York, 1960, 30.
383. Carpenter, R. et al., Proc. Fourth Intern. Conf. Med. Electr., New York, 1961, 194.
384. Cazzamalli, F. Congres International de Recherches Psychiques, Paris, 1928.
385. Ciecura, L. and Minecki, L. Med. pracy, 1964, 15, 159.
386. Clark, Y. Proc. IRE, 1950, 38, 1028.
387. Cogan, D. et al. Arch. Ind. Health, 1958, 18, 299.
388. Cook, H. Brit. J. Appl. Physiol., 1952, 3, 249.
389. Cook, H. Brit. J. Appl. Physiol., 1952, 1, 118.
390. Cooper, Th. et al. Aerospace Med., 1962, 33, 7, 794.
391. Cooper, Th. et al. Am. J. Physiol., 1962, 202, 6, 1171.
392. Cooper, Th. et al. Experentia, 1965, 21, 1, 28.
393. Daily, L. U.S. Naval Med. Bull., 1943, 41, 1052.
394. Daily, L. and Wakim, K. Am. J. Ophthal., 1950, 33, 1241.
395. Daily, L., Wakim, K. et al. Trans. IRE, Med. Electr., 1956, 25.
396. Deichmann, W. Ind. Med. Surg., 1959, 28, 5, 212.
397. Deichmann, W. Ind. Med. Surg., 1959, 28, 12, 535.

398. Deichmann, W. Biochem. Pharmac., 1961a.
399. Deichmann, W. Ind. Med. Surg., 1961b, 30, 7, 221.
400. Deichmann, W. Ind. Med. Surg., 1961c, 30, 7, 264.
401. Deichmann, W., Stephens, F. et al. J. Occup. Med., 1959, 1, 7, 369.
402. Denier, A. Bull. Soc. Fr. Electr. et Rad., 1932, 41, 191.
403. Denier, A. Wien. med. Wschr., 1937, 87, 28/29, 743.
404. Egan, W. Electr. Eng., 1957, 76, 2, 126. /226
405. Ely, T. et al. IRE Trans. Med. Electr., 1956, 38.
406. Engel, J. et al. Arch. Phys. Med., 1950, 31, 7, 453.
407. Epstein, M.A. and Cook, H.F. Brit. J. Cancer, 1951, 5, 1, 244.
408. Esaux, 1933. Cited from P. Libezni, 1936.
409. Fiandesio, D. Minerva Fisioterapica, 1961, 6, 44.
410. Fischer, H. Münch. med. Wschr., 1963, 105, 22, 1448.
411. Fleming, H. Electr. Eng., 1944, 63, 1, 18.
412. Frey, A. Aerospace Med., 1961, 32, 12, 1140.
413. Frey, A. Proc. Fourth Intern. Conf. Med. Electr., New York, 1961, 158.
414. Frey, A. Am. J. Med. Electr., 1963, 2, 28.
415. Fukui, K. Japan Balneo-Climatol. Ass., 1959, 23, 1, 46.
416. Gersten, J.W., Wakim, K.C., et al. Arch. Phys. Med., 1949, 30, 7.
417. Gruszecki, L. Biull. Woisk. Akad. Med., 1962, 5, 2, 61.
418. Gruszecki, L. Pregl. lek., 1964, 20, 7, 336. Ref. Exc. Med. Physiol., 1965, 8, 3378.
419. Gunn, S. Lab. Invest., 1961, 10, 2, 301.
420. Harte, C. Cromosoma, 1949, 3, 440.
421. Hasche, E. and Loch, P. Z. Hyg. Infectionskrankh., 1937, 120, 209.
422. Heller, J.H. Nature, 1959a, 183, 905.
423. Heller, J. Electronic, 1959b, 32, 4, 38.
424. Heller, J. Nature, 1963, 197, 997.
425. Heller, J. and Mickey, G. Proc. Fourth Intern. Conf. Med. Electr., New York, 1961, 152.
426. Hendler, E. IRE Trans. Med. Electr., 1960, ME-7, 3, 143.
427. Herrick, J.F. and Krusen, F.H. Electr. Eng., 195x, 72, 3, 239.
428. Hines, H. and Randall, J. Electr. Eng., 1952, 71, 10, 879.
429. Hirsch, F. and Parker, J. AMA Arch. Industr. Health, 1952, 6, 512.
430. Horai, H. Nippon Act. Radiol., 1962, 22, 173.
431. Howland, I. and Michaelson, S. Technical note, RADS-TH, 1959, 59.
432. Howland, J. et al. Proc. Biol. Eff. Microwave Rad., 1961, 1, 261.
433. Hubelbank, Sh. Electr. World, 1960, 63, 4, 45.
434. Hübner, R. Elektronische Rundschau, 1960, 14, 8, 229.
435. Imig, C. and Tomson, I. Proc. Soc. Exp. Biol. Med., 1948, 69, 382.
436. Iranyi, J. Münch. Med. Wschr., 1960, 102, 3, 142.
437. Jacobson, B. and Süsskind, C. IRE Nat. Convent. Record, 1959, 7, 9. 13.

438. Jaski, T. Radio Electr., 1960, 31, 9, 43.
439. Kaczynski, A. et al. Urol. Int., 1965, 20, 236.
440. Kalant, W. Canad. Med. Ass. J., 1959, 81, 7, 575.
441. Kemp, G.R. et al. Arch. Phys. Med., 1948, 20, 12.
442. Klimkova-Deutschova, E. Arch. Gewerbepathol. u. Gewerbehyg., 1957, 16, 72-85; 1963, 20, 1, 1.
443. Klinger, N. Einführung in die Microwellen und ihre wissenschaftlichen Anwendung (Introduction to Microwaves and Their Scientific Applications), Stuttgart, 1954.
444. Knauf, G. Arch. Indust. Health, 1958, 17, 5, 383.
445. Krusen, F. Proc. Soc. Med., London, 1950, 43, 641.
446. Krusen, F. Proc. Soc. Med., London, 1956, 43, 641.
447. Leary, F. Electronics, 1959, 32, 8, 49.
448. Leden, U., Herrick, J. et al. Brit. J. Phys. Med., 1947, 10, 177.
449. Lehmann, J. Arch. Phys. Med., 1964, 25, 555.
450. Lehmann, J., Guy, A. et al. Arch. Phys. Med., 1962, 43, 69.
451. Lehmann, J., McMillan, J. and Brunner, G. Arch. Phys. Med., 1962, 43, 538.
452. Lidman, B. and Cohn, C. Air Surgeon's Bull., 1945, 2, 448.
453. Linke, C.J. Urol., 1962, 88, 303.
454. Lubin, M. Engl. J. Med., 1958, 259, 16, 720.
455. Marek, H. Pracov. lek., 1959, 11, 8, 401-403.
456. McAfee, R. Am. J. Physiol., 1962, 203, 2, 374.
457. McAfee, R. Biomed. Sci. Instrum., 1963, 1, 167. /227
458. McAfee, R. and Berger, C. et al. Am. J. Physiol., 1961, 200, 192.
459. McLaughlin, J. California Med., 1957, 86, 336.
460. Merola, L. and Kinoshita, J. Biol. Eff. Microwave Rad., 1961, 1, 285.
461. Michaelson, V. Industr. Med. Surg., 1961, 7, 30, 298.
462. Michaelson, S. Am. J. Physiol., 1961, 201, 351.
463. Michaelson, S. Aerospace Med., 1962, 33, 3, 345.
464. Michaelson, S. et al. Rad. Res., 1962, 16, 4, 576.
465. Michaelson, S. et al. Aerospace Med., 1963, 34, 111.
466. Michaelson, M. et al. Aerospace Med., 1965, 36, 11, 1059.
467. Minecki, L. Med. pracy, 1964a, 15, 2, 69.
468. Minecki, L. Med. pracy, 1964b, 13, 4, 255.
469. Miro, I. Medicin de Reserve Sante, 1963, J-F, 1.
470. Mukulski, I. Kosmos A-9, 1960, 4, 451.
471. Mumford, W.W. Proc. IRE, 1961, 49, 2, 427.
472. Niffenegger, R. Michigan Technic, 1962, 80, 5, 22.
473. Nyrop, J. Nature, 1946, 157, 51.
474. Osborne, S. and Frederick, J. JAMA, 1948, 137, 1036.
475. Paff, G. et al. Anat. Res., 1963, 147, 3, 379.
476. Pätzold, I.Z. Hochfrequenztechn., 1930, 36, 85.
477. Pautrizel, R. and Riviere, M. C.R. Acad. Sci., 1966, 263, 5, 579.
478. Pierach, A. and Heynemann, K. Beiträge zur praktischen Medizin (Contributions to Practical Medicine), Stuttgart, 1959, 38.
479. Pinakett, T. Feder. Proc., 1963, 22, 2 pt., 1, 176.
480. Plurien, G. Sentenal-Roumanon, H. C.R. Soc. Biol., 1966, 160, 3, 597.

481. Prausnitz, S., Süsskind, C. et al., Proc. Biol. Eff. Microwave Rad., 1961, 1, 135.
482. Prausnitz, S. and Süsskind, C. IRE Biomed. Electr., 1962, BME-9, 104.
483. Rae, J., Herrick, J. et al. Arch. Phys. Med., 1949, 30, 199.
484. Richardson, A., Imig, C., et al. Arch. Phys. Med., 1950, 31, 19.
485. Richardson, A. Arch. Ophthal., 1951, 45, 352.
486. Richardson, A. Am. J. Phys. Med., 1954, 33, 103.
487. Robert, J. and Cook, H. Brit. J. Appl. Phys., 1952, 3, 2, 33.
488. Sacchitelli, F. and Lerza, P. Pathologica, 1964, 56, 291.
489. Saito, M. Biol. Eff. Microwave. Rad., 1961, 1.
490. Salati, O. et al. Electr. Indust., 1962, 21, 11, 96.
491. Schliephake, E. Preface by W.H. Veil. Physical Appendix by L. Bohde. Jena, 1932.
492. Schliephake, E. Kurzwellentherapie (Shortwave Therapy), Stuttgart, 1960.
493. Schliephake, E. Münch. med. Wschr., 1960, 102, 2020.
494. Schliephake, E. Electromed., 1960, 80.
495. Schliephake, E. Münch. med. Wschr., 1961, 193, 1244.
496. Schliephake, E. Münch. med. Wschr., 1962, 104, 1238.
497. Schwan, H. and Piersol, G. Am. J. Physical Med., 1954, 33, 6, 371.
498. Schwan, H. and Piersol, G. Am. J. Physical Med., 1955, 34, 3, 425.
499. Schwan, H. and Li, K. Proc. IRE, 1956, 44, 11, 1572.
500. Sercle, M. et al. Z. ges. Hyg., 1961, 7, 12, 897.
501. Searle, G.W., Dahlen, R.W., et al. C. Biol. Eff. Microwave Radiation, 1961, 1, 187.
502. Sercle, M., Yoros, O., and Svacina, Y. Kovarik, Pracov. lek., 1959, 11, 8, 395.
503. Sequin, L. L'onde Electr., 1949, 29, 27.
504. Sequin, L., et al. Rev. Sci., Paris, 1948, 86, 335.
505. Spiegel, F. Arch. Phys. Therap., 1956, 8, 3, 215.
506. Süsskind, K. Monthly Progress Report, Univ. of California, 1958.
507. Süsskind, C. Proc. IRE, 1962, 109, 23, 668.
508. Teixeire-Pinto, A. Exp. Cell, Res., 1960, 20, 3, 548.
509. Thorn, G.W. Nebenniereninsuffizienz, Diagnose und Behandlung (Adrenal Insufficiency. Diagnosis and Treatment), Bern, 1953. /228
510. Tomberg, V. IRE Intern. Convent. Rec., 1960, 8, 9, 94.
511. Tomberg, W. Biol. Eff. Microwave Rad., 1961, 1, 221.
512. Tomson, R. et al. Blood, 1966, 28, 2, 157.
513. Van Everdinger, Rev. Belg. Sci. Med., 1946, 17, 261.
514. Van Ummersen, C. Biol. Eff. Microwave. Rad., 1961, 1, 201.
515. Van Ummersen, C. and Cogan, F. Arch. Environ. Health, 1965, 11, 2, 177.
516. Vosburgh, B. IRE Trans. Med. Electr., 1956, 57.
517. Williams, D. Am. Med. Ass. Arch. Ophthal., 1955, 54.
518. Williams, D. and Monahan, I. IRE Trans. Med. Electr., 1956, 17.

519. Worden, R. Arch. Phys. Med., 1948, 29, 751.
520. Zaret, M. Biol. Eff. Microwave Rad., 1961, 2, 293.

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