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BIOLOGICAL EFFECT OF MICROWAVES IN OCCUPATIONAL HYGIENE

(Voprosy gigieny truda i biologicheskogo deistviya elektromagnitnykh polei sverkhvysokikh chastot)

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in the tissues. These investigations marked a new stage in the research on the biological effect of this little-studied region in the electromagnetic spectrum.

In the USA, interest in the biological effects of microwaves in the centimeter range was aroused in 1943 by examination of sailors servicing low-power radar units (Daily, 1943). Later, in 1954, the medical office of the U. S. aircraft industry embarked on dynamic investigations of personnel exposed to microwave emanations (Barron, Love and Barraff, 1956a, b, 1958).

Early investigations, both inside and outside the USSR, of operators exposed to centimeter waves did not reveal any biological effects. This failure was readily explicable. By analogy with the effect of ionizing radiations, the investigators looked for pronounced specific changes, for instance, in the blood, dermal lesions, etc. The failure was natural since attention was concentrated on radar operators, who were hand-picked personnel and were subjected to a high rate of rotation; they were working, moreover, for short periods and with low-power sources of centimeter waves. Consequently, scientists outside the USSR were skeptical. At the same time, however, research by Soviet scientists in the USW range suggested possible biological effects of decimeter and centimeter waves (Suponitskaya et al., 1937—1938; Frenkel et al., 1937—1939; and others).

World War II (1941—1945) facilitated the development of radar techniques, which naturally led to widespread use of microwaves, i. e. superhigh frequencies (SHF) in addition to their engineering uses. Physiotherapeutic applications, dependent on the thermogenic effects of microwaves, utilizing the possibility of local irradiation at different depths from the body surface, were developed from about 1947.

The development of radio engineering created the danger of the personnel's exposure to microwaves under industrial conditions, i. e. in the manufacture of microwave generators, in the testing and operation of microwave devices.

After ten years of investigations in collaboration with the laboratory staff in the fields of occupational hygiene and the biological effects of radio-frequency electromagnetic irradiation, it is now possible to generalize the accumulated data for the range of superhigh frequencies (SHF).

This monograph does not provide a uniformly detailed treatment of its subject matter but concentrates on the occupational hygiene of personnel working with SHF sources and on protection against detrimental effects established by clinical and experimental investigations.

In our research, we used a complex of methods aimed at elucidating the biological effect of SHF from a consideration of the combination and interrelations of the nonspecific reactions which they cause.

The author hopes to make a modest contribution to the development of investigations in this comparatively new field of hygiene, based on his own experience.

Chapter 1

CURRENT TRENDS OF RESEARCH IN THE FIELD OF OCCUPATIONAL HYGIENE AND THE BIOLOGICAL EFFECT OF MICROWAVES

Development of research in the USSR

As already mentioned, the earliest reports on investigations of the biological effect of decimeter microwaves appeared in the literature in 1937—1939 (Suponitskaya, 1933, 1937, 1938).

These investigations were the natural extension of those on USW, the range on which the decimeter region borders ($\lambda = 1$ m to 0.1 m). At that time investigations were conducted on a limited scale. Papers dealing mostly with the working conditions of radar operators began to appear much later (10 years) (Galanin et al., 1956; Shemyakov, 1955).

The laboratory of radio-frequency electromagnetic waves in the Occupational Health Research Institute of the Academy of Medical Sciences of the USSR was mainly concerned (from 1953) with studying the biological effects of electromagnetic waves of superhigh frequency but low intensities, which did not raise the body temperature. This approach to the new occupational-environmental hazard was prompted by the specific working conditions of personnel working with SHF energy sources in industry (construction of SHF generators) and radar technology.

Within a short time, we became convinced of the considerable biological activity of high irradiation intensities in experimental situations, and comprehensive investigations with low irradiation intensities were carried out to establish the maximum permissible irradiation intensities for personnel.

Studies of the biological effect of microwaves on human subjects and experimental animals have been pursued by the Soviet investigators in two directions: hygiene and microwave therapy. Research on the biological effect of microwaves (decimeter range) for medical purposes started back in 1938 (Suponitskaya). Continuously generated centimeter waves are now being widely used in Soviet physiotherapy.

The use of pulse microwaves is still limited. The only known paper is that by Bidenko (1959), who successfully used irradiation with 3-cm pulse waves (modulation frequencies 3,750 pulses/sec, pulse power 60 kW) for the treatment of chronic eczema and epidermophytosis, first in animals and then in man.

More thorough studies of microwaves for physiotherapeutic purposes and their actual application are conducted in the Central Institute of Resorts and Physiotherapy under the guidance of Prof. A. N. Obrosov, Associate Member of the Academy of Medical Sciences of the USSR. Without dwelling

INTRODUCTION

Radio engineering plays an important role in modern technological progress and there is hardly a field of human activity which does not make use of radio technology.

Important goals in this field were incorporated in the Program of the Communist Party of the Soviet Union adopted by its 22nd Congress.

The development of radio technology has passed through several stages. The first stage began with the invention of radio by Popov (1895—1918). Its distinctive feature was the application of long radiowaves for wireless telegraphy. The second stage (1918—1940) was marked by the invention of the electron tube, the beginning of industrial use of high-frequency currents for surface heating of metals, invention of radiotelephony and the development of short waves.

Finally, the modern stage of development is distinguished by practical utilization of still shorter waves — microwaves (decimeter, centimeter and millimeter waves), as well as pulse techniques. Examples of current developments include an increased range of radio transmission based on reflection of ultrashort waves from meteor trails, radio communication with spaceships and radiolocation of the planet Venus by means of decimeter radiowaves. Work is also proceeding on high-resolution location of objects by radiowaves in the millimeter range, which will provide a detailed panoramic picture of the surroundings on board aircraft or in controllers' offices in airports. Astronomical observations with millimeter waves permitted calculation of the temperatures of the sun and moon in 1957.

More than 65 years ago, Danilevskii proved the existence of a biological effect on remote exposure to electrical energy and advocated the application of electrical energy to medicine and biology. Over the intervening years, the uses of high-frequency electrical fields have developed in the USSR and other countries.

Investigations of short (SW) and ultrashort (USW) waves, aimed at elucidating the nature and mechanism of their biological effects (mainly for physiotherapeutic purposes), did not begin before the end of the 1920's to 1930's (Schliephake, 1932; Pflomm, 1931; Pätzold, 1932; and others). Pätzold (1932—1934) and Suponitskaya (1938) pointed out the promising prospects of utilizing decimeter waves (DW), making possible much lower irradiation intensities than with ultrashort waves.

The first comparative evaluations of the biological effects of USW and DW were provided by Suponitskaya (1938), Malov, Obrosov and Fridman (1940) and Mukhina (1940). The thermal effect of DW was found to occur at considerably lower power and to be much more pronounced than that of USW, and the difference was explained by Suponitskaya as being due to a difference in the resonance-induced vibrations of the molecular structures

on this research trend, we should only like to point out the large number of published papers and specialized reviews in this field (Skurikhina, 1961, 1962).

The second trend — research into the detrimental biological effects of microwaves — is being pursued by hygienists, occupational pathologists, engineers, biologists and radiophysicists.

Comprehensive investigations of the working conditions of personnel working with microwave sources in industry (Gordon, 1957a, 1957b, 1958, 1960.1961; Gordon and Belitskii, 1959; Osipov et al., 1962; Frolova, 1963) and in operation of radar stations (Spasskii, 1956; Galanin et al., 1956; Senkevich, 1959; Kalyada et al., 1959; Kulikovskaya, 1961, 1963; and others) have allowed evaluation of the hygienic conditions, including classification according to the intensity and exposure to microwaves in the case of industrial enterprises (Gordon, 1957, 1958, 1960).

The clinical picture of long-term effects of microwaves has been described by, among others, occupational pathologists in several occupational disease clinics (Kevork'yan, 1948; Merkova, 1949; Sadchikova and Orlova, 1958; Uspenskaya, 1959, 1961; Orlova, 1959; Drogichina, 1960; Drogichina and Sadchikova, 1963, 1964; Sadchikova, 1960; Belova, 1960; Sokolov and Arievich. 1960; Gur'ev, 1962; Gembitskii, 1962; Tyagin, 1962; and others). Basing their conclusions on frequent dynamic observations of subjects after long-term exposure to microwaves of nonthermogenic intensities under industrial conditions, a group of specialists headed by Drogichina differentiated three stages in the development of the disease and described its characteristic clinical syndromes (Drogichina, 1960; Drogichina, Sadchikova, 1963, 1964). The characteristics of the clinical syndrome depend on the intensity and duration of exposure to the microwaves. The syndrome caused by long-term exposure to SHF fields was described by Tyagin (1962) and others.

Considerable attention has been paid to experimental investigations of the nature of biological effects of microwaves. Research into the effect of high-intensity microwaves yielded unambiguous data on the resultant irreversible processes, characterized by heavy overheating of the body, formation of a cataract (Belova and Gordon, 1956), death of animals (Lobanova, 1960) and marked morphological changes in the organs and tissues of experimental animals (Pervushin and Triumfov, 1957; Tolgskaya, Gordon and Lobanova, 1959, 1960; Dolina, 1959; Gorodetskaya, 1962; and others). A large number of experimental investigations, especially in recent years, have been devoted to the effect of low-intensity microwaves. This preference is obviously well founded, since high-intensity microwaves obliterate the specific features of the irradiation effects, including the initial changes produced by the irradiation.

The body's reaction is quite distinct, especially in the case of long-term exposure to microwaves, and comes mainly from all divisions of the nervous system (Subbota, 1957, 1958, 1962; Tolgskaya, Gordon and Lobanova, 1957; Bychkov, 1957, 1962; Lobanova and Tolgskaya, 1960; Lobanova, 1964; Kitsovskaya, 1960, 1964; Tolgskaya and Gordon, 1960, 1964; Gordon et al., 1962, 1963; Kholodov, 1962; Zenina, 1964; Gvozdikova et al., 1963, 1964; Kholodov and Zenina, 1964; and others). Irradiation of low-intensity microwaves induced pronounced reactions in the cardiovascular system (Tyagin, 1957; Gordon, 1960, 1964; Presman and Levitina, 1962 a, b;

Gordon et al., 1962). These changes are mostly of a vagotonic nature, either reflex or related to direct effects on cerebral structures, the precise nature of which depends upon the range of microwaves (Gordon, 1960) and the localization of the irradiated area (Presman and Levitina, 1962 a, b).

Only comparatively few papers have dealt with the effect of microwave irradiation on the biochemical processes in animals and man (Nikogosyan, 1959, 1960, 1962, 1964; Syngaevskaya and Sinenko, 1959; Syngaevskaya et al., 1962; Gel'fon and Sadchikova, 1963; Smirnova and Sadchikova, 1960). They have established disturbances of protein and carbohydrate metabolism, certain enzyme activities and changes in the endocrine system. The results of long-term exposure to low-intensity microwaves suggested that the biological effect was cumulative (Gordon, 1957, 1960, 1964).

Comprehensive hygienic, clinico-physiological and experimental investigations led to tentative recommendations of permissible irradiation intensities for centimeter waves (Gordon and Presman, 1956). These estimates were made more accurate in 1957 and extended to the range of decimeter waves. In 1964, our laboratory submitted permissible norms for the millimeter range. Based on the permissible irradiation values, efficient measures for protection against the effect of microwaves were elaborated (Gordon and Presman, 1956; Presman, 1958; Belitskii and Knorre, 1960; Gordon and Eliseev, 1964).

The Soviet literature on this subject is represented by a collection of papers and reviews (Presman, 1961, 1963, 1964) which altogether comprise some 300 works.

Studies of the biological effect of microwaves outside the USSR

Investigations of the biological effect of microwaves are being conducted mainly in the USA, where this matter is regarded as important; guidance and planning of a special program of investigations have been entrusted to the U. S. Air Force Command (Knauf, 1958, 1961). Papers on the biological effect of microwaves have been published outside the USSR from 1943 on. They have been mostly concerned with the possible detrimental effect of microwaves and with their efficient use in physiotherapy.

The number of American investigations on detrimental effects of microwaves has steadily increased over the years, in proportion, evidently, to the growing power of transmitters.

At a special U. S. Air Force conference on the biological effect of microwaves (August 1960) it was pointed out that radar units for space flights, which generate fantastic power, will lead to considerable irradiation intensities for ground operators, since even parasitic leakages of microwave energy will obviously be of appreciable magnitude.

The main trends of studies of the biological effects of microwaves have included experimental investigation of the effects on various organs, functions and systems of the body, elucidation of the detrimental effect of microwave energy and elaboration of protective measures, clarification of the mechanism of biophysical processes taking place in live tissues and medical applications.