About the Book:

Biological Effects of Microwaves

by

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Contents

Preface

The present work constitutes an attempt to present to the English-speaking reader a survey of the literature on the biological effects of microwaves, including the available data on evaluation of health hazards and safe exposure limits. The authors are fully aware that the subject under consideration is highly controversial and has aroused heated discussion. It is our feeling that in the course of these discussions many misunderstandings arose from frequent misquotations, imperfect translations, and only fragmentary knowledge of the vast literature on the biological effects of microwave irradiation. Over 2000 titles could be listed as references; however, many of the papers published repeat descriptions of similar or even the same experiments. Repetitive or strictly confirmatory work was omitted from this survey. To avoid the same fault, the authors also tried to omit data already reported in the monographs by *Marha* [336] and by *Presman* [468], recently translated into English. Certain repetitions were, however, unavoidable. The reader who is especially interested in Soviet research is referred to the competent reviews by *Dodge* [127–131] and *Healer* [219]. An almost complete list of references was prepared by Z. Glaser (609) in his bibliography. The present authors have the uncomfortable feeling that at least in a few of the other existing English reviews or translations of foreign (especially Russian) work misunderstandings, arising probably from insufficient knowledge of the language and/or of the subject, may be detected. In view of this, one of us (*P. Czerski*) attempted the translation himself to prevent misunderstandings caused by insufficient knowledge of the Polish language; the authors hope that his knowledge of English will prove adequate. The native English-speaking reader is asked for forbearance.

A major cause of misunderstandings in the field of investigations on the biological effects of microwaves is insufficient multidisciplinarian collaboration. The physician or biologist usually has only limited knowledge of the intricacies of modern physics and electronic engineering. The first two chapters of this book should serve to recall certain basic data in a very simplified form and to demonstrate the need for further study. Our firm conviction is that each practical step undertaken by an industrial hygienist or physician should be checked with an engineer and a specialist in electromagnetic field propagation theory. Any biomedical research must be conducted in close collaboration with representatives of these sciences and checked with a biophysicist.

The differences in training and attitudes of mind of the interested specialists are a major source of misunderstanding in the field surveyed. An electronic engineer or physicist is able to obtain a complete quantitative description of the investigated phenomena. Such a complete description is only rarely possible in biology and medicine; many unknown or insufficiently known variables influence the investigated relationships. Statistical evaluations of the results permit the drawing of conclusions valid at a given confidence level and within the actual limits of biomedical knowledge. In certain instances it happens that a hypothesis based on questionable biological data supplemented with elegant mathematical demonstrations is accepted as scientific proof by the electronic engineer, simply because he does not realize that a given set of causally related facts was not included in the reasoning. Moreover, this set may not fit the proposed quantitative relationship. Faulty biological reasoning may lead to false conclusions in spite of the use of correct statistical methods. Conversely, the electronic engineer is apt to reject data that consist of a set of probably causally related facts on the ground that no causal relationship was proved using a quantitative description. In other words, the wide range of variation of biological phenomena and the limited possibility of giving a quantitative description of the reaction of a living system (because of its complexity) are not always appreciated by physicists and electronic engineers, perhaps with the exception of those who are interested in information theory as applied to radioelectronics.

On the other side, many biologists, and the medical profession on the whole, are insufficiently trained in mathematics and physics. The medical man is trained to react quickly to the needs of an urgent case without waiting for scientific proof of the correctness of his diagnosis. In many instances the decision must be reached quickly, and because of the short time allowed only probabilities may be considered. It is the authors' feeling that the rapid increase of electromagnetic pollution of both the working and natural environment of man should fill us with a sense of urgency.

Nevertheless, it seems that a satisfactory solution of all the questions posed by the problem of the interaction of microwaves with living systems may be obtained only by close interdisciplinarian collaboration of biologists, the medical profession, biophysists, electronic engineers, and many consultants in various specialities. The main condition of a fruitful collaboration is the realization of the limitations of each particular approach, one's own foremost.

In preparing this survey we tried to meet the requirements of the many people interested in the subject. The first two chapters are of a general introductory nature and are aimed at hygienists and physicians in industrial health service. Chapter 6, on safe exposure limits and the health surveillance of microwave workers presents the solutions proposed in various countries by the agencies responsible for the prevention of industrial health risks, with emphasis on the system adopted in our country. Certain personal views are also expressed. Chapter 4 represents a survey of the results obtained by animal experimentation and Chapter 5 the clinical findings and results of analyses of the health status of personnel professionally exposed to microwaves. Together with the list of references both these chapters may serve as a sort of annotated bibliography. In each, the final section contains an attempt at a condensed survey of the available data with a view to pointing out what may be considered as established and what questions must be posed. Such sections express the personal views of the authors and should be evaluated critically by the reader. The same concerns the short recapitulation in Chapter 7. Chapter 3, on the mechanisms of the interaction of microwaves with living systems, reports the views expressed in the literature, and the personal views of the authors on this matter, which consists mainly of doubts and question marks.

Our principal aim was to avoid any misquotations of findings or distortion of views expressed by others and to indicate clearly where personal, subjective, and probably highly controversial opinions are given.

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CHAPTER

1 Introduction

The term "microwave radiation" is used to designate that portion of the electromagnetic radiation spectrum which lies between the frequencies 300 and 300,000 MHz, which correspond to wavelengths in air of 1 m to 1 mm. This designation is accepted in most European countries [336, 378, 425]. Similar definitions are used in American literature [561], although the United States of America Standards Institute [468] considers the frequencies 10 and 100,000 MHz as the boundaries of the microwave region. In this book the particular spectral regions of electromagnetic radiation will be designated as shown in Fig. 1. The boundaries between successive regions were fixed arbitrarily, using the most common definitions.

A short discussion of Fig. 1, with the aim of localizing the microwave region in the electromagnetic radiation spectrum more precisely, may prove helpful. This portion of the spectrum, which encompasses the highest frequencies (the shortest wavelengths) and ends in the ultraviolet region, is called "high-energy radiation" [233] or "ionizing radiation". Because of the high photon energy of radiation from this part of the spectrum, the primary effect of its interaction with living matter consists of ionization.

Ultraviolet (UV) radiation may be considered to be the next spectral region [233]. It forms the boundary between the two large parts of the spectrum shown in Fig 1. Far UV gives biological effects similar to those induced by high-energy radiation; near UV belongs to the second part of the spectrum, "nonionizing radiation", term only now coming into wide use.

The designation of a large part of the electromagnetic radiation spectrum, comprising visible light, infrared (IR), microwaves, and radio-frequency waves by a common term, nonionizing radiation, is certainly a simplification. It seems, however to play a very useful role by indicating new tasks and perspectives in radiobiology. In the time-honored, traditional sense, the subject of radiobiology are the biological effects of ionizing radiation. The term "radioprotection" is commonly understood to pertain to the prevention of ionizing radiation health risks. The biological effects of UV, visible light, and IR are the domain of another well-established discipline, "photobiology".

Until relatively recently, the need for protection against hazards involved in the use of nonionizing radiation was negligible. The design and use of high-power sources of nonionizing radiation, which emit beams of high energy density, such as

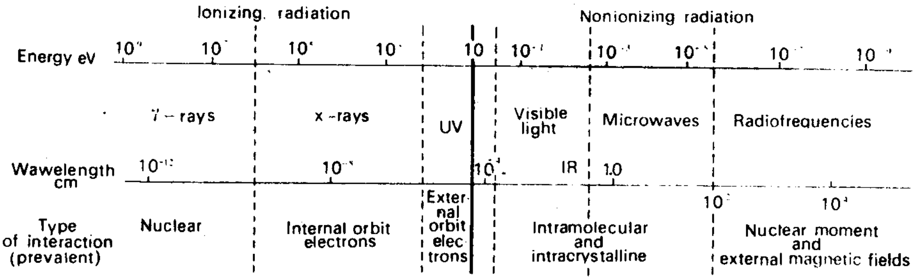

Fig. 1. Electromagnetic radiation spectrum. Boundaries arbitrary.

lasers or certain microwave apparatus, gave rise to the appearance of real hazards and the need for appropriate risk prevention. Because of the dynamic development of electronics, the number of high-intensity nonionizing radiation sources increases nearly each day.

It should be noted that many authors [336, 415, 438] designate the problems of the biological effects of microwaves and radio-frequency radiation and their health-hazard implications as problems of the biological effects of electromagnetic fields and of "protection againts microwaves" or "protection against radiowaves". The title of one of the monographs from this field, "Work Hygiene and Safety in Electromagnetic Microwave Fields", may be cited as a characteristic example [574]. Such titles reflect to a certain degree the opinions and approach of the author to the problem. In certain instances the diversity of the nomenclature may lead to misunderstandings, and one has the feeling that a part of the medical profession is disoriented and looks upon the biological effects of microwave irradiation as highly suspect and unclear phenomena, shrouded in mystery [401]. It should be stressed that the biological effects of nonionizing radiation must be evaluated in the light of modern physics, using all the possibilities offered by a biophysical interpretation of the interaction of this radiation with living systems. The starting point of all such considerations is the system

$$\text{source} \rightarrow \text{radiation} \rightarrow \text{target}$$

In other words, the system considered consists of a source that emits electromagnetic energy; the incident energy is absorbed and transformed within the target (irradiated object). The physical laws of optics, reflections, diffraction, dispersion, interference, quantum effects, and electromagnetic field theory are of importance and should be applied for an investigation and explanation of the observed phenomena. This statement applies of course to the whole spectrum of electromagnetic radiation.

Returning to the electromagnetic radiation spectrum as presented in Fig. 1, it may be seen that the borderline between ionizing and nonionizing radiation lies in the ultraviolet region (UV), next to which visible light and infrared radiation (IR) may

Table 1

Radio frequency and microwaves.

Approximate wavelength in air m	Frequency MHZ	DESIGNATIONS: Used in this work	Russian literature	Metric, used in USSR, Poland, and Czechoslovakia	English and American literature	Loosely used
15.10^3 and more	0.02 and less	Very long	NTch, niskie tchastoty (low frequency)	Dekamyria and myriameter waves	VLF, very low frequency	AF, audio frequency
10^4	0.03				LF, low frequency	
$3 \cdot 10^3$	0.1	Long waves	VTch, vysokie tchastoty high frequency	Kilometer waves		
1000	0.3				MF, median frequency	RF, radio frequency Hertzian waves
800	0.4	Median waves				
100	3			Hektometer waves		
30	10	Short waves		Dekameter waves	HF, high frequency	
10	30	Ultra short waves	UV Tch, ultravysokie tchastoty ultrahigh frequency	Meter waves		
1.5	200					
1	300	Microwaves	SVTch, sverch wysokie tchastoty superhigh frequency	Decimeter waves	UHF, ultra frequency	Designated as microwaves, radar emanations, UHF, or HF
10^{-1}	3,000			Centimeter waves	SHF, super high frequency	
10^{-3}	30,000					
$1.5 \cdot 10^3$	200,000					
10^{-3}	300,000			Millimeter waves	EHF, extra high frequency	
$0.75 \cdot 10^{-3}$	400,000	Intermediate and IR radiation infrared	IK, infra krasnye	IR	IR	IR
$0.3 \cdot 10^{-3}$	1,000,000					

be discerned. Microwaves constitute the next region. According to the definition adopted in this book an "intermediate radiation" between IR and microwaves (300 to 300,000 MHz) should be distinguished. Such a distinction has, however, no deeper meaning from the theoretical and practical points of view; it becomes necessary if the frequency of 100 GHz is adopted as the boundary of the microwave region. The further part of the spectrum may be divided into ultrashort waves (300 to 30 MHz, 1 to 10 m), short, median, long, and very long radiowaves (see Table 1). The microwave region may be subdivided into radar bands, as shown in Table 2. It should be noted that in this case the microwave region ends at 220 MHz, i.e., 1.333 m. Attention should be drawn to the fact that in many biomedical publications designations presented in Tables 1 and 2 may be used rather loosely.

Table 2

Microwave (radar) bands used in the United States [354] and with slight variations used internationally; supplemented by loose designations found in biomedical literature.

Wavelength in air cm	Frequency MHz	Band	Loose designation
133.3–76.9	220–390	P	1–or 1.5–m bands
76.9–19.3	390–1,550	L	50–, 30– or 20–cm band
19.3–5.77	1,550–5,200	S	20– or 10–cm bands
7.69–4.84	3,900–6,200	C	
5.77–2.75	5,200–10,900	X	3–cm band
2.75–0.834	10,900–36,000	K	
0.834–0.652	36,000–46,000	Q	Millimeter waves
0.652–0.536	46,000–56,000	V	Millimeter waves

One may easily wonder why such importance is attached to the microwave region, which constitutes only a narrow part of the whole, broad, nonionizing radiation spectrum. There are several reasons. Chronologically, microwave generators are the first nonionizing radiation sources that permitted the emission of focused beams of very high energy density. During World War II, the technique of radiolocation developed rapidly because of military requirements; this was followed by amazingly fast progress in microwave techniques. Already at this time, the first sings of concern about possible health hazards and risks to personnel occurred [106, 308]. Radiolocation equipment is constantly being perfected, and its power and the number of installations increase every day, thus leading to the present situation, where microwaves should be considered an atmospheric pollutant, similar to other industrial pollutants. In addition the introduction of color-television transmitters has caused an increase in microwave intensity in the atmosphere, since certain color TV systems work in this band. Incidentally, this new modern technique uses frequencies close to that at which waves were emitted by the first spark generator of

Benedict Hertz 455 MHz, i.e., 66 cm; however, his generator emitted waves of a decreasing amplitude (damped oscillations).

The increase in microwave pollution and possibility of health risks to personnel gave impetus to several large research projects [353]. In the 1950s and 1960s many investigations on the biological effects of microwaves were carried out in numerous research centers in several countries, among them France, Poland, Czechoslovakia, the United States and the USSR. During the last 30 years, a vast amount of experimental data and clinical observations was collected, and an attempt at a survey of this material seems timely.

During the last 10 years industrial applications of microwave techniques expanded greatly, and microwave heating entered into common use. Thus microwave techniques invaded private homes, where more and more microwave ovens were installed. This was a cause for public anxiety, alarm even, and led to polemics full of controversial statements. Discussions may be found in Electronics during the years 1969-1971 (see, e.g., [402, 568]). The general interest in the biological effects and health implications of microwaves induced us to attempt this survey of the relevant literature.

Table 3 presents selected examples of the most common uses of microwave techniques and equipment. It should be added that many nonionizing radiation sources widely used in industry, radiolocation, radiocommunication, and medicine (shortwave diathermy) emit waves of lower frequencies, 300 to 30 MHz. Many statements and findings concerning the biological effects of microwaves may be applied also to waves of this region, which is typical for television, one of the most common media of mass information. The increasing use of industrial equipment that generates waves of frequencies below 30 MHz should also not be forgotten. In actuality, frequencies of a few megahertz seem to be most important. Nevertheless, the increasing industrialization of the world and the tendency to increase the power of equipment, a veritable power race, incline one to consider the attempts at limiting microwave exposure as a possible model for the solution of the problem of nonionizing radiation hazards in the whole radio-frequency range, including low and very low frequencies. Because of this, Table 3 was supplemented by examples of the use of sources emitting radiations in frequency ranges other than the microwave. More data on the use of such equipment and related biomedical problems may be found in monographs by *Marha* [336] and *Presman* [438]. Textbooks on medical diathermy may also be consulted [472, 477, 565]; see also "reviews" in the Subject Index to References.

A detailed presentation of the application of microwave techniques and a description of the equipment lie outside the scope of this work. A few very simplified and brief remarks, based on *Panecki* [417], will be given.

One of the oldest, but still in wide use, microwave transmitter valves is the magnetron (Fig. 2). It contains two coaxially placed electrodes, thus ensuring circular symmetry. As in other electronic tubes, the cathode is heated by an electric heater,

Table 3

Selected examples of typical uses of equipment generating radio-frequency and microwave radiation (based on [80, 354, 378]).

Frequency	Use	Occupational exposure	Examples of potential incidental exposure — general population hazards
Below 3 MHz	Metallurgy: welding, melting, tempering, etc. Broadcasting, radiocommunications, radionavigation	Various factory workers, e.g. furniture veneering operators, drug and food sterilizers, auto industry workers	Factory executive personnel, watchmen, guards
3–30 MHz	Many industries e.g., auto, wood, chemical, food. Heating, drying, welding, gluing, polimerization, sterilization of dielectrics. Agriculture, food processing, medicine, radioastronomy, broadcasting	Electronic engineers and technicians: air crewmen, missile launchers, radar mechanics and operators, microwave-oven operators and maintenance workers	Airport and seaport personnel of various professions; inhabitants of areas in the vicinity of high-power radar installations, broadcasting stations, and TV transmitters
30–300 MHz	Many industries as above. Medicine. Broadcasting. TV, air traffic control, radar, radionavigation	Scientists, physicists, microwave development workers	
300–3,000 MHz	TV, radar (troposcatter and meteorological). Microwave point-to-point. Telecommunication, telemetry. Medicine. Microwave ovens. Food industry	Microwave testers; diathermy, microwave diathermy, operators and maintenance workers: medical personnel	Housewives and children (microwave ovens in private homes)
3–30 GHz	Altimeters, air- and shipborne radar, navigation, satellite communication, microwave point-to-point	Broadcasting transmitter and TV personnel	
30–300 GHz	Radioastronomy, radiometeorology, space research, nuclear physics and technique, radio spectroscopy	Marine and coastguard personnel, sailors, fishermen, persons professionally present on board ships	

which leads to the emission of free electrons into the space between the electrodes. A constant magnetic field, perpendicular to the trajectory of the electrons, is generated by a magnet or an electromagnet. This field causes changes in the trajectory of the electrons before they are eliminated through the anode (electric current flow), and electromagnetic waves are generated. A metal loop (coupling loop)