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# CRITICAL EVALUATION OF MAXIMUM PERMISSIBLE LEVELS OF MICROWAVE RADIATION\*

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Biological effect of microwaves and electromagnetic radiation of lower frequency is reviewed, with particular reference to the problem of the so-called extrathermal effect, which - in the author's opinion - should be given due consideration. The assumption that the biological effect of microwaves is only based on thermal effect, unduly simplifies the whole problem, especially in connection with the determination of maximum permissible doses.

The results are presented of the clinical observations of a larger group of persons occupationally exposed to microwaves ranging from 750 to 200 MHz. These results indicate that in the group with prolonged exposition the occurrence of some symptoms was considerably higher than in the control group. The results of some experimental work on the effect of microwaves, with special reference to the so-called thermal effect, are also discussed.

The basic question in research on biological influence of microwaves and electromagnetic radiation of lower frequency is the mechanism of its action upon living matter. The most important aspect of this general question is the role of extrathermal effect for development of injury. Elucidation of this point is of utmost importance for evaluation of professional exposure to microwaves.

In spite of the fact that a great number of papers, dealing with the mechanism of microwave-action upon living cells and organisms has been published in last years, the question of the existence of extrathermal effect remains still open. This situation is reflected in proposed values of maximum permissible intensity of radiation under conditions of professional exposure and levels suggested by different authors, groups, committees etc. differ among themselves often by a factor of thousands (Table 1). An assumption that biological action of microwave depends entirely upon thermal effect simplifies considerably the question of establishing the maximum permissible intensity (1, 2). It allows also to

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Table 1.  
Maximum permissible intensities of high-frequency electromagnetic fields

Author or institution	Frequency in MHz	Max. permissible intensity in mW/sqr. cm.	Remarks
Ely, T. S. Goldinan, D. E. (1957)	3000	100 150 5	whole body eyes testis
U. S. Army Forces (1958)	every	10	—
Schwan, H. P. Li, K. (1956)	<1000 1000-3000 >3000	30 10 20	whole body whole body whole body
General Electric (U. S. A.)	>700	1	—
Meahl, H. (1956)	750-30.000	1	—
North Atlantic Treaty Organisation (1956)	—	0.5	—
Mumford, W. (1956)	—	0.1	—
Sveden (I. S. S. A. International Colloques, Warsaw, 1963)	<87 >87	222 V/m 25 V/m	— —
General Post Office of Great Britain (I. S. S. A. Intern. Coll., Warsaw 1963)	>300	0.01	—
U. S. S. R. (1958)	>300 <3	0.01 0.1 1 5-10 V/m	whole working day 2-3 hrs. daily 15-20 min. daily —
Poland (1961)	>300	0.01 0.1 1	whole working day 2-3 hrs. daily 15-20 min. daily
Czechoslovakia (Marha, K. 1963)	>300 0.01-300	0.025x/ 0.01 x/ 5-10 V/m	continuous waves pulsating waves —

\* Daily exposure in hrs. multiplied by intensity in  $\mu\text{W}/\text{cm}^2$  have not to exceed the value of 200.

accept relatively high values, depending on thermoregulative capability of human organism. This concept has been incorporated in majority of American m. p. values.

There are numerous investigations published, in which authors attempt to prove the hypothesis that biological action of microwaves is due to thermal effect only (3, 4, 5). In majority of cases these experiments were carried out under conditions of single or few repeated acute irradiations with beams of relatively high intensity. In these circumstances symptoms depending mainly on extrathermal effect may remain hidden due to prevalence of thermally conditioned ones.

Moreover, it has to be pointed out that in course of time a number of data became accumulated which cannot be explained on the basis of thermal effect only (2). A number of investigations does speak in favour of the rôle of extrathermal factors in biological action of microwaves (6, 7, 8, 9).

Results of experiments being carried out and performed recently in the Institute of Occupational Medicine in Łódź (see bibliography) seem to indicate that extrathermal effect exists and does play a rôle in manifestation of biological injury due to microwave radiation. In such situation, importance of these effects for evaluation of hazards due to professional exposure to high frequency electromagnetic fields is obvious. Research is being carried out in two directions: an experimental and a clinical one, the latter including the observations of people subjected to the action of electromagnetic radiation in wide range of frequencies from hundreds KHz up to tens of thousands of MHz.

In 1960-1961 about 200 persons who were exposed professionally to the influence of electromagnetic fields (the frequency ranging between 750 MHz and 200 MHz) were examined clinically. This study was supplemented with radiation-intensity measurements in working places, making thus possible the determination of approximate values of field-intensity, to which people were exposed during their working day (10). It could be shown that maximal values of intensity did not exceed  $3 \text{ mW}/\text{cm}^2$  and average values in different plants were not higher than  $1 \text{ mW}/\text{cm}^2$ . Exposure did not therefore exceed the most common American m. p. intensity value and in several cases measured intensities were even below the Soviet m. p. levels. For statistical evaluation two groups of workers were chosen: they were almost uniform with respect to age distribution but mostly differing in average time of employment. The frequency of several symptoms in these two groups was compared (tab. 2). A tendency to higher frequency of several symptoms with increasing time of exposure was marked. The percentage of people without any symptom in both groups was significantly different. The fact should be pointed out that the character of symptoms in examined persons was very similar to that described by Soviet authors (11, 12).

Table 2.

Occurrence of some symptoms in human beings exposed professionally to high-frequency electromagnetic fields (750 KHz-200 MHz)

Symptoms	Duration of exposure			
	1-6 years (in average 4.3) (73 persons)		7-16 years (in average 9.6) (73 persons)	
	per cent of cases	number of cases	per cent of cases	number of cases
Headache	20.5	15	32.9	24
Disturbance of sleep	13.7	10	23.3	17
Fatigue	12.3	9	17.8	13
General weakness	7.0	5	12.3	9
Disturbance of memory	5.5	4	8.2	6
Lowering of sexual potency	5.5	4	8.2	6
Drop in body weight	2.7	2	12.3	9
Disturbance of equi- libration	5.5	4	11.0	8
Neurological symptoms	0.0	0	15.1	11
Changes in ECG	17.8	13	28.8	21

These data appear to justify the conclusion that long-term exposure to high-frequency electromagnetic fields of the intensity of few mW/cm<sup>2</sup> can lead to health injury, even if the thermal effect does not play any significant rôle (the temperature of the body cannot be raised even by h. f. electromagnetic fields of 10 mW/cm<sup>2</sup> intensity). These data did not permit to accept any one of the m. p. values listed in Table 1, except the Soviet ones. However, the safety factor incorporated in the latter did not seem sufficient either.

Experimental investigations were carried out in our Institute, applying electromagnetic radiation in another frequency band, namely microwaves of about 2860 MHz. These experiments were aimed at clearing the action of microwaves on testicles and at proving the existence of extrathermal effect.

The eminently injurious effect upon the testes has been emphasised by several authors, it was taken also into account in proposals for maximum permissible intensities (Table 1). *Ely and Goldman* proposed different m. p. intensities for irradiation of whole body and testicles alone (100 and mW/cm<sup>2</sup> respectively). However hitherto in experiments of this kind most often direct irradiation of testicles was in use.

In our experiments (13) rats were subjected to whole body irradiation of the intensity amounting to 60 mW/cm<sup>2</sup>: the beam was directed from one side of the body. Irradiation lasted 2 minutes and was given every day for 6 weeks. Histological examination of testes was performed 24

hrs. one, and 6 weeks after discontinuing the irradiation. In spite of the fact that exposure time (2 min.) was very short, the body temperature (measured in rectum) was raised by 2° C and the temperature of the skin

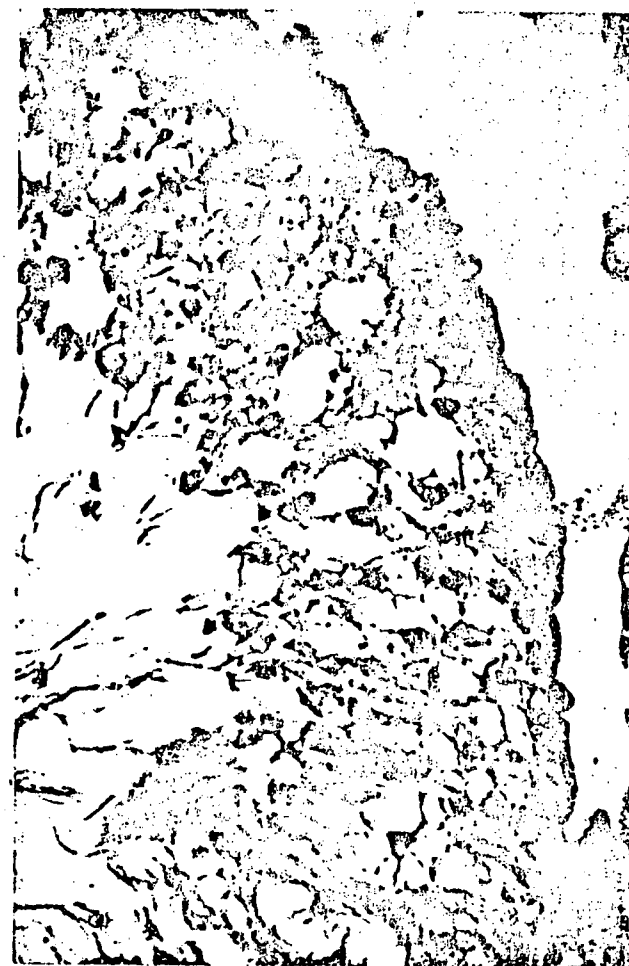


Fig. 1. Histological picture of rats' testes 6 weeks after discontinuing the exposure. Vacuolar degeneration of germinal epithelium cells is clearly visible. Whole body irradiation for 2 min. daily over 42 days. (2860 MHz, 64 mW/1sq. cm.)

of scrotum even by 6° C. From histological examination it followed that damage of testes was very severe, especially heavy injury was found in germinal epithelium (vacuolar degeneration - fig. 1 - disturbance of spermatogenesis and spermiogenesis). It was remarkable that these changes

showed no tendency to heal, but rather became more severe and pronounced in course of time. There were observed changes in activity of hydrolytic enzymes too (14). The general condition of experimental animals was practically indistinguishable from that of controls.

These experiments do not prove directly the existence of extrathermal effect (they do not disprove it either) and are cited here only for evidence that safety factors incorporated in permissible intensity of microwaves, as proposed by some authors, are highly insufficient. It seems obvious also that in establishing permissible levels of exposure, an account must be taken of a different sensitivity of particular organs and tissues.

Table 3.

Average duration of consequent periods in the experiment on effects of protracted exposure to microwaves (30 mW/cm<sup>2</sup>, 1 min. daily). Eight rats

Period	Average duration in days	
Since beginning of irradiation to first reaction of excitation . . . . .	14.0	min. 10 max. 18
Period of excitation . . . . .	5.4	min. 3 max. 9
Period of inhibition . . . . .	5.2	min. 3 max. 7
Period without conditioned reflexory activity . . . . .	6.4	min. 5 max. 8

(after discontinuing the exposure 4,4)

Another factor appears to play a rôle in considering m. p. levels for microwave radiation: Several observations indicate that cumulative effects might exist, even if single exposure does not lead to detectable disturbances or injury. Investigations were performed applying principles of conditioned-reflexes technique, as the functional state of the central nervous system seemed to be the most suitable, sensitive, and integrating index.

Two series of experiments were performed. In the first series 15 rats were irradiated only once and correlation was established between the character of changes in conditioned reflexes on the one hand and intensity as well as the time of irradiation on the other. Changes in conditioned reflexes appeared in phases, the first one being characterized by excitation, followed by the period of inhibition up to complete abolishing of the reflex. In fig. 2 the latent time of reflex (in seconds) is plotted against the duration of exposure to the intensity of 30 mW/cm<sup>2</sup>. The same is done for intensities of 16, 60 and 90 mW/cm<sup>2</sup>. In all instances changes in conditioned-reflective behaviour were similar. The ma-

gnitude of these deviations from normal was parallel to the elevation of body temperature, above 42° C conditioned-reflexes ceased completely.

In the second series of experiments 16 animals were irradiated daily for 40-50 days and conditioned-reflexory functions were examined every day. The duration of exposure was 1 minute, intensity of radiation amounted to 30 mW/cm<sup>2</sup>. Under these conditions single exposure was without any observable effect upon conditioned-reflexory functions (fig. 2). The elevation of body temperature did not exceed 0.3-0.6° C at the

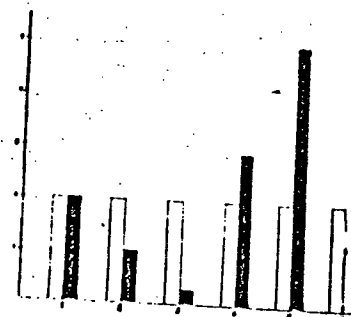


Fig. 2. Changes in conditioned reflexes in rats as a function of duration of single exposure (30 mW per sq. cm.). Vertically - latent period in seconds. Horizontally - duration of single exposure in minutes. Dark fields - values for experimental rats. White fields - values for controls. Irradiation lasting 6 minutes abolished the reflexes completely.

end of each single irradiation period. In such conditions the elevation of brain temperature is lower than the body temperature (17). 10-18 days after the start of exposure period, disturbances in conditioned-reflexory functions became apparent. Their character and time-pattern was similar to that found in the first series. Symptoms of excitation, followed by inhibition and abolishing of reflexes appeared (Table 3). If irradiation was stopped, reflexory activity returned to normal after several days; however, repeated irradiation was followed more rapidly than the first one by the inhibition of reflexes (a few days).

The results presented above indicate clearly that biological effects of microwaves may be cumulative and that the rôle of extra-thermal effects is dominant in long-term exposure to radiation of low intensity.

Cumulative effect and extra-thermal effect of microwaves emerge also from investigation of cholinesterase activity in blood of mice subjected to repeated irradiations at the intensity of ab. 16 mW/cm<sup>2</sup> (18) and from investigation of development of chick embryo under the influence of microwave radiation (19).

Even these fragmentary data indicate clearly enough that justification and scientific background of the majority of proposed maximum per-

missible intensities of high-frequency electromagnetic fields in working places are still insufficient. Taking due account of other authors' data (specially of the Soviet ones) the statement seems justified that existing m. p. levels should be verified and due attention paid to the rôle of extrathermal effects.

Apart from the latter, a possibly different biological action of continuous and pulsating waves radiation should be considered, as well as varying sensitivity of different organs and tissues. Due respect should also be given to the time factor (duration of exposure per day, week and month, continuous or fractionated irradiation, etc.), which should influence the development of prophylactic measures against injurious effects of high-frequency electromagnetic fields. All factors mentioned above should be considered when formulating rules for health protection of workers exposed to the action of microwaves.

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#### Sadržaj

### KRITICKA OCJENA MAKSIMALNO DOPUSTENIH DOZA MIKROVALNOG ZRACENJA

Prikazana su iskustva u vezi biološkog učinka mikrovalnog i elektromagnetskog zračenja niskih frekvencija. Posebno se razmatra pitanje tzv. ekstratermalnog efekta. Na temelju prethodno provedenih ispitivanja autor zastupa u prikazu mišljenje da treba uzeti u obzir i taj učinak ove vrste zračenja. Pretpostavka, da se biološko djelovanje mikrovalnog zračenja osniva isključivo na toplinskom učinku, po mišljenju autora, pojednostavljuje na nedozvoljeni način čitav problem, naročito u vezi s utvrđivanjem maksimalno dopuštenih doza.

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