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BIOLOGICAL EFFECTS BY MICROWAVES

(invited paper)

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ABSTRACT

Domestic and industrial applications of microwaves are everyday extended implying protection conditions and safety standards which require a better knowledge of biological effects associated with microwave radiations.

Interactions of microwaves with living systems are reviewed on the basis of levels of organization which may be molecular, unicellular and pluricellular. Among a large number of publications, those giving correlated experimental observations at low or medium power density or associated to frequency dependent effects are particularly examined. Results are still insufficient for establishing permissible exposure levels lower than that derived from thermal biological effects. These thermal effects are now being studied as the induction of hyperthermia in living tissues, for instance, as an adjunct to the cancer treatment.

INTRODUCTION

The increase in microwave pollution and possibility of health risks are associated with the constantly perfected microwave equipment, its power and the number of installations growing every day. Color TV transmitters have recently caused an increase in microwave intensity in the atmosphere and, during the last 10 years, industrial applications of microwave heating at high power level and isotropic radiation entered into common use. Since 30 years, an amount of experimental data and clinical observations on the biological effects of microwaves has been collected. Nevertheless the exact knowledge of the interactions of microwaves with living systems remains weak. A detailed discussion of these biological effects lies outside the scope of this paper and it is only tempted to review some well established experiments and results which contribute markedly to the advancement of the field hazard knowledge and to the definition of the health standards.

MECHANISMS OF THE ABSORPTION OF MICROWAVE ENERGY

The action of electromagnetic fields on living tissues can produce either the oscillation of free charges or the rotation of dipole molecules at the microwave field frequency. The complex permittivity comprising both conduction currents and dielectric losses will be dispersive due to various relaxation processes associated with polarization phenomena. Because of the

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high complex dielectric constant of water, it is evident that the dielectric behavior of living tissues at microwave frequencies for which water relaxation takes place is controlled by the water content. It is to be noted that this relaxation frequency for free water is near 17 GHz at 25°C ; but the frequency is strongly temperature dependent and at 40°C, it gets near 28 GHz (1 cm in wavelength). It was thus observed that parameters such as penetration depth, reflection coefficient, power absorption are highly different for tissues such as skin, fat, muscle, bone, etc. and that the power absorption at interfaces as (fat-muscle) or (skin-muscle) is discontinuous leading to subcutaneous burns or thermal necroses sometimes observed in irradiated animals.

The foregoing consideration indicates that the evaluation of microwave field distribution inside the body of irradiated experimental animals will be difficult to use for the interpretation of observed effects. Moreover, during irradiation, hot spots may originate in various body organs and lead to local thermal effect when the complex dielectric constant of these organs are higher than that of the surrounding media (say "specific thermal effects"). It should also be added that, because of the shortening of wavelength in biological media, microwaves may have a wavelength comparable to the dimensions of macromolecules thus growing spatial resonances of such components. The low Q factor of these resonances however requires a high field intensity for this to occur.

The above electric properties do not reveal whether mechanic effects may or not be imparted due to forces evoked by microwave electric field. The well-known pearl chain formation, the orientation of nonspheric particles are some of the effects which have been studied |1, 2|. It was generally stated that such field evoked forces become significant compared to random thermal ones if the corresponding electric potential energy is larger than the thermal energy when particles of some microns are considered as it is the case for typical cellular particle dimensions.

INTERACTION OF MICROWAVES WITH LIVING SYSTEMS

A living system may be considered at various levels of organization: molecular, unicellular, pluricellular. A complete discussion of associated phenomena is outside the scope of this review and the competence of the authors, more particularly at the pluricellular level, and we only consider certain typical interactions in which significant new results were recently obtained. For a more general point of view, see for instance reference |3| and |4|.

I - MOLECULAR LEVEL.

Only a few works were devoted to the study of possible coupling mechanisms between microwave radiations and molecular components of biologic systems which may lead to an alteration of the energetics or dynamics of the molecular system. An interesting discussion was made by ILLINGER |5| who considered more particularly the case of a poly-amino acid with polar side-chains attached to the polymer backbone which is capable of undergoing a helix-coil transition. It was expected that the helical form of such biopolymers and their polar side chains exhibit overall or group rotational relaxation and couple to a high frequency electric field in the region of 1 to 10 GHz. Such relaxation processes have in fact been experimentally found |6|.

Another mechanism exists for microwave absorption in an ordered structure which is a quasi-lattice vibration corresponding to the (3N-6) normal modes of vibrations where N is the total number of atoms in the structure. Such mechanical vibrations corresponding to essentially the entire polymer (in contrast with group vibrations and building block vibrations) would take place in the centimeter or millimeter wave region. Moreover, one may expect the quasi-lattice vibrational frequency to be independent of the thermal energy of collisions, i.e. independent of temperature. The observations mentionned at reference |7| were not indeed temperature dependent thus indicating the possibility of damped resonant interactions between millimeter waves and biopolymers. Other experimental observations are mentionned in the next part with bacteria cells which also show microwave selective absorptions in the millimeter wave range.

II - UNICELLULAR LEVEL.

At this organization level, experimental works were generally made at low power density, say equal or smaller than 10 mW/cm². Studies are essentially devoted to the cell survival, mutation creation from a modification of the cell genetic materials and cell growth.

Concerning the cell survival, it appears that microwaves have no effect even when very radiation sensitive cells are used |9|. Mutations were also studied in same experiments and very few variations were observed with sensitive cells which allows us to exclude any direct interaction between microwaves and nucleic acids such as DNA.

Regarding a possible action on the cell growth, significative results were obtained at millimeter band waves. A strong inhibition of bacterial growth was observed after irradiation at specific frequencies and for very low power density (7 µW/cm²) |8|. These results were confirmed with a completely different irradiation technic |9| and a growth inhibition was also observed at 71.5 and 73 GHz which is not explained by any reason as survival or mutagenic effect (see Figure 1). At the same time, several Russian groups have obtained various actions at the cellular level and with millimeter waves (between 42 and 46 GHz) |10|. Experimental studies made at low energy level (no more than a few mW/cm²) have produced highly interesting specific effects of irradiation which generally confirm those observed in references |8| and |9|. For most of the biological systems studied they have found that:

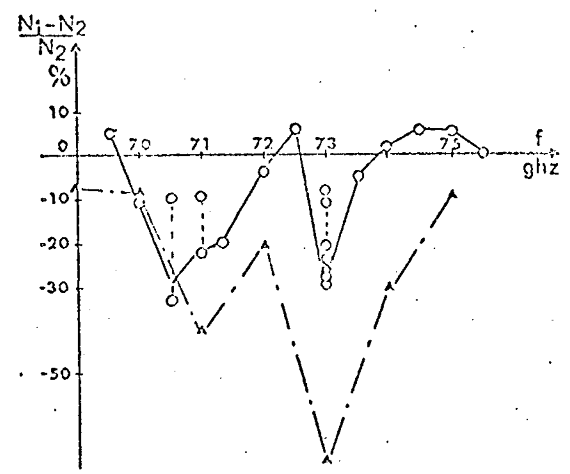

Fig.1 - Frequency variations of the relative difference between cell number of irradiated and control cultures: ▲ ▲ ref |8|
○ ○ ref |9|

1°. the effect of irradiation strongly depends on the microwave frequency;

2°. in certain microwave power ranges, the effect of exposure weakly depends on variation of the power through several orders of magnitude;

3°. the effects are observed as significantly depending on time of irradiation.

If they were confirmed, the effects obtained on irradiation of microorganisms at millimeter ranges should be of great scientific and practical interests.

Experiments were also performed near 2.45 GHZ and 10 mW/cm^2 which consist to irradiate cells of chinese hamsters during 20 minutes |11|. A 10 to 50 percent decrease in the growth rate of the cells and a 50 percent change of normal cells into giant cells were observed by authors who suggest an action at the cellular membrane level.

Other experiments on various enzymes |12| and protein synthesis |13| at 3 GHz and a power density between 1 to 20 mW/cm^2 have given positive results such as an increase in the enzyme activity, in the protein synthesis and in the glucose utilization; an inhibition of the cell growth was sometimes observed in these experiments. These results seem not to be thermal in nature.

Recent experimental results concerning the effect caused by microwave irradiations of either procaryotic or eucaryotic cells are summarized at tables I and II. It may be concluded that below a moderate power density of 10 to 20 mW/cm^2, no direct genetic action upon DNA of cells takes place contrary to the case of ionizing radiations (X-rays, U.V.). But it clearly appears that microwaves have a small effect upon cells which should be the result of an action upon cytoplasm or membranes of cells as the observations of cell growth, metabolism increase or giant cell formation suggest. There should be a great interest to complete the experimental approach of interactions particularly in the millimeter wave ranges.

III - PLURICELLULAR LEVEL.

In this highly organized living system, separation was made for the insect case and the mammalian one.

III.1 Insects.

The existence of teratologic effects in insect pupae was observed in separated experiments |14, 15|. Microwave irradiation of Tenebrio Molitor pupae was made at 9 GHz with a power density of 20 mW/cm^2 during two hours and significantly increased the number of morphological anomalies such as pupal death, absent or reduced elytra, shredded elytra, etc. These anomalies vary with the growth cycle, the pupae age, the orientation into the electric field, the power density, etc.

FREQUENCY (GHz)	POWER DENSITY (mW/cm²)	OBSERVATIONS	RESULTS	REFERENCES
70 to 75		Growth	++	WEBB, BOOTH 1969
2.45	5	Growth	-	BLACKMAN et al 1975
70 and 73	10	Growth	+	BERTEAUD, DARDALHON, REBEYROTTE, AVERBECK 1975
2.45	450	Growth	-	HAMRICK et al 1973
17 and 73	60	Survival, mutations	-	AVERBECK, DARDALHON, BERTEAUD 1976
17 and 73	50	Interaction with X-rays	+	AVERBECK, DARDALHON, BERTEAUD 1976

Table I – *Effect of microwaves on procaryotic cells.*

FREQUENCY (GHz)	POWER DENSITY (mW/cm²)	OBSERVATIONS	RESULTS	REFERENCES
1) Unicellular mushrooms.				
2.1 and 6.4		Growth	+	THOUREL 1976
70 and 73	60	Survival, mutations	-	AVERBECK, DARDALHON, BERTEAUD 1976
2.45	10	Survival, mutations	-	BARANSKI, CZERSKI 1976
2) Mammalian cells.				
3	5-20	Protein synthesis	+	SZMIGIELSKI et al 1976
3	5-20	Virus multiplication	+	LUCZAK et al 1976
3	1-5	Enzyme releasing	+	SZMIGIELSKI et al 1976
2.45		Growth and cell transformation	+	CHEN, LIN 1976

Table II – *Effects of microwaves on eucaryotic cells.*

Rather similar experiments were made with Drosophila at millimeter waves |16|, at 17 GH and 73 GHz |17| more particularly to study the influence on the survival rates, the ability to reproduce and the influence on the offspring.

Irradiation between 15 to 60 minutes of adult male and female Drosophila had no lethal effect; insects showed no externally evident changes and breeding of such insects generally produced normal offspring |16|. However, the offsprings were fewer in number and the insect fertility was modified depending on the radiation frequency and the time exposure when experiments were made at millimeter waves |16|. Irradiation during 2 to 3 hours at 17 GHz or 73 GHz (50 mW/cm^2) has confirmed the absence of lethal effects at the various growth phases of Drosophila |17|. But irradiation of adult male or female insects before breeding generally produces a significantly increased number of eggs during all the laying cycle |17|. Though this work is actually in progress, its first result upon insect fertility is markedly correlated with that of the Russian authors and others recently obtained with larger animals (see below).

III.2 Mammals.

Low level irradiations (less than 10 mW/cm^2) at 2.45 GHz during 6 months (23 h/day) were made |18| which show no effects on eyes, body weight, urinary output, hematocrit, rectal temperature, etc. But nothing is indicated about hormonal or gestation systems.

Effects on the central nervous system or the hematopoietic system were clearly reviewed at reference |3| and |4|.

Interesting results were obtained on the neuroendocrinian system. Indeed attention must be paid to the endocrine functions because the function of male gonads show a natural sensitivity to the harmful effect of excessive heating and because hormones such as acetylchonine and adrenaline are mediators between the nervous system and tissues. It seems therefore possible that microwave radiations may modify the activity of these mediators. First experiments on rats exposed to microwaves with a power density from 1 to 100 mW/cm^2 did not reveal any important changes in the thyroid function |19| contrary to the cases of other experiments on rabbits in the same range of power density which show a stimulating influence on the trapping and secretory functions of the thyroid gland |20|. Evidence was in fact demonstrated of the microwave influence upon hypophysis since it was found that the survival period of irradiated rats was significantly longer in hypophysectomized than in normal rats. Other recent experiments studying testosterone and corticosterone contents in plasma of rats irradiated at 2.45 GHz have shown that the plasma testosterone level is significantly higher in irradiated animals than in normal ones |21|. In general, it was often observed that the content of gonadotropins (LH and FSH) in the hypophysis had increased in animals killed just after the irradiations and had decreased in animals killed 18 to 20 hours after irradiation |22|.

Finally, it appears that the time related quantitative changes of hypophyseal gonadotropins (LH, FSH) can depend on the blocking or inhibitory effects of microwaves on the secretion or releasing hormones in hypotalamic centers |23| and the harmful effects by microwaves on testicular and other endocrine functions could be of both local and central origin. Recent experiments made on Drosophila (as above described |17|) tent to confirm the effects on brain (hypophyseal, hypotalamic) level.

GENERAL THERMAL EFFECTS

Thermal effects were studied many years ago and allowed to determine a safety standard (near 10 mW/cm^2 in most of western countries). Presently, these thermal effects tend to be used for various hyperthermal applications, more particularly in cancer therapy. The general idea is based on the fact that the thermal sensitivity of tumor cells is rather higher than that of normal cells in the temperature range from 41 to 42°C. Uniform heating of tumor cells near 42°C tends to decrease its survival ability or to increase its sensitivity to X-rays or chemical agents.

But high difficulities in the microwave design requirements are still not solved and must provide:

- high thermal uniformity in tumor tissues;
- heating to be localized to the tumor region;
- heating time to achieve a very specified temperature;
- heating to be independent of tumor size.

Many research groups are presently interested in this study of the effect of microwave hyperthermia alone and combined microwave heating with X-ray radiation as modes of cancer therapy.

CONCLUDING REMARKS

As the electromagnetic pollution of the atmosphere steadily increases, a large series of experimental investigations were made in every country to increase the precise knowledge of interactions of microwaves with living systems, more particularly in the last five years. The investigation results are not yet completely known but it seems now clear that the safety standards of a power density smaller than some mW/cm^2 can be considered as satisfying when thermal and non frequency specific effects are taken into consideration. But when specific interactions with certain functions of the living systems are considered, (interactions which are often frequency specific) it appears that these interactions may be present at low or medium power density. The power range limits have not yet been determined and may differ for various species and with a variety of parameters which do not allow a valuable decrease in the safety standard at present time.

It appears to us that further biologic studies are needed to improve understanding of biological effects and more particularly in the following domains:

- study of effects at centimeter and millimeter bands of microwaves;
- study of effects occurring at the molecular level;
- study of effects related to cellular transformations and differentiations;

- study of effects related to neuroendocrinian system.

The present authors think that if microwaves at low or medium power density seem to have no irreversible effect at genetic level, and particularly on DNA, presently known results indicate a possible action of microwaves at the cytoplasmic or membrane level.

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