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ENVIRONMENTAL POLLUTION BY MICROWAVE RADIATION - A POTENTIAL THREAT TO HUMAN HEALTH

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PREFACE

This report concerns work that is part of a program of research on the effects of electromagnetic fields on living tissue conducted in collaboration with the Department of Anatomy, Queen's University, Kingston, Ontario, Canada.

ABSTRACT

Due to the ever-growing application of microwave devices in ind.ustry, research, for military purposes, and domestic appliances (encouraged in part by the advent of economic solid state microwave devices) microwave background radiation may increase to a dangerous level in the near future. This presents a potential threat to human health and measures must be taken to control the proliferation of these devices and their applications.

Power density, the presently accepted index of health hazard, is reviewed. Electric and magnetic field vectors are recommended in its place as meaningful parameters in the evaluation of non-ionizing radiation hazards.

A brief discussion on "weak interactions" between microwave radiation and biological systems is presented.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

It is only in recent years that man has become fully aware of the potential hazards created by his own generated pollution of the environment. Not only is he starting, to, gain full significance of its effects on his health but also on the complex chain of events that characterize natural ecosystems of which he is a small part.

Pollutants in general can be divided into two main groups according to their origin:

1. Man-made pollutants
1. Naturally occurring pollutants .

We are mainly concerned here with what we believe will be a major problem to mankind in the near future -that of microwave pollution of the environment by man-made microwave sources.

2. 0 MICROW AVE SOURCES

The term microwave refers to wavelength. The term is used to describe that portion of the electromagnetic spectrum ranging from about 30 centimeters to about 3 millimeters (i.e., from 1 GHz to 100 GHz in frequency terms, see Figure 1).

Microwaves are widely used. Some typical applications include:

1. Tracking and Navigation (radar installations).
2. Communications, i.e., telephone and television transmission (ground and satellite installations).
3. Research, i.e. , radioastronomy, spectroscopy, MW electron accelerators
4. Industrial appliances, i.e. , MWovens, freeze dryers, sterilizers, etc .
5. Domestic appliances, i.e. , MW ovens.

Since most of the above uses require very expensive MW power devices such as klystrons and magnetrons, only industrial, military and research establishments can operate these costly installations. However, the advent of radically new types of MW generators[1] introduced during the past few years will most probably dramatically change this state of affairs. The new MW generators are of the solid-state type and are considerably cheaper than MW tubes. They include:

1. Gunn oscillators
2. Limited space-charge accumulation diodes (L. S. A.)
3. Read diodes
4. Impatt diodes

These devices are practically battery operated and their cost is expected to drop to a few dollars per unit in the next few years. They are reliable and though their power output is at present limited to less than 1 watt in most cases, it is only a matter of time before solid state MW-technology will have advanced to much higher power MW devices.

From a cost point of view it is easy to foresee the many different domestic and other applications[2] that could be found for MW, so it may be anticipated that MW devices will become widely used in the near future. The uncontrolled proliferation of MW devices would considerably increase the ambient level of MW radiation in a highly complex and unpredictable fashion.

Since the object of this paper is to bring attention to the potential threat that uncontrolled and irresponsible use of these devices could place on human beings, animals and vegetation, we mention in passing a few of the possible major contributors to the MW radiation background:

1. Domestic and private uses of MW devices, i.e. , MW ovens, etc.
2. Use in cars of collision avoidance radar systems, etc .
3. Traffic signalling systems
4. Utility poles
5. Extensive ground communications where the need of closely spaced repeaters is required due to MW attenuation
6. Large scale satellite-earth communications.

3.0 <u>BIOLOGICAL CONSIDERATIONS OF MICROWAVE RADIATION</u>

In view of the lack of knowledge on the biological effects of microwave radiation, the following actions are required:

1. A systematic study of the biologic al effects of MW radiation must be initiated, and
2. The maximum permissible MW radiation levels for occupational workers and public in general must be determined.

Extensive but somewhat inconclusive and controversial studies have been conducted in both areas. An excellent source of references up to 1965 is given by Pressman[3]. Since then, many other publications on this subject have appeared including our own contributions[4-23].

The interaction of microwaves with living systems13 is a subject of extreme complexity, as depicted by the block diagram of Figure 2. .In this diagram an arbitrary division has been made between wave and non-wave effects in order to point out some of the wave effects common , to all electromagnetic radiation. Some of these interactions can be correlated with the biological effects elicited. However, a considerable amount of work has yet to be done in this field to elucidate the subtleties that would lead to an understanding of the observed effects at very low radiation levels.

In the study of the effects of MW on living systems consideration must be given to (i) energy level of radiation and (ii) exposure time.

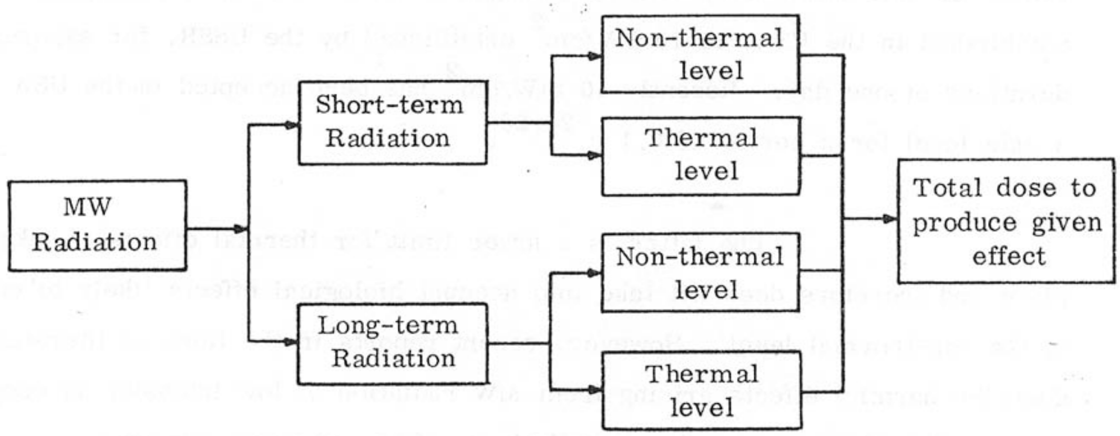
Radiation levels can be divided into two categories:

1. Thermal
2. Non-thermal.

This division requires some clarification. Irradiation intensities below 10 mW /cm2 are considered athermal (non-thermal) for both pulsed and CW beams, either with general or local irradiation of humans and animals. At a power level of 10 m W /cm2 , the energy transformed into heat in the body is roughly equal to the heat loss per square centimeter of body surface of humans and warm-blooded animals under normal environmental conditions.

Further, effects related to exposure time can be divided into two categories: (i) short-term and (ii) long-term.

Exposure time and energy level of radiation together with the observed biological effects are three of the factors which determine the maximum permissible radiation levels, as shown by the following block diagram.



Because of the dramatic effects produced by thermal MW levels resulting in permanent damage and/or death of the biological specimen under irradiation, the short-term thermal level combination has been the most fruitful area of experimentation. Little work has been done on the short-term non-thermal and long-term non-thermal modes of MW radiation.

Since it is reasonably easy to detect and monitor high radiation levels we emphasize the importance of the last two irradiation modes . From these we consider the long term non-thermal combination as being of the utmost importance in the near future because of the doubt we have expressed concerning the uncontrolled proliferation of MW devices .

With this in mlnd a systematic investigation should be undertaken to determine the "safe" levels of exposure for man, animals, plants and various other organisms.

4.0 SAFETY LEVELS

International accord has not been achieved as yet on safe exposure levels in the short and long-terms. Microwave radiation exposure levels for safe whole body radiation ranged from 100 cW/cm^2, originally established in the USA, to 10 $\mu W/cm^2$ established by the USSR, for exposure durations of one day. Recently 10 mW/cm^2 has been accepted in the USA as a safe level for a period of 0.1 h.[24,25].

The latter is a lower limit for thermal effects to take place and therefore does not take into account biological effects likely to occur at the non-thermal level. However, recent reports in the Russian literature describe harmful effects arising from MW radiation of low intensity on people living and working near radar installations. This confirms our own experimental findings in another area.

We mention in passing that although natural MW sources have received practically no attention, such natural pollutants may prove to be of utmost importance in the future.

The status quo of safety levels established by different countries is an indication of the lack of knowledge of the extent of biological effects. The presently accepted safety levels in several countries are summarised in Table I.

All the safety levels are given in terms of MW power (flux levels). Furthermore, and this is not apparent from Table I, these standards have been established by assuming plane waves of linear polarization travelling in free-space reaching points of interest located in the far zone of the radiating element, and far from any disturbing component -- including the biological specimen itself.

In addition, normal incidence of the wave on the specimen is usually assumed together with the fact that the size of the object is much larger than the wavelength of the incident radiation.

Also, standard environmental conditions of temperature, humidity and pressure are postulated and no previous history of the biological system is taken into consideration. In other words the system is assumed to be "normal".

These are indeed very strong assumptions that raise questions as to the validity of the nowadays commonly accepted standards of safe exposure.

5.0 QUANTIFICATION OF M!CROWAVE FIELDS

Power density (Real part of Poynting's vector) has traditionally been used as a parameter of the biological effects associated with a microwave field. Safety standards for levels of exposure have been set based on this concept. The usual procedure is to calculate the power density from the microwave source in the far zone (in free space) where the plane wave approximation is valid

Country	Radiation Level	Period	Remarks
USA and Western European Countries	10 mW/cm^2	0.1 h	
USSR	10 $\mu W/cm^2$	Working day*	
	10-100 $\mu W/cm^2$	2 h/day	Obligatory use of protective glasses
	1000 $\mu W/cm^2$	15-20 m/day	" " " "
Czechoslovakia	25 $\mu W/cm^2$	Working day	Occupational workers, CW
	10 $\mu W/cm^2$	Working day	" " , Pulsed
	2.5 $\mu W/cm^2$	Continuous**	Other workers, CW
	1.0 $\mu W/cm^2$	Continuous	" " , Pulsed

* 8 h/day
** 24 h/day

TABLE I : MAXIMUM MEAN VALUES OF SAFE MICROWAVE IRRADIATION ACCEPTED IN CERTAIN COUNTRIES and set an upper limit to this level as biologically significant for a given biosystem of known electromagnetic characteristics. In this approach the following is further assumed:

1. The object under illumination is semi-infinite in size.
2. The illuminated object and radiating element are far from any reflecting surfaces .
3. No reflection of radiation takes place from the illuminated object in the direction of the radiating element.
4. The radiation field is not affected by the object under illumination .

The above implies that no Electromagnetic Interference (EMI) takes place and that resonance effects are neglected.

It is not difficult to see that none of the above premise are satisfied. Firstly, the energy absorbed by an object is dependent upon its shape and physical dimensions[25], particularly when the wavelength of the incident radiation is of the same order of magnitude as the dimensions of the object itself. Secondly, the object (biosystem) creates a strong disturbance of the field. Thirdly, unless the object is completely transparent or a perfect absorber of microwaves, a standing. wave (SW) will be formed between the radiating element and the illuminated object. Fourthly, objects (including radiating elements) interact with partially reflecting surfaces such as walls , ground, etc. Thus complicated Interference Patterns (IP) arise in most cases.

Even in the far zone of a radiating element (where $D \geq n \frac{a^2}{\lambda}$ with > 1) power density measurements performed in the absence of the object are of very limited value. The situation is worsened because illumination takes place very often in the intermediate and near zones of radiating elements where complex multipath fields (MF) occur and where plane wave approximations are invalidated. For instance, wave-fronts due to cracks, slots, etc. , would be of spherical or cylindrical form for which certain parts of the body (or the body as a whole) cylindrically, or spherically shaped would respond differently from the case where the wavefront is a plane wave. Thus, in most cases information at a given point of the amplitude of the components and phase of the magnetic (electric) field gives no information regarding the electric (magnetic) field at that point.

The alternative of calculating the power density inside the illuminated object as representative of the biological effects induced by the radiation (apart from practical difficulties) is even more complicated and ambiguous. A simple fact will clarify the difficulties. For instance, once the wave front has reached the object of interest the transmitted electric and ~ magnetic fields are out of phase by an angle ϕ which depends upon the properties of the medium and the frequency of the imposed radiation. Because of this phase the power density concept loses its meaning since the maxima and minima of E and H does not take place at the same time and so E/H varies widely in time and from point to point at a given time.

Assuming that the fields inside the object are given by:

$$\underline{E} = E_o \quad e^{-\beta \underline{n}.x} \quad e^{i\,(\alpha \underline{n}.\underline{x}\ -\ \omega t)} \qquad \ldots.(1)$$

$$\underline{H} = \underline{H}_o \quad e^{-\beta\, n.x} \quad e^{i\,(\alpha \underline{n}.\underline{x}\ -\ \omega t)} \qquad \ldots.(2)$$

it is easy to show that for a conducting medium[26] (i.e., biological tissues and fluids)

$$\underline{H}_o = \sqrt{\frac{\varepsilon}{\mu}} \left[1 + \left(\frac{4\pi\sigma}{\omega\varepsilon}\right)^2\right]^{1/4} e^{i\phi} \quad (\underline{n} \times \underline{E}_o) \qquad \ldots.(3)$$

where ϕ (phase angle) = $1/2 \tan^{-1}\left(\frac{4\pi\sigma}{\omega\varepsilon}\right)$ ....(4)

Equation 3 simply means that $\underline{H}$ lags $\underline{E}$ in time by the phase angle ϕ.

In addition the ratio H_o/E_o is given by[26]

$$\frac{H_o}{E_o} = \sqrt{\frac{\varepsilon}{\mu}} \left[1 + \left(\frac{4\pi\sigma}{\omega\varepsilon}\right)^2\right]^{1/4} \qquad \ldots.(5)$$

which indicates that as σ increases the field energy is mainly magnetic in nature .

Due to the phase angle between the fields it is possible to have zero instantaneous power density (i. e ., one of the fields being zero at some instance of time) and arbitrarily large electric (magnetic) energy density, and electric (magnetic) field strength.

A. further complication arises from the fact that the ratio £/H varies along the path of the electromagnetic wave (£MW} due to the different absorption coefficients of the medium for electric and magnetic fields. For example, if one deals with a medium of high electrical conductivity the field will be magnetic itl nature due to the absorption of the electric field as the wave penetrates into the system. Conversely, in a medium of low electrical conductivity and high magnetic susceptibility the field will be predominantly electric .

To appreciate the intrinsic ambiguity of power density measurements in relation to biological effects, consider the following. In the near zone of a radiating element (few wavelengths from the source) the time-averaged power density is zero (energy bouncing back and forth) , yet the electric and magnetic fields associated with the wave may be arbitrarily large (and therefore their energy densities). In some regions near the antenna only a magnetic field exists with no electric field present. There,the power density is zero, but the magnetic energy density may be arbitrarily large.

The standing wave formed by two single plane waves travelling in opposite directions but of the same linear polarization and amplitude has a zero time-average power density. However, the magnetic and electric energy densities associated with the standing wave may be as high as four times that of the original waves at some points.

Once the fictitious nature of power density has been established it remains to decide what quantities are meaningful for quantifying MW fields in relation to their biological effects. In this regard energy density (electric U_E , magnetic U_M , and Total U), the strength and orientation .of the fields (electric and magnetic) and their squared magnitudes (E^2, and H^2) are likely candidates[13].

It is not an easy task to determine which of these parameters is more meaningful from the biological standpoint due to the fact that some biologic al effects are known to depend on the square of the electric and/or magnetic field intensities. Others are determined by the strength and orientation of the fields. Examples of the first kind are those effects depending on energy absorption (electric, magnetic, or both). It will be noted that energy density is proportional to the square of the field intensity where the proportionality factor is the real part of the complex dielectric and/or magnetic permeability. On the other hand some effects fall in the second category such as some magnetomechanical and electromechanical phenomena, field forces on charged particles (Lorentz force) , orientation effects, pearl chain formation, etc .

We believe that the field vectors (strength and orientation of E, and H) are more fundamental parameters than their corresponding squared magnitudes or energy densities because ultimately all biological effects (thermal, or non-thermal) are directly related to them.

The properties of an anisotropic medium with respect to an Electromagnetic Wave (EMW) are defined by the two tensors $\in_{ik}(\omega)$ and $\mu_{ik}(\omega)$ which give the relation between the inductions and the fields:

$$D_i = \epsilon_{ik}(\omega)\, E_k \quad \text{and} \quad B_i = \mu_{ik}(\omega)\, H_k \qquad .....(6)$$

where both ϵ_{ik} and μ_{ik} are symmetrical tensors.

For a transparent anisotropic medium, the internal Electromagnetic Energy (EME) per unit volume (energy density) is[27]

$$\bar{U} = \frac{1}{16\pi}\left[\frac{d}{d\omega}(\omega\epsilon_{ik})\, E^*_i\, E_k + \frac{d}{d\omega}(\omega\mu_{ik})\, H^*_i\, H_k\right] \qquad .....(7)$$

For the case where absorption of the EME takes place (i.e., electric losses), we have[27]

$$\frac{i\omega}{8\pi}\left[(\epsilon^*_{ik} - \epsilon_{ki})\, E_i\, E^*_k + (\mu^*_{ik} - \mu_{ki})\, H_i K_k{}^*\right] \qquad \ldots.(8)$$

These expressions are greatly simplified for the case of an isotropic medium.

In the case of an isotropic transparent dispersive medium the energy density becomes[27]

$$\bar{U} = \frac{1}{16\pi}\left[\frac{d}{d\omega}(\omega\epsilon)\, \underline{E}.\underline{E}^* + \frac{d}{d\omega}(\omega\mu)\, \underline{H}.\underline{H}^*\right] \qquad \ldots.(9)$$

where ϵ and μ are functions of ω, i.e., $\epsilon(\omega)$, and $\mu(\omega)$

Equation (8) can be further simplified for a non-dispersive medium to give

$$\bar{U} = \frac{1}{8\pi}\left[\epsilon\, \underline{E}^2 + \mu\, \underline{H}^2\right] \qquad \ldots.(10)$$

In the case where absorption of electromagnetic energy takes place the losses are given by

$$\frac{\omega}{4\pi}\left[\epsilon''\, \overline{E}^2 + \mu''\, \overline{H}^2\right] \qquad \ldots.(11)$$

where an accounting of the law of increase of entropy yields

$\epsilon''(\omega) > 0$ and $\mu''(\omega) > 0$ except for $\omega = 0$ for all substances at all frequencies. ϵ'' and μ'' are the imaginary part of the complex dielectric ϵ and magnetic permeability

$$\epsilon = \epsilon' + i\,\epsilon''$$
$$\mu = \mu' + i\,\mu''$$

6.0 PERMISSIBLE LEVELS

I

Permissible levels are based on the appearance of some biological effect. Because heat is usually involved in the interaction of a MW field with the biosample, effects we.re first observed at MW levels that produced a measurable increase in the temperature of the specimens. Western countries based their maximum permissible levels on this level. Tissue and biological fluids being lossy materials of relative high electrical conductivity, high Ohmic losses occur in them which are proportional to σE^2. Thus the effect of an electric field (or its magnitude squared) has predominance over the magnetic field.

Strong experimental evidence of biological effects produced at much lower MW levels than those set by Western countries forced Eastern countries (where low-level studies were pioneered) to lower 1u those levels by a factor of 1000. In both cases, nevertheless, safety levels are mainly based on short-term irradiation whether or not they are thermal in nature. That is, effects that appear during an irradiation time much shorter than the life span of the system under consideration. It is therefore possible (and almost certain) that lower field levels may induce biological effects in the long term.

It is important to note that the effect that the magnetic field associated with the MW may have in the biological system has received very little consideration.

In the region where the predominant effects are thermal in nature it is obvious that the electric field plays a key role. In this region subtle non-thermal effects may be obscured by the thermal effects. But actually what happens in the non-thermal region ?

How are the electric and magnetic fields related to a specific non-thermal effect and what sort of interaction on a molecular or macroscopic level takes place? A number of theories have appeared in recent years proposing mechanisms whereby low intensity MW fields can affect biological systems, particularly in regard to effects on the central nervous system (CNS) .

Among the more advanced theories are the following:

1. Batteau[28] suggested as a result of his studies on the mechanism of hearing that sensation in the organisms may be caused by the shifting of the transition probability of electrons from an excited state to the ground state in some organic molecules.

2. A suggestion has been put forward by Berg[29] in which membranes and neural tissues may behave as wax electrets .

3. Wei's[30] theory suggests that the neuron has the potential profile and structure of a p-n-p transistor.

4. Based on experimental evidence of electron transfer taking place in biomolecules

(metabolites, hormones, etc.) Szent-Gyorgy[31] proposed a quantum mechanical theory in which the cell is treated as a solid state system in which the different energy levels that are possible can be occupied by valence electrons fusing into common energy bands.

7.0 WEAK INTERACTION

One can extend the Szent-Gyorgy theory to very large aggregations of like and unlike biomacromolecules to form tissue, organs, or even the whole body. Thus one may picture these as giant complex molecules endowed with practically unlimited numbers of quantum energy states approaching a continuous band distribution. Allowed transitions between different energy states probably constitute the rule and not the exception though this is difficult to foresee without detailed knowledge of transition probabilities between states.

The complicated energy spectrum of such a system is due to complex interactions between. different particles, atoms, functional groups, and molecules making up giant molecules. The structure of their energy spectra would probably consist of various quasicontinuous {or continous) bands (more or less separated by better defined quantum states , etc.) This is due to the different vibrational, rotational, spin, and possibly translational quantum states .

In principle, it is then possible for MW radiation to be absorbed by such a system, inducing in turn a change in quantum state; though only through experimentation is it possible to determine what biological effect would result from this type of interaction. The possibility of a cascade mechanism triggered by a MW photon or by photons of lower or higher energy cannot be ruled out.

Thus the possibility of direct interaction between an EM field and a- macroscopic system such as the human body may be significant.

There are other possibilities. The interaction of an external MW field generated by a living system should also be considered. Little is known about the MW spectrum generated by living organisms. We believe that apart from the so-called black body radiation (Planck's distribution) MW radiation may be produced through specific biophysical mechanisms and chemical reactions. If this is so the continuous spectrum should exhibit maxima and/or minima indicating the generation or absorption by the biological system of MW radiation of non-thermal origin. Currently we are conducting experiments along these lines with an X-band correlation radiometer[32].

Subtle biological effects may also be caused by the magnetic field associated with a MW field. The magnetic field, because of its highly pervasive nature, may in principle affect any, or every, cell in the body of a living system .

Pronounced effects are known to be induced by very weak magnetic fields[33] ranging from afraction of a Gauss to several Gauss. This is the same magnitude of intensity as that commonly encountered in MW fields of moderate energy density. Although most of the experiments have been conducted with DC fields there is no reason to believe that similar effects may not be induced by high frequency magnetic fields. It has been long maintained that the effects of a varying magnetic field are due to the induced emf and currents. However, a change in the magnetic field has been shown to produce direct biological effects[34]. Attention should also be given to the possible influence of the magnetic field on unbounded Ni and Fe. These elements appear in body fluids (plasma, intracellular and extracellular fluids, etc.) and in macromolecules containing ferromagnetic elements *(biomagnetite....jb)* such as iron (hemoglobin) where high magnetic fluxes may be induced.

Many other possibilities fall into what may be referred to as weak interactions. One area of investigation might be the effect of an external MW field on the very low magnetic field known to be produced by the heart, brain, and most recently by skeletal muscles[35]. These fields are in the order of 10^{-7} Gauss (one millionth of the earth's steady magnetic field).

Knowledge of weak interaction is sparse because of the minute strength of these interactions. The tendency is to disregard them on the assumption that they are insignificant. However, biology provides an incredible number of cases that prove otherwise.

We believe investigation into some of these interactions may yield useful and interesting information.

8.0 SOME REMARKS ON MICROWAVE DOSIMETRY

Microwave dosimetry as any other type of dosimetry, is a highly complex matter. Determination of electromagnetic fields inside the system under study is not an easy task because these fields are not related in a simple way to the fields that exist at the same point in space in the absence of the object. This means that either probes have to be implanted in the living system or inside a phantom simulating its characteristics and geometry.

To determine tolerances of MW levels in man one obviously must perform measurements on phantoms since no other animal has man's combined properties of size, shape, skin characteristics, ε^*, μ^*, σ, of tissues, etc. However, it is not possible to simulate (not even approximately) any living system. Not only is it necessary to reproduce the electromagnetic parameters but also the thermal characteristics, cooling mechanism (passive and active) etc., of the system.

Implantation of probes per se introduces a number of problems particularly when it is necessary to determine both field strength and field orientation simultaneously. The latter is very important in cases where field orientation is a determining factor in specific interactions. One further complication arises due to physical dimensions of the probes. Recall that the wavelength (in a medium other than free space) is given by $\lambda_0/\sqrt{\varepsilon'\mu'}$ where λ_0 is the free space wavelength. The complication is more apparent in the centimetric and millimetric regions where electrical performance is greatly affected by the physical size and construction of probes.

9.0 CONCLUSIONS

In view of the expected proliferation of MW devices in many different applications, a substantial increase in MW background activity is feared that may endanger human health. On this basis strict control of the use of these devices must be introduced while present safety standards are revised and extensive research is conducted into long term effects of exposure to low intensity MW radiation. In particular, a study of possible accumulative effects of MW radiation (directly or indirectly) through sensitization must be conducted .

The inadequacy of power density as an index of radiation hazard has been discussed. Meaningful parameters are energy densities (electric and magnetic), electric and magnetic field vectors and their squared magnitudes. We suggest the field vectors to be better quantitative measures to relate to biological effects (thermal or athermal) than their squared amplitudes or energy densities.

Systematic investigations of the weak interactions of MW fields with complex biological systems must be conducted together with exploratory experiments to determine the importance of the magnetic field associated with the EM wave.

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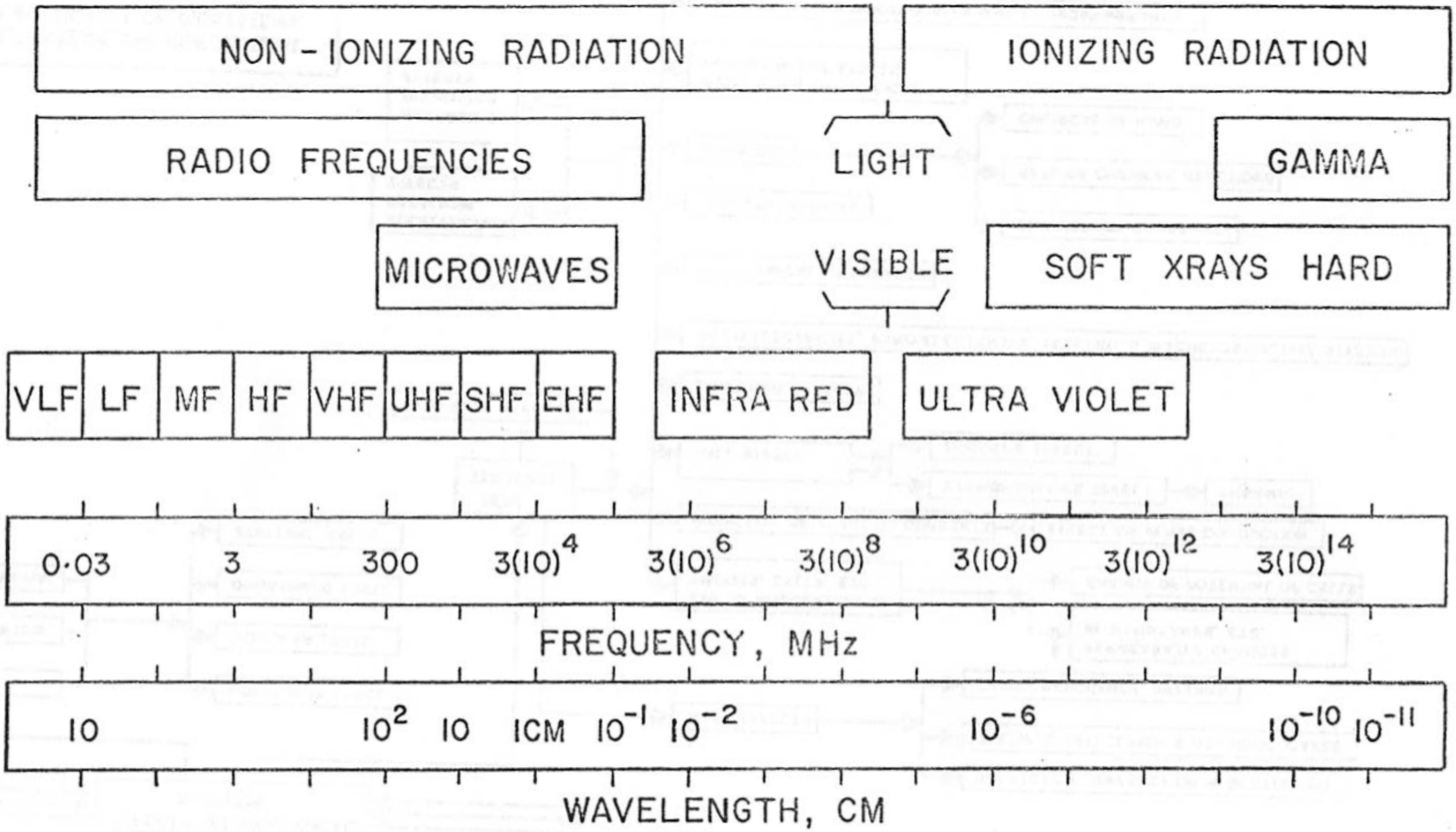
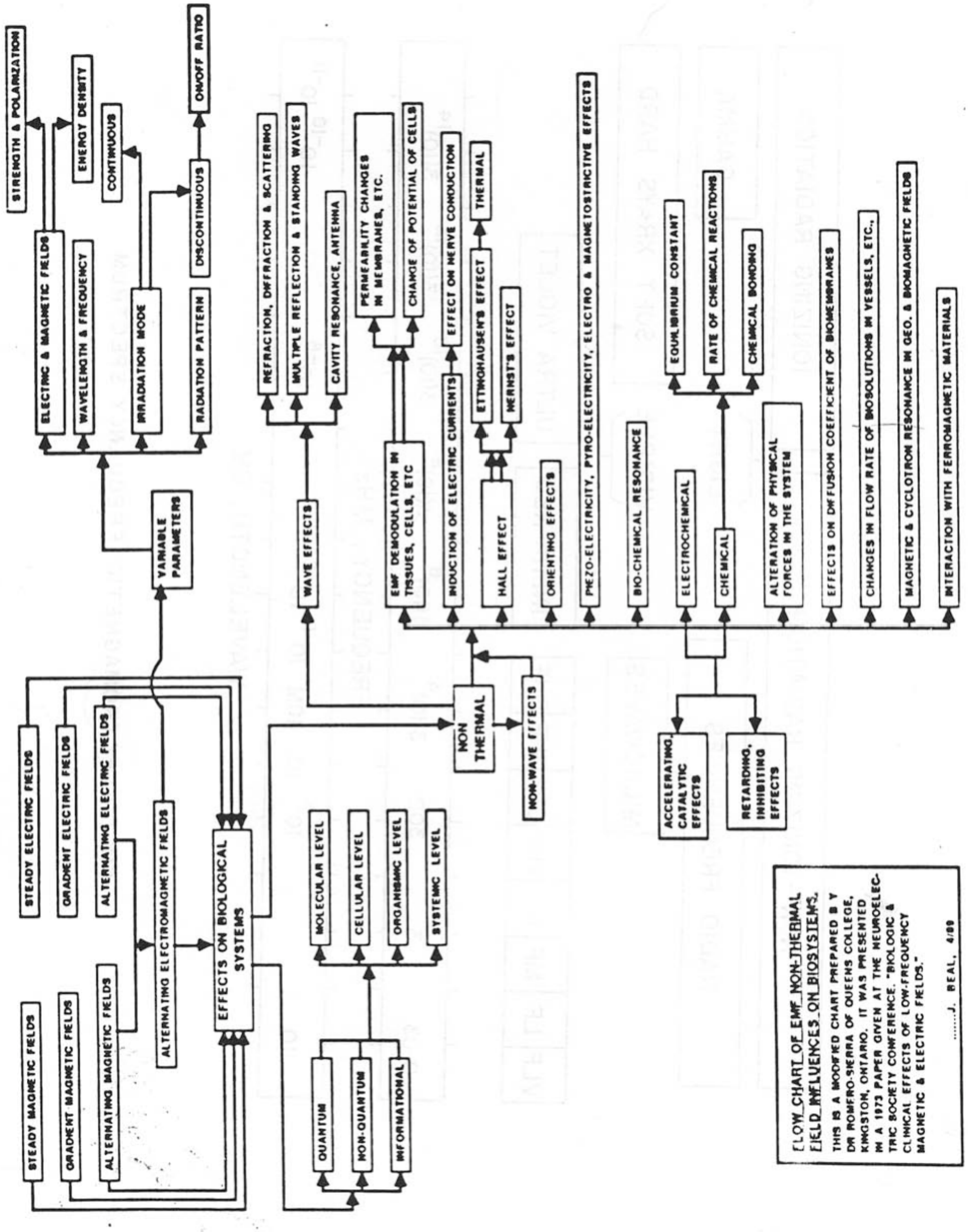


FIG.1: ELECTROMAGNETIC FREQUENCY SPECTRUM


STEADY ELECTRIC FIELDS
GRADIENT ELECTRIC FIELDS
ALTERNATING ELECTRIC FIELDS
STEADY MAGNETIC FIELDS
GRADIENT MAGNETIC FIELDS
ALTERNATING MAGNETIC FIELDS
ALTERNATING ELECTROMAGNETIC FIELDS
EFFECTS ON BIOLOGICAL SYSTEMS
VARIABLE PARAMETERS
ELECTRIC & MAGNETIC FIELDS
WAVELENGTH & FREQUENCY
IRRADIATION MODE
RADIATION PATTERN
STRENGTH & POLARIZATION
ENERGY DENSITY
CONTINUOUS
DISCONTINUOUS
ON/OFF RATIO
MOLECULAR LEVEL
CELLULAR LEVEL
ORGANISMIC LEVEL
SYSTEMIC LEVEL
QUANTUM
NON-QUANTUM
INFORMATIONAL
NON THERMAL
NON-WAVE EFFECTS
WAVE EFFECTS
REFRACTION, DIFFRACTION & SCATTERING
MULTIPLE REFLECTION & STANDING WAVES
CAVITY RESONANCE, ANTENNA
EMF DEMODULATION IN TISSUES, CELLS, ETC
PERMEABILITY CHANGES IN MEMBRANES, ETC.
CHANGE OF POTENTIAL OF CELLS
INDUCTION OF ELECTRIC CURRENTS
EFFECT ON NERVE CONDUCTION
HALL EFFECT
ETTINGHAUSEN'S EFFECT
THERMAL
NERNST'S EFFECT
ORIENTING EFFECTS
PIEZO-ELECTRICITY, PYRO-ELECTRICITY, ELECTRO & MAGNETOSTRICTIVE EFFECTS
BIO-CHEMICAL RESONANCE
ELECTROCHEMICAL
CHEMICAL
EQUILIBRIUM CONSTANT
RATE OF CHEMICAL REACTIONS
CHEMICAL BONDING
ALTERATION OF PHYSICAL FORCES IN THE SYSTEM
EFFECTS ON DIFFUSION COEFFICIENT OF BIOMEMBRANES
CHANGES IN FLOW RATE OF BIOSOLUTIONS IN VESSELS, ETC.,
MAGNETIC & CYCLOTRON RESONANCE IN GEO. & BIOMAGNETIC FIELDS
INTERACTION WITH FERROMAGNETIC MATERIALS
ACCELERATING CATALYTIC EFFECTS
RETARDING, INHIBITING EFFECTS
FLOW CHART OF EMF NON-THERMAL FIELD INFLUENCES ON BIOSYSTEMS.
THIS IS A MODIFIED CHART PREPARED BY DR ROMERO-SIERRA OF QUEENS COLLEGE, KINGSTON, ONTARIO. IT WAS PRESENTED IN A 1973 PAPER GIVEN AT THE NEUROELECTRIC SOCIETY CONFERENCE. "BIOLOGIC & CLINICAL EFFECTS OF LOW-FREQUENCY MAGNETIC & ELECTRIC FIELDS."
......J. BEAL, 4/89