RF/Microwave Radiation Protection

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Introduction

Radio frequencies (RF) and microwaves are *non-ionizing*, unlike much higher frequency waves above the visible range. The interaction of RF/Microwaves with cell tissue can be considered as the result of three processes :

1. Penetration by electromagnetic waves and their propagation into the living system.
2. Primary interaction of the waves with cell tissue.
3. Possible secondary effects of the primary interaction.

The word *interaction* is important. It signals that end results depend not only on the action of the field but are influenced by the reaction of the living system. Living systems have a great capacity for compensating the effects induced by external influences, including electromagnetic sources. While this is often overlooked, it is one main reason why conclusions derived from models must be approached with caution. *Physiological compensation* means that the strain imposed by external factors is fully compensated, so that the organism is able to perform normally. *Pathological compensation* means that the imposed strain leads to the appearance of disturbances within the organism's functions and even structural alterations may result. The borderline between these two types of compensation is not always easy to determine. There are immediate consequences :

Guidelines for limiting the exposure provide protection against ***known*** *adverse health effects.*
Biological effects, on the other hand, ***may or may not*** *result in an adverse health effect.*

Spreading industrialization and increasingly powerful equipment raise issues about the health risks firstly to workers, then to the general public. At the same time, rapid technological advances in electronics, electro-optics and computer science have set the stage for an unprecedented drive towards improving existing medical devices and developing new ones. In particular, advances in RF/Microwave technology and computation techniques have paved the way for new treatments and diagnostic methods. RF/Microwaves are presently used or under study for therapeutic applications in areas such as cardiology, urology, surgery, ophthalmology, cancer therapy, and others, and for diagnostic applications in areas such as cancer detection, organ imaging, and more [1].

Biological effects

Introduction

The main radiation mechanism consists of a *source field* that emits electromagnetic energy. Part of the incident energy is reflected by the body. The other part is absorbed and transformed within the biological system. It is associated with the *internal field*. The ratio between reflected and absorbed parts depends on a variety of parameters : frequency, body size, clothing, skin condition, etc. The physical laws of electromagnetic field theory, like reflection, diffraction, dispersion, interference, optics, and quantum effects must be used for explaining the observed phenomena. This is true for the whole spectrum of electromagnetic radiation. This article, however, considers only RF/Microwaves.

Other mechanisms exist : *bioelectricity* is extremely important in living bodies. It has to be taken seriously into account because a number of components are electrically sensitive : cells, cell membranes, nerve cells, nerve fibres, sheathed or not in the fatty substance called myelin, etc. Bodies are also equipped with a vast array of *receptors* that generate *electric potentials* : nerve impulses propagate in the living system.

A variety of subjects of interest have received attention : power absorption in living bodies, interaction with the nervous system, influence of extremely-low-frequency-modulated fields on cellular membrane channels, and molecular effects. Epidemiological studies have also been done. There is evidence that RF/Microwaves directly affect living systems, as indicated by *in vivo* absorption experiments. Evidence is also provided by *in vitro* studies, revealing effects at various frequencies and intensities, on a number of cellular endpoints, including calcium binding, proliferation, ligand-receptor-mediated events, and alteration in membrane channels. There is ambiguity, however, about the relative contributions of *direct* and *indirect* thermal effects, as well as the possibility of direct *non-thermal interactions*. European research in biomicrowaves was reviewed in 1993 [2], while a detailed discussion of microwave therapeutic medicine can be found in A. Rosen [3].

General review

Biological effects depend upon the internal electromagnetic field, which is the field *in the tissues*. This leads to the definition of the Specific Absorption Rate (SAR), expressed in watts per kilo (W/kg). It measures the power absorbed per absorbing mass. The size of the mass considered determines whether the SAR is

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defined on a local or an average basis. Thermal effects depend on the SAR spatial distribution. The value of SAR influences the *absorption* effects :

- 1 W/kg yields an increase of 1°C in human body, taking thermal regulation into account;
- corneal damage has been observed on monkeys for a SAR of 2.6 W/kg, at 2.45 GHz, while with drug pre-treatment the same damage was observed for SAR in the range 0.26 - 0.5 W/kg;
- retinal damage has been observed on monkeys for a SAR of 4 W/kg, in the range 1.25-2.45 GHz, with pulsed fields;
- SAR above 15 W/kg produces malformations, with more than 5°C temperature increase.

These are *thermal* effects. They are produced by energy transfer from radiation to matter, varying slowly with frequency, largely governed by dielectric loss, the loss being about proportional to the intensity of radiation.

Pulsed exposure produces a detectable effect at power levels smaller than at continuous wave (CW) : comparing CW and pulsed radiation indicates that pulsed radiation is more likely to produce biological effects than CW radiation at the same average incident power density.

The action on the *nervous system* has been a subject of great controversy. The number of experimental results has increased significantly in recent years [4], although the variety of experimental configurations and exposure schemes is so wide that quantitative conclusions are difficult to draw.

The question of *microwave syndrome* at low exposure-level was raised several decades ago in Eastern Europe. It involves a number of signs like headache, perspiration, emotional instability, irritability, tiredness, somnolence, sexual problems, loss of memory, concentration and decision difficulties, insomnia, depressive hypochondriac tendencies, etc. Evaluation is difficult because of the absence of a control group and lack of reliable dosimetric data. A recent paper supports RF sickness syndrome as a medical disorder [5].

Ion fluxes through *cell membranes* have excited great interest. The ions use specific voltage-gated channels to cross the membrane. Normally closed, channels open in response to action potential. Membrane thickness is 10 nm, while membrane potential is –90 mV at rest and may reach +40 mV. Hence, the membrane is submitted to an extremely high electric field, of the order of 1 to 10 millions V/m. Computer simulation on one cell has shown that : (1) there is a significant influence from GSM and DECT signals, (2) pulsed signals are more effective than CW, and (3) low-frequency components in the signal induce an opening probability of 60 % in calcium channels [6]. This computer model for one cell, however, is not sufficient to deduce whole-body consequences.

At the *molecular level*, there is experimental *in vitro* evidence of an increase of chromosomal aberrations in human blood when exposed to 0.5 mW/cm^2 and more [7].

There are indications that microwaves can affect the behaviour of *ear, eye, and heart*, as well as specific medical devices. Electromagnetic interference effects were detected at a distance of 10 cm from a pacemaker [8].

Frequency and amplitude *windows* have been observed in genetic, immune, haematological, and nervous systems, with reproducible window responses from extremely low frequencies to millimetre waves. The phenomenon is that a given effect may be observed for instance at low and high exposure-levels, but not in the intermediate range. In the millimetre range at high power densities, window effects have been observed on protein synthesis by mammalian cells over the ranges 38-48 and 65-75 GHz. Auditory effect by thermoelastic expansion is the most well-known window effect.

Effects on blood-brain barrier

The blood-brain barrier (BBB) is an anatomic/physiologic complex associated with the cerebral vascular system. It is a natural defence system that maintains the physiochemical environment of the brain within certain narrow limits that are essential for life. It functions as a differential filter that permits the selective passage of biological substances from blood to brain. For instance, amino-acids, anaesthetics, and glucose may gain access to brain cells, while carbohydrates, proteins, and most micro-organisms and antibiotics are excluded from brain tissues by the BBB. Unintentional opening of the BBB may subject the central nervous system to assault from extraneous micro-organisms. This might lead to cerebral oedema, increased intracranial pressure, and, in the worst case, irreversible brain damage.

This selective permeability has the disadvantage that agents and drugs that are effective in treating diseases in other parts of the body may not be able to gain entry into the brain to combat infection. The ability to selectively open the BBB suggests the possibility of using microwave regional hyperthermia to facilitate chemotherapy for brain tumours and the delivery of anticancer drugs such as methotrexate. This substance is the drug most often used for high-dose chemotherapy, with a BBB permeability, however, which is among the lowest for the agents used clinically.

A series of investigations of BBB-permeability changes at a very low level of microwave exposure has captured increasing attention. About thirty investigations into the effect of microwave radiation had been reported by 2002, divided about equally between those that showed increased permeability in experimental animals and those that did not, at high as well as at low SAR. The first investigations exhibited changes at high SAR. More recent reports, however, using serum albumin leakage, suggest that exposure to microwave exposure can alter BBB permeability at SAR well below the maximal permissive level for cellular phones, for instance (which is 1.6 W/kg), including extremely low levels (0.016 W/kg). A reasonable line of inquiry therefore is whether, as a result of repeated exposures of the human brain to microwaves from cellularmobile phones, albumin and other toxic molecules might leak into and accumulate around and in the brain cells [9].

Non-thermal, isothermal, and microthermal effects

The possibility of non-thermal effects is a controversial issue. The *controversy* is not only scientific, but largely political and commercial. The idea that non-thermal effects may be caused by RF/Microwaves implies effects at possibly low or very low levels. Accepting or rejecting non-thermal effects is neither a minor nor a recent issues. As far back as 1971, Michelson and Dodge, comparing Soviet and Western views on the biological effects of microwaves, argued that : "The importance of the difference between the Soviet and Western views is readily apparent when it is realized that practical consideration of Maximum Permissible Exposure (MPE) is based on the acceptance or rejection of non-thermal effects of microwaves as biologically significant" [10].

It is important to note that temperature is not an electromagnetic parameter. SAR is proportional to absorption losses, and induces a temperature elevation : if there is absorption, there is a temperature rise. From a phenomenological point of view, electromagnetic theory cannot impose a constant temperature. Hence, it cannot investigate the possibility of non-absorption effects : when using electromagnetics alone; only thermal effects can be evaluated and other considerations clearly have to be taken into account, in which temperature is a parameter. This of course leads to thermodynamics, with its four parameters : volume, pressure, temperature, and entropy. Thermodynamics is able to investigate effects at constant temperature. In other words, *electromagnetics and thermodynamics* have to be used jointly in searching for *isothermal* effects, with energy and entropy being evaluated in combination. This, of course, seriously complicates the study.

Such phenomena, of course, are known to electronics. One typical example is *luminescence*, where there is conversion of heat into luminescent radiation, the heat coming from the thermal energy of the crystal lattice with an energy efficiency which can be greater than unity. As a result, there is a cooling of the lattice, often termed optical cooling. This can be explained by analogy with a heat engine transforming mechanical work into heat, *i.e.* more-ordered energy into less-ordered energy, and where the limit efficiency can be greater than one. Similarly, measurements on an interface between water and air as well as between human tissue and air exhibited what has been called the Saratov phenomenon [11] : at millimetre-wave exposure levels as low as 1 μW/cm^2, an interface response has been recorded at 0.4 and 1.0 GHz for exposure in three frequency ranges : 50, 65, and 100 GHz, respectively. This cannot be explained by electromagnetics alone.

On the other hand, the possibility of isothermal effects does not preclude "non-thermal" effects, which should more accurately be called *microthermal* effects [12]. The question is : *Is it possible for extremely weak electromagnetic radiation to have large biological effects ?* This refers to the possibility of trigger action by microwaves. Microthermal effects could occur in certain frequency ranges only, exhibit saturation at fairly low intensity, and possibly be overshadowed by thermal effects. Such theories have been posited [13]. One known example is the human visual system at low intensities with an energy gain of more than 10^6 for the light quantum to *trigger* the nerve impulse and where *energy is provided by biological system*. Considering for instance radial oscillations of cell*lmembranes* as a basic phenomenon yields resonance frequencies of about 50 GHz. Experimental results support this theory essentially in the millimetre wave region, between 40 and 150 GHz [13] [14] [15]. They are not conclusive, however, or the controversy would have been laid to rest.

It is worth observing that biological effects on living components or systems have been observed at power levels of exposure down to 0.1 μW/cm^2, *i.e.* 0.6 V/m. Two remarks are called for : one is that they have not been observed to be harmful, and the other is that such low values of field are very difficult to measure correctly without expensive equipment.

Epidemiology

Identifying links between *cancer* and environmental exposure of any kind is extremely difficult because of the absence of a single cause of cancer and for a variety of other reasons. Even if there was no link between mobile phones and cancer, thousands of users would still develop brain cancer each year, given the hundreds of millions of mobile phone users around the world. There is a consensus that RF/Microwaves do not initiate *carcinogenesis* by inflicting direct damage on the genome by any mechanism similar to the effect of ionizing radiation. There remains the possibility that RF/Microwaves could (co)promote neoplastic change or act indirectly. Epidemiological studies have resulted in conflicting evidence, with no statistical significance.

In vitro investigations on *genetic effects* have led to some positive results, showing a statistically significant increase of DNA alterations in mice and rats.

Out of four epidemiological studies on human populations exposed to TV/FM transmitted power, two have evidenced a two-fold increase in leukaemia, for childhood and adult populations, respectively. The exposure level was a few μW/cm^2, *i.e.* an electric field of about 3 V/m.

Protection

From this short review, it can be seen that the picture is not clear-cut, especially given that guidelines for limiting EMF exposure provide protection against known adverse health effects while biological effects may or may not result in an adverse health effect. Let us be systematic.

1. The general social environment is that most people : (1) do want a mobile phone, (2) do not want phone masts close by, (3) feel concerned about mobile phone exposure, while (4) no-one worries about TV or FM transmitters, although the whole family of microwave frequencies produces the same biological effects.

2. In the present recommendations, two kinds of limitations are considered :
- basic restrictions that should be always respected;
- reference levels, that could be exceeded when the basic limitations are not exceeded.

The reason is simple. The basic restrictions are expressed in quantities which are internal to the body and are not measured, like SAR. On the other hand, the reference levels are expressed in quantities which are measured *in the absence of human beings*, like electric field. There are theories and estimations relating these two sets of quantities.

3. Only one biological effect of microwaves is well known : *heating*. The present recommendations, being based only on scientific evidence, are limited to heating processes. As an example, the Scientific Steering Committee of the European Commission stated in June 1998 : "As regards non-thermal exposure to EMFs, the available literature does not provide sufficient evidence to conclude that long-term effects occur as a consequence of EMF exposure", the conclusion being : "Therefore any recommendation for exposure limits regarding non-thermal long-term effects cannot be made at this stage on a scientific basis".

4. So far, the appropriate bodies in Europe have chosen to avoid recommendations not based on scientific arguments. This is a choice. Our opinion is that non-scientific arguments have also to be taken into account. Observations made by medical doctors on public health grounds, as in the recent Freibuerger Appeal, are a case in point [16].

5. The recommendations are based on one single source. They originally come from the World Health Organization (WHO), 1993. Today, they are essentially based on documents produced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), with a main document in 1998 giving guidelines for limiting exposure to electromagnetic fields up to 300 GHz [17]. These inspired the European Council when drawing up recommendations for protecting the public from exposure to electromagnetic fields from 0 Hz to 300 GHz.

6. Accepting the possibility of *isothermal* or *microthermal* effects is a big issue : it implies an extra factor of about 100 on power level in the recommendations. This has financial and industrial consequences.

7. There are ambiguities in the basic texts. The WHO 1993 document [18] says on Page 21 : "In normal thermal environments, an SAR of 1-4 W/kg for 30 minutes produces average body temperature increases of less than 1°C for healthy adults", and on Page 23 : "A safety factor of 10 is introduced, in order to allow for unfavourable, thermal, environmental, and possible long-term effects, and other variables, thus arriving at a basic limit of 0.4 W/kg". Note that the document states that an effect is produced from 1 to 4 W/kg and calculates the protection from 4 and not from 1 W/kg. Starting from 1 W/kg yields a safety factor of 2.5 only, which is not much. Further down on Page 23, it says : "An additional safety factor should be introduced for the general population, which includes persons with different sensitivities to RF exposure. A basic limit of 0.08 W/kg, corresponding to a further safety factor of 5, is generally recommended for the public at large". This additional factor yields a total factor of 50 when starting from 4 W/kg and of only 12.5 when starting from 1 W/kg. Most documents refer to a safety factor of 50, based on 4 W/kg. The same discrepancy is found in the document ICNIRP 1998, on Pages 505, 507, and 509, respectively [17].

8. The safety factors for workers about the known effect of increasing the body temperature by less than 1°C for 30 minutes for healthy adults are 10 and 2.5, when starting from 4 and 1 W/kg, respectively. The corresponding safety factors for the general public are 50 and 12.5, when starting from 4 and 1 W/kg, respectively. The safety factor has to take into account the following :
- the temperature increase should be much less than 1°C;
- the exposure may be 24 hours a day and not 30 minutes;
- not all adults are healthy;
- the public is partly composed of non-adults (children);
- not all children are healthy; and
- there are "unfavourable, thermal, environmental, and possible long-term effects".

Are the safety factor values high enough? This is a question for health epidemiologists.

9. Some studies on BBB show an increase of permeability for serum albumin at an SAR of 0.016 W/kg,

i.e. 5 times less than the 0.08 W/kg value to which WHO and ICNIRP put the limit for general public.

10. Let us compare some reference levels at one specific frequency. Take the value for *900 MHz* for the *general public*, expressed in volt per meter, because this is the figure most often published for cellular phones. It should be remembered that the corresponding level for *workers* is 5 times higher in power, which is 2.24 times higher in electric field, because the electric field is proportional to the square root of the power. We have the following :

- WHO, ICNIRP and European Union recommend not exceeding 41.2 V/m;
- several European governments have adopted lower values, like Belgium (20.6 V/m), Italy (20 V/m, and 6 V/m for an exposure of 4 hours or more), Luxembourg (3 V/m), and Switzerland (4 or 6 V/m);
- in February 2003, Paris City Council reached agreement with operators not to exceed a value of between 1 and 2 V/m, depending on the ratio of output transmitted at 900 and 1800 MHz, respectively;
- effects on BBB-permeability have been observed at 0.016 W/kg, *i.e.* 18 V/m;
- considering the possibility of *isothermal* or *microthermal* effects implies an extra factor of about 100 in power, yielding 4 V/m;
- two epidemiological studies on TV/FM exposure evidenced a two-fold increase of leukaemia under 2 to 4 V/m exposure;
- the Belgian High Council for Health has recommended an extra safety factor of 100 to 200, yielding 4 to 3 V/m; and
- when asked, we ourselves have recommended not exceeding 3 V/m.

Conclusions

The situation is complex, because a number of arguments exist, not all of which lead to the same conclusions : there is quite a variety of recommendation levels. There are also ambiguities in the texts formulating the recommendations; these should be put right. One other ambiguity to be avoided is the claim that the recommendations do not address *long term effects*, because of the lack of conclusive scientific evidence, while recommending that employers should give particular attention to *any* effects concerning the health and safety of workers exposed to particular risks. There is also a fundamental difficulty in relying on a doctor or occupational health professional to establish that a health problem is the result of exposure to electromagnetic fields. ■

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