

**Latin American Experts Committee on High Frequency  
Electromagnetic Fields and Human Health**

**Scientific Review**

**Non-Ionizing Electromagnetic Radiation  
in the Radiofrequency Spectrum and its  
Effects on Human Health**

**With a Review on the Standards and Policies of  
Radiofrequency Radiation Protection in Latin  
America**

**Organized by:**



**The Edumed Institute for Education in Medicine and Health  
Independent Research Group on the Impacts of Mobile  
Technologies on Health**

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## Preface

In 2008 a multidisciplinary panel of Latin American researchers in the areas of mobile communications, biology, medicine and health, was assembled with the aim of studying and producing an independent critical review of the recent literature on the possible biological and health effects of low-intensity, high-frequency electromagnetic fields, from the viewpoint of the region's scientists and experts. Special emphasis was to be placed on the results of studies conducted in Latin American countries. Examples of these electromagnetic fields, which are called radiofrequency (RF) fields, are those used for radio and TV communication, mobile voice and data communication and wireless data networks.

The study was called for and coordinated by the Edumed Institute for Medicine and Health, a non-profit research & development institution based in Campinas, State of São Paulo, Brazil, specifically as a project sponsored by its Research Group on Health Impacts of Wireless and Mobile Telecommunications.

Its main motivation, as explained in more detail in the Introduction section of this report, was to address the increasing preoccupation of the general public of Latin American countries with the possible detrimental effects of exposure of humans to non-ionizing electromagnetic fields generated mainly from base stations and cell phones, wireless data communication networks, and similar technologies. For this reason the review focused on RF fields.

The guiding principles that the authors of this Review have adopted were:

- Selecting papers which reported original research, or reviews of the literature, which were published in peer-reviewed journals or books according to the best practices and standards in this field of science;
- Reporting science-based evidence only and ignoring popular reports of the mass media;
- Using a neutral reporting tone and expressing conclusions based on the balance of scientific evidence.

The Latin America Science Review Expert Panel was composed by the following members:

- Prof. Renato Marcos Endrizzi Sabbatini, PhD (Biomedical scientist, Dept. Medical Genetics, School of Medical Sciences, State University of Campinas and President, Edumed Institute, Head of the Research Group on Health Impacts of Mobile Communications, Campinas, Brazil) – General Coordinator and Editor

- Prof. Gláucio Siqueira, PhD (Electrical Engineer, Dept. Electrical Engineering of the Pontifical Catholic University of Rio de Janeiro, Brazil)
- Prof. Victor Cruz Ornetta, EE, MSc (Electronic Engineer, National Institute for Research and Training in Telecommunications (INICTEL-UNI) , Faculty of Electronic Engineering of the University of San Marcos, Faculty of Engineering of the University Ricardo Palma, Lima, Peru)
- Prof. Ricardo Taborda, EE, PhD (Electrical Engineer, Researcher and Professor at the School of Electrical Engineering, University of Cordoba, Cordoba, Argentina)
- Ing. Jorge Skvarca (Electrical Engineer, Ministry of Health and Environment, Buenos Aires, Argentina)

In order to assure the highest quality possible for this review, the Expert Panel was advised by a group of noted international experts, who worked independently and who contributed with guiding principles and standards of quality, and who suggested many helpful modifications and improvements to the final report.

- Prof. Michael H. Repacholi, PhD (Biophysicist, Visiting Professor, University of Rome "La Sapienza", Rome Italy. Former Coordinator, Radiation and Environmental Health Unit, World Health Organization, Geneva, Switzerland. Responsible for WHO's radiation (ionizing and EMF) health programs. Past Chairman and Chairman Emeritus of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) – Chairman
- Prof. Paolo Vecchia, PhD (Physicist, Chairman of the International Commission on Non Ionizing Radiation Protection (ICNIRP), Research Director at the National Institute of Health (ISS) in Rome, Italy)
- Prof. Leeka Kheifets, PhD (Professor of Epidemiology at the University of California Los Angeles School of Public Health, USA).

In addition, the group evaluated the most recent research produced in the Latin American region on these topics by using an extensive search strategy and rigorous selection criteria regarding scientific quality and non-biased approaches to the investigation.

The present report contains the results of reviews and assessments of papers published up to February 2010.

The specific outputs of the initiative were to produce:

- A detailed technical report addressing six areas:
  - a critical review of the globally published scientific literature relating to the biological and health effects of exposure to low-level RF fields, including *in vitro* and *in vivo* experimental and

observational scientific studies on effects at the molecular, cellular, organ and whole animal levels, as well as human laboratory and epidemiological studies;

- the identification of Latin American research groups, active experts and researchers in the field, as well as the published literature record;
  - the relevant social issues of mobile telecommunications, including how to communicate with the general public in regard to possible health effects, safety issues, precautionary measures, etc.
  - the status of non-ionizing electromagnetic protection standards and legislation in Latin American countries;
  - a roster of Latin American researchers and experts in RF fields, biology and health; and safety standards;
  - a list of recommendations of research topics that could and should be usefully conducted in Latin American countries
  - A public website in Portuguese, Spanish and English containing useful and practical information on health effects of RF fields, distance learning courses and other RF topics for the general public, teachers, legislators, etc.;
- One or more review papers, to be published in peer-review journals of relevance to the region, as well as in journals having an international reach.

A preparatory meeting of invited Latin American and international experts to establish the Report's aims and objectives, strategies and information sources, including the more detailed planning of contents and deliverables, preceded the work of the Expert Panel. Drs. Michael Repacholi and Paolo Vecchia delivered scientific review presentations at the meeting in August 2007, held in the city of São Paulo, Brazil. The review work was assigned to three working groups, coordinated by Expert Panel members:

1. Biological and health effects (effects on cells, tissues and whole animals);  
Coordinated by Dr. Renato M.E. Sabbatini (Brazil)
2. Standards and policies (standards, regulations, protection programs, policies);  
Coordinated by Prof. Victor Cruz (Peru), members Dr Gláucio Siqueira (Brazil) and Ing. Jorge Skvarca (Argentina)
3. Social research and public communication  
Coordinated by Prof. Ricardo Taborda (Argentina) in collaboration with Dr Renato M.E. Sabbatini.

A second meeting was also held in São Paulo in May 2008, in collaboration with an International Symposium on High Frequency Electromagnetic Fields and Human

Health (LASR 2008) held at the Polytechnic School of the University of São Paulo<sup>1</sup>. Several of the members of the Expert Panel Working Groups presented preliminary reviews, conclusions and directions for further work. This conference was open to the public, and many government officials, physicians, engineers, representatives of the telecom industry, etc., were invited to participate and to join the discussion. Drs. Repacholi and Kheifets gave two pre-conference short courses on the subject.

A third and final meeting was held in October 2009 during the international meeting of the ICNIRP (EHE 2009) in Rio de Janeiro, Brazil, where a special session was devoted to Latin American perspectives on RF fields, and where Dr. Sabbatini presented the preliminary findings and conclusions of the biological and health effects chapters.

After passing through extensive reviews of the International Advisory Group, between November 2009 and January 2010, the final version of the document is presented here.

The Latin American Science Review Report is organized into the following main sections:

1. Introduction
2. Executive Summary
3. Review of the literature on biological and health effects
4. Social and communication issues
5. Safety and radiation protection standards in Latin America
6. References
7. Annexes

The review on biological and health effects is further subdivided into *in vitro* and *in vivo* studies, human experimental provocation studies, and epidemiological studies, and constitutes the main body of the Report. It was intended to be a general critical review of the literature, with the most up-to-date information as possible, but it is not a comprehensive, systematic review or a meta-analysis of published papers.

The contents and conclusions in this Report represent the consensus view of all members of the Expert Panel. The Expert Panel strove as much as possible to use language that can be easily read by everyone and explained the meaning of more obscure jargon and abbreviations.

The Report is not intended to be a tutorial or a general text on the subject since it does not include background material on the physics and radiobiology of RF fields, technical descriptions of radio communication devices and systems and scientific

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<sup>1</sup><http://www.edumed.org.br/lasr2008/en/>



methods of investigation in the area. These materials can be found elsewhere. Due to the complexities of epidemiological research on humans, an annex with a short description on the types of such studies has been added.

The Latin American Expert Panel hopes that this Report will be useful for students, the general public, teachers, physicians and researchers, particularly those working in Latin America. In addition the Report should assist policy makers, legislators and government officials who often have to deal with demands for greater safety and need to make difficult decisions based on reliable information on the health aspects of RF fields used in telecommunications of all sorts. Mass media communicators are also invited to use the information provided herewith, in order to base their work on science-based evidence of the highest standard.

Finally, on behalf of the Expert Panel and of the Edumed Institute, I would like to gratefully acknowledge the efforts and excellent contributions of all the people and institutions that collaborated and helped to make possible this Latin American Science Review.

Especially we would like to thank our international sponsors, the Mobile Manufacturers Forum (MMF) and GSM Association (GSMA), who provided some of the funding needed for the meetings, travel and preparation/translation of the report. Their support for the Latin American Science Review allowed for a truly independent assessment by the Expert Panel. All decisions and conclusions on the content of this Report were the sole responsibility of the Expert Panel and may not represent the views of the sponsors or their member companies.

In addition, all the members of the Expert Panel declare that they have no financial interests or binding commitments to private companies related to the subject of the Science Review.

Renato M.E. Sabbatini, PhD  
Editor  
April 2010

## **Executive Summary**

The aim of this report was to produce an independent critical review of the recent literature on the possible biological and health effects of low-intensity, high-frequency electromagnetic fields, from the viewpoint of the region's scientists and experts. Examples of these electromagnetic fields, which are called radiofrequency (RF) fields, are those used for radio and TV communication, mobile voice and data communication and wireless data networks. Special emphasis was to be placed on the results of studies conducted in Latin American countries. International and national exposure limits, policies and standards are also examined in this respect.

### **Biological and Health Effects**

The first and most important part of the the literature review examined the scientific evidence for possible biological and health effects of RF. The two known actions of RF fields on living matter are assessed: thermal (due to dielectric heating of molecules); and non-thermal (mechanisms not due to local or whole body increases in temperature). The first part of the review examines experimental evidence based both on *in vitro* (cell cultures and isolated tissues) and *in vivo* (living animals) models. The second part reviews the literature on RF effects on human performance and health parameters, both from the point of view of laboratory (provocation) studies, as well as by means of observational (epidemiological) studies. This review has concentrated on exposure of humans to RF levels compatible with base stations (so called community exposures) or during the individual operation of mobile phone handsets close to the body.

### **Experimental Studies**

The general conclusion of *in vitro* studies is that there is, so far, inadequate evidence or a lack of consistent and validated evidence to establish my cause-effect relationship between exposure to low level RF and short-term effects on cell cycle and regulation, membrane transport, apoptosis, genotoxicity, mutation rates, gene and protein expression, damage to genetic material and cell proliferation, transformation and differentiation of cells and tissues. Some reported effects that have been established appear to have little significance on cancer or impact on larger cell systems, at least when RF exposures are kept below recommended safety levels, even for long periods of time. Thus, there is very little plausibility for effects at the cellular level that might lead damage at the higher organ levels or for human health consequences.

In regard to *in vivo* animal studies, one of the most significant RF effects to be reported is disruption of the blood-brain barrier (BBB). This was reported in small laboratory animals in less than 30% of reviewed studies. However, most well controlled studies have not reported these effects and it seems that the positive

results could be explained more simply by uncontrolled effects of heating. Further, the translation of such results to human beings, with entirely different cranial geometries and blood flow, is very doubtful.

The induction and promotion of tumors or blood neoplasms by RF exposure in animals as well as the appearance of cellular molecular predecessors of tumorigenesis, etc. has also been investigated. Despite using RF exposures, measured as specific absorption rates (SARs), far above those that people are normally exposed to, and in some cases exposures for the duration of the animal's lifetime, about 93% of *in vivo* studies published since 1990 have shown no significant short or long-term effects. Further, the average survival of irradiated groups of animals was not affected in some 96% of studies.

No convincing evidence has been presented for RF acute or chronic effects of RF on other physiological and biochemical parameters in animals. Thus, the general conclusion, after more than 20 years of *in vivo* studies, is that no consistent or important effects of RF could be demonstrated in intact animals below international safety standards. There seems to be no important pathophysiological effect of RF fields, apart from thermal effects caused by exposure to fields many times larger than those encountered in our living and working environments.

**Human provocation studies** have investigated mostly possible effect on the nervous system, including many cognitive and behavioral responses, in response to low-level RF fields emitted by mobile telephones near children as well as in adults. It is now generally accepted that there are no significant effects of cell phone usage or reasonable proximity to radiating antennas of base stations on them. Other investigated effects on pain, vision, hearing and vestibular function, as well as on the endocrine and cardiovascular systems, were mostly negative. Taste and olfaction have not been studied, so far. Even in studies that reported a mild effect, they were not considered as detrimental to health. However, their significance from long-term exposure could not be verified. Studies using functional imaging of the brain and deep infrared thermography have shown that there is no significant heating caused directly by RF exposure in the bone or brain.

In the so-called "**RF hypersensitivity symptoms**", 4 to 5% of the population report being sensitive to RF fields, while some of these intolerant individuals report ill health and a number of distressing subjective symptoms during and after using a cell phone and from exposure to other radiofrequency-emitting devices, or being near an RF antenna site. These symptoms are quite nonspecific and are present in many diseases, such as cold and flu-like symptoms (headache, nausea, fatigue, muscle aches, malaise, etc.). However, several studies, systematic reviews and meta-analyses in the last 15 years have concluded that hypersensitivity and the observed symptoms have no correlation to RF exposure of individuals. There is presently no scientific basis for characterizing RF hypersensitivity as a medical syndrome.

One can conclude from human experimental studies that current science-based evidence points to there being no adverse effects in humans below thermal thresholds, no hazardous influences on the well-being and health status of users and non-users of cell phones and people living near base stations, and that no convincing evidence for adverse cognitive, behavioral and neurophysiological and other physiological effects exist.

### **Epidemiological Studies**

With regard to community exposures from base stations antennas, there is a scientific consensus that these levels are many thousands of times below the international safety standards, even at short distances from the antennas. The few published epidemiological studies with a minimally accepted degree of quality have not demonstrated any clear effects of RF exposure on morbidity, mortality, effects on well-being and health status of population groups living near the RF sources. Long duration studies are lacking, however. Furthermore, it is difficult to separate exposures to cell phone base stations from those of other sources, such as radio and TV broadcasts, with any degree of accuracy.

On the other hand, a much larger number of epidemiological studies investigating possible effects of RF exposure of cell phone handset users have been published. Many of them have a good methodological quality and a large number of subjects. While some large cohort studies have not detected any higher risks for users of cell phones for a period up to 15 years when compared to non-users, for a number of outcomes, including malignant and benign tumors of the nervous system; a small number of restricted epidemiological studies have contradicted these results for some tumors, among heavy and long time users, in the most used side of the head. Larger and better controlled studies, such as INTERPHONE (an international collaborative study which has involved 16 careful case/control studies in 13 different countries), generally reported a lack of statistical associations, except for a disputable slighter higher risk of gliomas and acoustic neuromas for users with more than 10 years of use. No epidemiological studies with long term exposures larger than 20 years have been published so far, as well as no study addressing health risks of cell phone usage by children and adolescents.

Epidemiological studies of associations between exposure of populations to RF of cell phones or base stations and several other health problems, such as neurodegenerative disorders, cardiovascular diseases, cataracts, reproductive health changes, behavioral changes and nonspecific symptoms, etc. have resulted in mostly statistically non-significant associations.

In addition, there is a large number of methodological difficulties in epidemiological studies of exposure to low-level RF, including several kinds of biases which are hard to identify and compensate for.

We conclude, therefore, that current published RF epidemiological studies have not shown any sizable, incontrovertible and reproducible adverse health effect, and that numerous methodological flaws, along with only the few outcomes examined so far, do not allow for firm conclusions, particularly as it relates to children and to continuous exposure for periods larger than 20 years.

### **Indirect Effects**

The possibility that medical devices could interfere or be adversely affected by RF emitted by the antennas of base stations and portable wireless devices in their proximity has prompted, in the 1990s, many engineering and clinical tests around the world. This might be one of the few documented, albeit indirect detrimental effects of low level RF fields on the health of exposed people. This is especially the case for patients using implanted cardiac pacemakers or defibrillators, or hooked up to life support devices, such as mechanical ventilators, which are vital for their continued survival.

Our review of this subject concluded that wireless communication technologies with enough output power and very close proximity to medical devices of several kinds, including implanted devices, have the possibility of causing electromagnetic interference with potential hazardous effects on the well being and critical life support of patients. However, the low power technologies and frequency spectrum used by present-day digital communications devices and the electronic filters installed on modern medical devices have greatly reduced the chance of occurrence of such hazards, when they are used normally. Thus, scientifically and technically there is presently no need to restrict the use of medium risk mobile phones and wireless data communication devices in any area of healthcare institutions, and no general ban policy is necessary, or legislation to this effect. Higher powered communication radios and data communication modems, which may pose a higher risk of interference, should be used sparingly and in emergency situations only if they are very near to medical devices, implanted or not.

Another kind of indirect effect of cell phones and other portable voice and data communication media is the risk posed by using them while driving a motor vehicle. Since this risk does not relate to an effect of RF fields, it has not been examined by the review.

### **Social Issues and Public Communication**

A lack of good risk communication and understanding of the public's perception and acceptance of risk seem to be a major contributor to the fear about possible health effects from mobile communications technology. Also important is the public's understanding of science.

Fear of technology is not novel. There has been fear of detrimental health effects when telegraph wires, TV sets, power transmission lines, aspartame, silicone breast implants, and many others were first introduced. Also, EMFs are not perceptible to our senses, adding to the public's concern.

An obvious way to alleviate this fear and anxiety about possible RF effects is to provide people with as much information as possible (user education), provided such information is well proven and provided by qualified experts and organizations. Every effort must be made not to increase peoples' concerns. For example, discussing scientific uncertainty and implementing precautionary measures may have a negative impact on the public's perception of risk or its trust in policies and government agencies if not done with care.

An important factor for public acceptance of new technologies seems to be risk/benefit comparison, which is not obvious. Of particular interest to mobile phone users, industry and government is the fact that there have been few recent studies on risks versus benefits for mobile communications, compared to many other technologies that have a strong impact on society.

Despite the existence of an overwhelming body of serious research demonstrating no confirmed detrimental health effects from RF, with the exception of using a mobile phone while driving, alarmist media reports have created a public view that is out-of-step with the scientific evidence.

All technologies have their share of risks. These must be counterbalanced by a careful study of its benefits. Such is the case of automobiles, airplanes, chemicals used in agriculture, food conservation, oil and coal combustion, nuclear power, genetically modified foodstuffs, etc. Society has recognized and accepted all of them, due to their extreme usefulness provided the risks are managed by enforcing exposure limits, making technological modifications, or similar measures to reduce risks. Thus, there is a need for more studies focusing on the social and economical benefits of mobile communication technologies.

This section covers the report on social research and communication to the public, and addresses several interrelated topics, such as risk perception, risk acceptance and risk/benefit issues, social resistance to new technologies, the understanding benefits: perceived and real impacts of mobile communication on health, well-being and security of the public, public understanding of science. public communication on EMF and health issue,communicating about uncertainties in science. applying and communicating the precautionary measures, evaluating the quality of information to the public and ethical and professional responsibility of the mass media.

Latin American references on public communication and social research on EMF are scarce. Most of this review was based on references from country reports in

Europe, the USA or other non-Latin American countries.

It is suggested there should be a reference location for the Latin American region providing Internet coverage of all relevant issues related to EMF and Health. It should be located either in the appropriate government regulatory agency or in a prestigious university or research institute.

Having many different rules only creates confusion and mistrust of government. Every effort should be made to harmonize standards at all levels (from national to state or municipality level) adopting science-based standards recommended by international bodies such as ICNIRP.

### **Non-Ionizing Radiation Protection Standards and Policies**

In the last third of the 20<sup>th</sup> century, concern about possible detrimental effects on human health of artificial non-ionizing electromagnetic radiation (NIR) prompted many efforts to determine the maximum levels of exposure and to set up recommendations for safety standards for the entire EMF spectrum, both for occupational and for the general public. These standards of safety are based on evidence provided by scientific studies worldwide, and are revised periodically. In addition, the World Health Organization's International Electromagnetic Fields (EMF) Project has been promoting the adoption of science-based international standards and the harmonization of national standards. As important tools to achieve these commitments, WHO has compiled a worldwide standards database and has published two policy handbooks that are very useful for countries developing NIR standards.

The purpose of the chapter is to provide information on standards and policies in Latin American countries in order to inform government and other authorities about policies and regulations in the region and about international standards recommended by WHO. The structure of several standards and recommendations are examined, such as those developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the IEEE (Institute of Electrical and Electronic Engineering), the ITU (International Telecommunications Union) and the USA FCC (Federal Communications Committee).

After 1992 the ICNIRP has been charged with the development and maintenance of international guidelines for NIR. Its 1998 publication established general public and occupational maximum permissible limits against NIR exposure and are the most credible international guidelines on NIR, being endorsed by WHO, the International Labor Office (ILO) and the International Telecommunications Union (ITU). By 2009 they had been adopted as national standards by more than 50 countries worldwide. The IEEE standards adopted in North America are similar, but less strict than the ICNIRP Guidelines although they are based on the same science.

The ITU has made recommendations on compliance of telecommunication systems with EMF exposure limits. At the regional level in Latin America the Inter-American Telecommunication Commission (CITEL) has compiled information and regulations of the WHO, the Pan American Health Organization (PAHO), the ITU, the ICNIRP, the Mobile Manufacturers Forum (MMF), the International Electrotechnical Commission (IEC), with respect to the effects of NIR and the established technical standards. CITEL has also compiled EMF regulations in force in Latin America and other regions.

Currently in Latin America there are 10 countries that have implemented non-ionizing radiation standards for telecommunication systems: Argentina, Bolivia, Brazil, Colombia, Chile, Ecuador, Panama, Paraguay, Peru and Venezuela. Others are being developed, such as Costa Rica, Dominican Republic and Uruguay. Most of the implemented standards are based on ICNIRP guidelines.



# Chapter I - Radiofrequency Fields (RF) and their Biological Effects

## Introduction

In the physical realm, matter and energy interact with each other in many forms and levels. Of particular interest to biology is how electromagnetic energy interacts with matter, especially organic matter, and how this affects in any way the form and function of living cells, tissues and organisms. For the health sciences, these interactions may have interest for its detrimental effects on organisms, particularly human beings.

In the last 100 years, a great deal of scientific research has discovered and studied the nature and properties of electromagnetic radiation and how it interacts with matter in general, and living matter in particular. The visible part of the electromagnetic spectrum, which was the only one known by Man until the last quarter of the 19th century, has been studied for a number of such interactions. In fact, life forms are mostly possible on Earth only because of these interactions, such as photosynthesis. With the discovery of other forms of electromagnetic energy, such as x-rays, gamma rays and ultraviolet, all of which are non-visible to the human eye, other mechanisms and effects of energy-matter interaction were discovered. For instance, the detrimental nature of x-rays to molecules, cells and organisms was discovered only when radiologists began to develop malignant skin diseases after extensive and prolonged exposure to x-rays in the beginning of the 20th century, leading to the scientific study on the nature of these effects, and to the elucidation of its genotoxic potential (such as inducing mutations in the genetic material of cells, cell death, etc.).

As a consequence of these studies, science has determined that, with regard to its effects on atoms, molecules and its bonds, the electromagnetic spectrum can be roughly divided into two types.

- 1) frequencies that possess enough energy to remove electrons of the outer orbitals of some atoms, thus rendering them into ions (charged atoms called ions), a process which is called ionization; and
- 2) frequencies that do not have enough energy to produce ionization, and that interact with matter in other forms, such as producing mechanical vibration of atoms, which is expended as thermal energy.

Accordingly, electromagnetic energy has been classified into ionizing and non-ionizing radiation, which has been somewhat in an overly simplified way associated to frequency alone, which is wrong, since the ionization potential depends not only on frequency but also on the properties of matter which it impinges upon,

specifically the vulnerability of molecular bonds to ionization. For example, photosynthesis depends on an ionization step, caused by yellow light, which is generally considered as a non-ionization frequency, as well as the effects of light on melatonin in the skin, the synthesis of vitamin D, the primary molecular mechanism of vision, and several others.

## **Natural and Artificial Sources**

Electromagnetic energy is found everywhere in the Universe, and has many natural sources for Earth-bound life forms, such as the Sun itself (by far the largest one, particularly for visible light, but also for other frequencies as well), other stars (x-ray and cosmic radiation) and planets (radio waves), the magnetosphere of the Earth, etc. In fact, any body at a given temperature emits some EMF energy, including our own bodies.

In the last century, with the discovery of practical applications and novel devices that use electromagnetic energy, such as x-ray tubes, gamma ray sources for medical treatment, infrared and radio communicators, lasers, electrical transmission lines, motors and dynamos, electromagnets, electronic devices, etc, the environment where we live has been gradually and increasingly “invaded” by artificial sources that superimpose on the natural electromagnetic sources. Most of them, being invisible and with unknown interaction properties with living matter began to generate a fear of possible detrimental effects on health. This fear is a natural response and has happened with practically all new technologies, such as the telegraph, the telephone, the television, the computer, the cell phone, and so on.

The intensities of emissions of these artificial sources vary a lot: they can be extremely high (such as microwave ovens, high-power lasers and masers, or near long-range radio communication or radar antennas) to the extremely low (such as in geosynchronous satellite communication and short range data communication devices). Thus, some can have obvious detrimental effects, such as the cooking of biological matter by microwave ovens, while others appear to have no effect at all, such as the small wireless signal we use to open garage doors.

More recently, due to the enormous growth of wireless mobile communication, especially cell phones, worry about the possible effect of such mass implementation of radio base stations and the use of handheld devices began to appear, leading to the increase in scientific investigation on whether non-ionizing radiation (NIR) used in these technologies could have short-, medium- or long-term biological effects, and whether they could represent a health hazard to human populations. In fact, any detectable detrimental effect, even small, could be very important, due to its widespread use, the monumental numbers of people exposed to NIR on a daily basis, and the social, economical and health impacts this could have.

This research began to appear in significant numbers in the 1970s, and has grown exponentially since then, generating an enormous body of published information. Learned societies and governmental and international committees, agencies and groups were formed to examine the subject and have produced also a great number of technical reports and recommendations, which have been updated regularly for many years. Large scale cooperative multi-country research efforts have also been initiated and a great deal of work and financial and human resources have been applied to these efforts, fueled by the public apprehension and the need to institute standards of protection and precautionary measures, or to introduce government-mandated regulation and limitations to the spread and use of man-made EMF sources.

### **Rationale for this Review**

Although many competent and exhaustive reviews of the literature on the biological and health effects of non-ionizing electromagnetic fields have been published worldwide recently (e.g, ICNIRP, 2009), we have many reasons to believe that a new literature review conducted by Latin American experts in the field is justified to give a regional perspective on this issue.

Firstly, although there is a small body of research carried out in this area in Latin American countries, it is important to bring them to light and to review and discuss their findings. Some of these regional contributions might provide a significant contribution to the overall body of knowledge, since they reflect social, environmental, professional or technical particularities of Latin American countries.

Secondly, there are nowadays in the region many growing concerns about the possible health effects of NIR in human populations exposed to it, mainly due to the explosive growth of wireless mobile communication and data networks in Latin America in the last decade. In a recent statistical report, it has been stated that:

*“Mobile penetration in Latin America and the Caribbean was approximately 80% in early 2009, well above the world average which was about 58%. With 458 million people owning a mobile phone in early 2009, Latin America and the Caribbean together hold approximately 12% of the world’s 3.97 billion mobile subscribers. Several countries, including Brazil, Argentina, Jamaica, Uruguay, and Venezuela have passed the “100% penetration threshold” (Latin America Mobile Communication Statistics, May 2009). According to a GSM Alliance Report, “Latin America and the Caribbean led the world market percentage growth rate for GSM, adding more than 74 million new customers in the one year period from March 2005 to March 2006, nearly doubling their subscriber base with a growth rate of 97%”*

This fear has been pervading in all social and economical classes, despite the extensive use of cell phones by the population, and is fueled often by reports in the

lay press that reproduce, in a non critical way, what the international press publishes. In addition, a widespread call to restrictive legislation by politicians has produced many laws that are not solidly supported by scientific evidence, and which has been causing more harm than good. Thus, the examination and the expert opinion of Latin American scientists is important and adds an all-important factor of trust. Besides, Latin American scientists are obviously more aware of the particularities of NIR use, legislation and enforcement of regulations, etc. in the region.

Therefore, the literature review was carried out with these purposes and approaches in mind, and as often as possible we will review Latin American contributions to the body of research, and issue recommendations in regard to its importance, applicability and viability in Latin American countries.

In order to find relevant and high quality papers published in this field in Latin America we have researched three literature databases: 1) the LILACS (*Literatura Latino Americana em Ciências da Saúde*, maintained by the Regional Center of Health Information for Latin America and the Caribbean, an agency of the Pan American Health Organization, which concentrates on journals published in the region.; 2) MEDLARS literature database of the US National Library of Medicine, and 3) The EMF-WHO (*World Health Organization Electromagnetic Fields and Health Programme*) research database. The search strategy was using the names of Latin American countries in conjunction with proper keywords. Papers and books published by scientists and technicians of Latin American origin but working in countries not in the region were not considered.

### **Limitation of Scope**

With the above in mind, the literature review and critical analysis that follows will limit its scope to the biological and health effects of non-ionizing electromagnetic radiation (jointly called **bioeffects**), limiting it to the frequency ranges used for radio and microwave communication, such as that used in radio and TV broadcasting, mobile voice and data communication, wireless data communication networks, etc.

We cover in the review not only the possible effects of occupational and general public exposure to these radiofrequency (RF) fields, but also direct and indirect effects of RF (such as the effects on medical devices). The review will not deal with other less common NIR sources, such as higher power sources of RF, light and infrared or with extremely low frequencies (ELF), such as in electrical power transmission.

### **Biological Effects of Non-Ionizing Radiation**

The traditional and most effective approach to study cause-effect relationships in

the biological sciences is by experimentation with cells and organisms. **Radiobiology** is the field of biological sciences that tries to elucidate how the several forms of radiation interact with and affect living beings of all kinds. **Bioelectromagnetics** is the sub-field of radiobiology that focuses on the study of electromagnetic fields, both ionizing and non-ionizing, be it naturally or artificially generated. It can be pure or applied research, but most of the applied research has as its target the eventual applicability of the acquired knowledge to human matters, such as the vulnerability to externally applied RF generated by devices, such as TV transmitters and cell phones.

In this section we will review the experimental evidence gathered on the biological effects of high frequency electromagnetic energy, particularly in the radio and microwave frequency range, carried out in many *in vitro* and *in vivo* models except human beings; this will be covered in the next chapter. This chapter includes *in vitro* (cell cultures and isolated tissues) or *in vivo* (living animals), particularly mammals, which are genetically and physiologically more similar to human beings than bacteria, worms or insects. In this way it is hoped that this knowledge can be transferred to human beings, who, for ethical reasons, cannot be used for most kinds of experiments.

*In vitro* models have been extensively used for studying non-ionizing electromagnetic field interactions at the level of molecules and the chemical machinery of life that works at these levels. They include cell and tissue metabolism, biochemical pathways and cascades, ion transport across membranes and inside cells, cellular division and growth, the entire system of genes, genetic expression, synthesis of proteins, codification and translation of information, DNA, RNA, enzymes, and many others. Theoretically, every single aspect of this immense and complex cellular works can be investigated in relation to RF. An important caveat, however, is that effects discovered at molecular or cell level do not automatically mean that they are relevant to abnormal functioning or to have consequences to health of the entire organism (D'Inzeo, 2009, Repacholi, 1998).

*In vivo* models used for experimentation with RF have been centered mostly on mammals, particularly laboratory-bred rodents, such as rats and mice. There are many advantages in using these species: they have more than 70% of their genes in common with *Homo sapiens*, are warm-blooded mammals, with similar physiology and biochemical systems, are easy to breed and maintain, have a relatively short life span and high reproduction rate (ideal for lifetime and genetic studies) and can be as genetically homogenous as one wishes, including strains that are genetically programmed to be highly susceptible to cancer and other diseases.

In regard to the ability to transfer or to apply the knowledge gained by way of experimenting with them, this is more difficult. For one thing, rats and mice are small, so radiation absorption and propagation are different from humans, including

into the sensory organs, brain and hematopoietic systems, which are protected very little from external radiation by its thin bones. Furthermore, the biology of rodents is entirely the opposite of primates in general: since they are mainly nocturnal and underground dwelling, and so they have little protection developed by evolution against solar and other kinds of radiations. This can make them more sensitive to EMF than *Homo sapiens*. In addition, the behavioral biology, memory and cognitive abilities cannot be easily extrapolated to humans.

The freedom of performing systematic experimentation with living cells or organisms allow for extensive data gathering and the variation of many parameters, such as using several RF power densities, for example, in many different exposure schemes. A larger number of variables can be studied simultaneously or in isolation. In one example of the experimental exposure studies with rats, 151 physiological and clinical variables were recorded. The number of subjects in animal exposure studies is usually higher than those used in human experimentation, but is far less than in human epidemiological studies.

### ***In Vitro* Studies**

Since laboratory conditions are easier to set up for *in vitro* studies, and because apparently simpler and more stable biological systems can be studied with this approach, there is an exceedingly large experimental literature on RF interactions on these aspects, which we do not intend the review in detail here. Recent exhaustive reviews by other authors have been published elsewhere and the reader is referred to them (see particularly D’Inzeo, 2009; Marino, 2008a and 2008b; ICNIRP, 2009).

In vitro studies try to answer the fundamental question which is at the roots of all putative RF bioeffects: if these effects cannot be demonstrated clearly and without doubt at the level of molecules or isolated cell preparations, there should be no reason to continue the scientific search for these effects at other levels of complexity in living organisms.

D’Inzeo (2009) proposed a layered or hierarchical model for interpreting results according to these levels of complexity, whereas

*“Interaction models aiming at the evaluation of possible health consequences have to take into account the complex organization typical of living systems. All biological systems must be considered, from a logical point of view, as a stratification of complexity levels, from the microscopic one of atoms and molecules, up to the macroscopic one of the whole organism, going through sub-cellular structures, cells, tissues, organs, and systems. (...) Due to the complex structure of biological systems, for electric or magnetic fields to initiate or promote adverse health effects in an organism, they must trigger a series of steps, through different levels of*

*biological complexity, from molecular level up to cell, organ and organisms”*

These levels are:

- Small inorganic molecules and ions at the atomic, physico-chemical level
- Large organic molecules, such as proteins and nucleic acids
- Cell membrane, including receptors, ionic gates and active transport mechanisms
- Metabolic function and biochemical pathways in the whole cell
- Aggregates of cells, such as networks of excitable cells, immune networks, etc

Furthermore, even if they are demonstrated to exist at a certain level, this doesn't mean automatically that they are significant or influence other levels of complexity above them. Also, according to D'Inzeo, *“(Although) the functionality of each level is related to those of all lower levels it is not completely determined by them, i.e. each upper level shows the so-called emergent proprieties.”*

From a didactic point of view, possible bioeffects of RF fields at the molecular level have been classified into two main types:

1) **thermal effects** due to the dielectric heating phenomenon that is typical of non-ionizing radiation (NIR), such as microwaves. NIR has not sufficient quantized energy to interact with the outer orbitals of atoms and break intra- or extra-molecular bonds, so radiation-induced agitation of polar molecules accounts for temperature enhancement as its only plausible effect. This has been well established to occur, even for very small temperature changes, since cells have a complex mechanism to respond to them, including molecular cascades, heat shock proteins, etc. With exposure to large temperature changes for a sufficient time, denaturation of some molecules, such as proteins, may ensue. For small thermal heating, which might occur when cells are exposed to low-level RF, only indirect effects such as these are plausible and they have been sufficiently well documented;

2) **non-thermal effects** have been theoretically proposed as other interaction mechanisms not due to direct or indirect increases in local temperature. A large number of these models have been proposed and experimentally studied in *in vitro* preparations. A number of authors have claimed that they could be demonstrated, but this is still an open debate in the scientific community, since many studies have also been unable to demonstrate that they exist. In many cases, it has been argued that these effects are actually due to normal responses of living cells to heating. As shown below, of all non-thermal effects that have been reported to occur in cells, such as changes in enzyme levels, none have been shown to have any health consequence, since the body easily compensates for them.

Thus, in relation to low level RF, the debate centers on 1) the existence of non-thermal effects at a given level of organization, 2) whether they are of sufficient magnitude and 3) whether they interact with other levels of complexity above it in order to play a role in pathophysiology and causation of disease in intact (in vivo) organisms.

Recently, more than 100 papers in 15 different journals on mechanisms of action have been reviewed by D’Inzeo (2009), allowing for the classification of putative non-thermal effects into four groups of models:

- resonance mechanisms;
- coupling with non linear systems;
- effects due to the direct action of electric and magnetic fields;
- cooperative mechanisms due to interactions among several membrane components

All have been documented experimentally, sometimes at exceedingly low power density levels of exposure, but authors and reviewers diverge widely as to the most plausible mechanism for non-thermal interaction of EMF with matter. D’Inzeo concludes that *“however, such results are hardly extendable to higher levels of biological complexity and thus to possible hazardous effects on human health.”*

Other recent reviews, by Swicord & Balzano (2009) and by ICNIRP (2009), examined in detail the current evidence in published literature which supports mechanisms of interaction of RF with living matter both at cellular and organism level. The reader is referred to these two comprehensive reviews for more detailed coverage and analysis.

### **Oncogenesis Studies at Molecular and Cellular Level**

Since cancer-related effects of EMF are considered particularly important, the potential impact of cellular and sub-cellular effects for oncogenesis have been given a high importance in international research, and, accordingly a large literature body has been produced. Marino (2009) has reviewed the literature on these aspects before 2000 and from 2000 to 2007. The review has classified the papers according to a four-point scale (comprising Sufficient Evidence, Limited Evidence, Inadequate Evidence, and Evidence Suggesting Lack of Effect) in order to describe the degree of uncertainty for the effects reviewed. The scale has been adapted from one developed by the International Agency for Research on Cancer (Repacholi and Cardis 1997)

Oncogenesis at subcellular and cellular levels is exceedingly complex and still under study. Cancer is in fact a generic denomination to probably hundreds of different diseases, with different causes and different natural histories. However, a common denominator is genetic instability, caused by a cumulative chain of



changes in intracellular DNA-repair mechanisms, activation of tumor inhibition genes or expression of oncogenes, the apoptosis of defective cells, the reproduction, growth and survival mechanisms of cells, etc. Eventually, such accumulated changes in the genomic machinery of cells lead to a cell line that inherits the changes and gains reproductive advantage over normal cells and do not die (**tumorigenesis**).

In vitro studies can be classified into six areas of inquiry and experimentation.

**Genotoxicity:** is the name given to the property of external agents, such as EMF, to damage directly DNA. DNA damage can be evaluated experimentally by the so-called comet assay, which identifies whether base damage and single-strand breaks in the DNA molecule inside the cell nucleus have occurred (neutral comet test) or double-strand breaks have occurred (alkaline comet test). The first indicates repairable damage, while the latter is non-repairable, and thus more dangerous damage to DNA.

Another common class of experiments is to test whether low-level RF is able to potentiate genotoxicity induced by a second known genotoxic agent, or in already abnormal (cancerous) cell lines. Another way of testing genotoxicity is investigating for the appearance of micronuclei and aneuploidy (abnormal number of chromosomes), which are related to DNA alterations. A number of experiments on genotoxicity of low-level RF published before 2000 have demonstrated effects (usually very weak or difficult to interpret due to technical inadequacies, improper controls, etc), but there are also many experiments that didn't show any genotoxic effect, including replication or confirmation studies or previously positive ones (in some cases by the same authors under exactly the same conditions (Marino, 2008a). Her recent review of 83 published papers on genotoxicity have revealed that 69% of them reported absence of effects, 20% reported presence of effects, and the rest were inconclusive. A general evaluation following the classification of evidence used by IARC (International Agency for Research on Cancer) arrived at the conclusion that there is so far inadequate evidence for a low-level RF interaction causing genotoxicity as well as potentiation of other mutagens. Therefore, since oncogenesis depends strictly on its occurrence at cellular level, there is no plausible mechanism for cancer causation at or below international safety levels.

Even so, REFLEX, a high-profile European research on genotoxicity, which alleged finding evidence of double strand DNA breakage in cultured human fibroblasts by EMF in the cell phone range, made the news worldwide in 2008 (Schwarz *et al.*, 2008), but was later found to have unblinded and possible fabricated data. This demonstrated the perils of flawed research techniques when biased expectations are in play.

Another parameter for carcinogenicity in cell lines is the transformation potential of

external agents (*i.e.*, transforming healthy cells into neoplastic ones). This can be investigated either by assessing direct effects (initiation) or whether RF increases transformation under other known agents (promotion or co-promotion). The absolute majority of experiments reported so far were unable to detect neoplastic transformation from microwave signals used in mobile communication; thus reviewers have concluded that there is lack of evidence for these effects.

**Cancer-related gene and protein expression:** a more modern and technically superior testing of carcinogenicity potential of exposure to low level RF, including the use of high-throughput techniques for investigating simultaneously the expression of thousands of genes and several proteins related to cancers (genomics and proteomics), have been used recently (*i.e.*, after the year 2000). Up to 8,000 genes can be tested simultaneously using so-called micro-array probes. Among the genes of importance for cancer are the proto-oncogenes inside the cell genome, such as *c-fos*, *c-jun* and *c-myc*, and proteins such as P53, related to cancer suppression. When a gene is found to be up-regulated, it means that it is expressing at a higher rate than normal (*i.e.* synthesizing more of its related protein); when it is down-regulated it is the contrary.

The results so far have been highly heterogeneous: some experiments using large scale testing of gene expression have found in some cases complete absence of effect of low-level RF, while others have found up-regulation and down-regulation in a significant proportion of genes. For example, Zhao R. et al. (2007) investigated the effects of intermittent exposure of cultured rat neurons to RF at a SAR of 2 W/kg on gene expression. Among 1,200 candidate genes, 24 up-regulated genes and 10 down-regulated genes were identified. Several other papers have identified mostly the up-regulation of apoptosis-related genes (expressing caspase proteins), while down-regulation was related to cell cycle functionalities. Validation data was lacking in most of these positive studies, so their significance is hard to interpret. In contrast to these studies others have failed to provide evidence for significant changes in gene expression using microarray technologies. For example, Gurisik et al (2006) found changes in only 6 of 8,400 genes tested, and even then they were only slightly down-regulated.

The finding of a large number of altered genes or proteins, without a consistent pattern, also points to nonspecific effects, most probably due to heat shock, although experimenters have claimed to control for temperature changes. The alteration of proteins of the heat shock proteins (hsp) family in many of the positive studies provides evidence that such might be the case, particularly because they are altered when no RF irradiation is present, but that the temperature of the culture medium is raised. In addition, the pathological significance of such gene expression is unknown and difficult to interpret. In general, reviewers have concluded that the evidence is limited or there is a lack of consistent evidence for cancer-related low level gene and protein expression from RF exposure.

**Cell proliferation and differentiation:** These are two important characteristics of neoplastic cell lines: an increase in cell proliferation, leading to tumour growth, in general, and the decrease in differentiation (*i.e.*, de-differentiation of neoplastic cells, increasing its resistance to chemo- and radiotherapy, its metastasis potential and its overall malignance). The most common cell lines investigated are normal human or murine fibroblasts (cells from the conjunctive tissue) and some neoplastic cell lines, such as lymphoblasts and neuroblastomas. Again, there is wide variability of results among different papers, which are difficult to interpret, since the methods and conditions used could not be adequately identified or compared, including the most important controls for exposure; level of power density and controls for temperature variation. The reviewers concluded that “there is globally inadequate evidence for positive effects of low-level RF on these parameters.

**Apoptosis:** is programmed cell death, *i.e.*, a very specific and complex chain of intrinsic and extrinsic cellular events that induce defective cells to “suicide”. The contents of ruptured cells are digested by cells of the immune system. A line of enzymes (caspases) are involved in the process, so they can be evaluated in experimental assays. Apoptosis in normal cells as well as in cancerous (neoplastic) cells of tumour lines have been investigated following exposure to low- and high-level RF. A potential induction of apoptosis in normal cells is considered deleterious, while it is considered beneficial in tumor cell lines (this could be the explanation for the efficacy of some kinds of instrumented irradiation in decreasing tumor growth, since one of the main defects observed in cancer is the production of cells that are incapable of apoptosis, *i.e.*, “eternal” cell lines).

Again, the overall results of the assessment of published papers on this subject are that there is no evidence that low-level RF exposure could induce apoptosis in normal cells limited evidence that RF acts as a pro-apoptotic agent in tumoral cells, and inadequate evidence that low-level RF exposure may interact with known pro-apoptotic agents and/or on the genetic background in vitro (Marino, 2008a).

### **Conclusions of *In Vitro* Studies**

The current scientific evidence on molecular and cellular mechanisms of RF has been evaluated by several international specialized bodies. In all of them so far, conclusions have been the same, such as:

**Sweden SSI (2008)** Recent Research on EMF and Health Risks- Fifth Annual Report from SSI: Independent Expert Group on Electromagnetic fields, 2007(Revised edition 15 April, 2008

<http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Stralskydd/2008/ssi-rapp-2008-12.pdf>

Most of these studies have not demonstrated effects of RF exposure on the

studied outcomes, including also attempts to replicate the genotoxic effects observed in the REFLEX European program.

Six recent studies on carcinogenicity, some with higher exposure levels than previously used, consistently report lack of carcinogenic effects, and two studies on genotoxicity report no increase in micronuclei or DNA strand breaks after RF exposure.

**ICNIRP (2009):** "Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz)"  
<http://www.icnirp.de/documents/RFReview.pdf>

The mechanisms by which RF exposure heats biological tissue are well understood and the most marked and consistent effect of RF exposure is that of heating, resulting in a number of heat-related physiological and pathological responses in human subjects and laboratory animals. Heating also remains a potential confounder in in vitro studies and may account for some of the positive effects reported

### **Research in Latin America**

Very few experimental in vitro studies of bioeffects of RF have been carried out in Latin America. Working at the State University of Campinas in Brazil, Heinrich and collaborators (2006, preliminary communication WHO-EMF database) have studied the effect of microwave radiation emitted by cell phones on the chromosomes of human lymphocytes in vitro. Spectral karyotyping was used for this purpose. The researchers concluded that no chromosomal damage could be observed at levels compatible with or below the ICNIRP standards, at least for 800 MHz AMPS CDMA devices. Levels exceeding 10 W/kg were observed to cause some damage indicating a dose dependent effect on increasing acrocentric chromosomes and altering satellite length

### **Conclusions**

As judged from the available literature on oncogenesis-related cell function and exposure to low-level RF, the general conclusion is that there is, so far, inadequate evidence or lack of consistent and validated evidence, that such a cause-effect relationship can be established. There is some confusion and controversy in this area of research, because many times experiments that had rendered positive effects could not be validated or replicated.

Particularly, short-term effects on cell cycle and regulation, gene and protein expression, damage to genetic material and transformation/dedifferentiation cannot be automatically translated to causation of cancer. For example, most of the cell cultures used in these experiments are highly susceptible to any external agent,

such as cells from the hematopoietic system. Even small temperature changes affect them, but this probably happens when they are irradiated when cultured externally, thus removing the strong protection from inside the body. Thus the relevance of these results can be contested.

In the following section we will discuss cancer-related studies in intact (*in vivo*) organisms.

## **Experimental Animal Studies**

Experimenting with animals is a classical and logical solution to investigating, in a controlled manner, the possible interactions of RF fields with whole biological organisms. This was extensively done before the 1990s, when safety thresholds for RF fields were being established. Therefore, high power densities were first utilized and lowered until the lowest levels were found to cause a disruption of behavior in certain controlled tasks, such as operant conditioning, or in observational arenas, such as open fields. We are not reviewing these studies here, since we intend to concentrate on those carried out at or below safety levels standardized by bodies such as ICNIRP and IEEE. The reader is directed to IEEE (2005, Annex B) for a thorough review on this research before the 1990s.

Animal experiments registered in the published literature can be divided roughly into three groups:

- cancer induction and promotion,
- behavioral effects
- other physiological and pathological alterations.

By the end of 2008, according to an extensive review by Swicord and Balzano (2009), there were 781 papers in the WHO EMF Health Project database reporting research on the effects of RF fields from 0.1 to 100 GHz on animals. The majority of the investigations employed laboratory rodents (mice and rats) and investigated effects of RF in the range of 900 MHz to 2.5 GHz. As we have mentioned before, results obtained with these animals do not necessarily translate to humans and other animals, since the absorption characteristics of RF in their internal organs are quite different, as well as various aspects of their biology. Interestingly enough, despite the importance of knowing the distribution of RF fields in the body of these animals, only one paper was concerned with dosimetry.

Due to this, mass media reporting of possible detrimental effects on humans based on animal studies can be, and were, prematurely misrepresented to the general public. This is because they omitted the methodological difficulties and caveats regarding the interpretation of results and its translation to humans, and reported mostly on single studies.

Animal studies cover a very large variety of organisms, structural and functional effects, and are given in the following table (adapted from Swicord & Balzano (2009), by permission):

**Type and Number of Published In Vivo RF studies**

<b>In Vivo Study Type</b>	<b>Number Published</b>	<b>% Total</b>
Animal Behavior, Brain Biochemistry, Neuropathology, Drug Interaction	140	17,9%
Teratogenicity, Reproduction, & Development	117	15,0%
Thermal Analysis	85	10,9%
Immune Function & Hematology	83	10,6%
Blood Brain Barrier, Brain (PET scan) and Other Tissue Blood Flow	56	7,2%
Eye Pathology	37	4,7%
Auditory Pathology & MW Hearing	36	4,6%
Gene & Protein Expression & Activity	29	3,7%
Micronuclei & Chromosome Aberrations	28	3,6%
Chemical-Radiation-Genetically Initiated Tumor Bioassay	27	3,5%
Oxidative Stress	24	3,1%
Blood Press., Heart Rate, Circulation, and Resp. Rate	23	2,9%
DNA Breaks, Damage & Mutation	19	2,4%
EEG, Event Related Potentials, Sleep Disturbances	19	2,4%
Long Term Rodent Bioassay	19	2,4%
Hormone Changes	12	1,5%
Calcium (and other ion) Studies	10	1,3%
Cell Line Injection Tumor Bioassay	5	0,6%
Other Animal Studies	5	0,6%
Proliferation, Growth Rate, & Cell Cycle Analysis	5	0,6%
Animal Study with Multiple Parameters Examined	1	0,1%
Experimental Dosimetry in Animals	1	0,1%
<b>Total</b>	<b>781</b>	

The majority of studies (about 71%) fell under the following categories:

- Thermal effects

- Animal behavior
- Brain biochemistry
- Neuropathology
- Teratogenicity
- Reproduction and development
- Immune function
- Hematopoietic system
- Blood-brain barrier
- Brain blood flow
- Visual and auditory systems

Another 14 % were related to the effects on genetic material and cell function and biochemistry under *in vivo* conditions.

Due to the large number of studies, we will focus our review on what we feel are the three most important areas: effects on the blood-brain barriers, teratogenesis (cancer induction and promotion) and long term survival under chronic exposure.

### **The Blood-Brain Barrier**

The blood-brain barrier (BBB) has a very important function in mammals, providing a selective barrier between the blood supply to the brain and its internal milieu (extracellular fluid). This unique and complex system involves vascular membranes and supporting cells of the brain (glia), and provides a kind of selective filter that avoids undesired substances that circulate in the blood (and which could have toxic effects on neurons, for example), entering this milieu. Therefore, anything that weakens or opens the controls of the BBB might be detrimental to the health of the brain.

Reports were published in 1977 suggesting that irradiation of rats with RF at levels below current safety standards affected negatively the BBB was documented with standard techniques, using dyes or nuclide-labeled compounds which normally do not cross the barrier. Research published more recently by the group of Salford in Sweden (1993), with a series of more than 1,600 rats, showed that the BBB changed its permeability to the animal's own albumin, but not to fibrinogen, immediately as well as 7 and 14 days after being irradiated with 900 MHz GSM signals for 2 hours. His research received much press coverage and provoked alarm in the general public. Later, Salford tried to demonstrate indirectly that the albumin which passed the BBB and accumulated around neurons in the extracellular fluid of the spinal cord and the brain, could lead to lesions and neuron death in several areas of the brain (Salford *et al*, 2003), and that these lesions might be responsible for a decrease in memory observed in a small groups of

irradiated rats (Nittby *et al*, 2008). Furthermore, the same group suggested a dose-response relationship between SAR level of GSM irradiation from 0.1 to 1.2 W/m<sup>2</sup> and that the uptake of albumin could be responsible for neuronal death (Eberhardt *et al.*, 2008).

According to Swicord & Balzano, since 1990, 52 papers investigated the possible effects of RF on the disruption of BBB permeability. After clustering the multiple results of the same laboratory into 29 single studies, the score came to 11 studies showing no effect, 10 reporting thermal effects and 8 reporting other, possibly non-thermal effects (27,5%). Irradiation levels varied widely among the studies or were not documented at tissue level, making comparisons difficult.

In addition, most of the investigations were not controlled enough to rule out other possible factors present during the study, such as manipulation stress or head trauma, which are known to affect the BBB. The most possible explanation for the 8 remaining studies is that they were also due to thermal effects. For example, it was shown by Sutton & Carroll (1979) that a gradual elevation of the brain temperature to 40 °C occurred during typical exposure of rats to RF, due to the small size and thin cranial bones of these animals, causing increased permeability of the BBB. This effect was reversed by a perfusion of the brain with cooled blood. Merritt *et al.* (1978) compared the effects on the BBB of a temperature increase by either blowing hot air or RF exposure, and obtained similar effects.

More recently, Fritz *et al* (1997) and Ohmoto *et al* (1996) demonstrated experimentally that the temperature increase caused by RF heating of brain tissues might be the most likely explanation for BBB disruption in rats.

With one exception, BBB effects were not researched on larger animals, such as dogs, cats or monkeys, which have cranial configurations closer to humans. Since temperature doesn't change appreciably while using a cell phone handset for several minutes by humans, as ascertained with PET scan imaging, BBB disruptions are not to be expected (Huber *et al.* 2005).

## **Cancer Induction and Promotion**

*In vivo* experimental studies on teratogenicity (induction and promotion of tumors and/or blood neoplasms) is an important line of inquiry, since this rates among the highest fears of possible long-term effects of RF exposures below safety levels, i.e., possibly due to the break-up of DNA, formation of micronuclei, etc. These studies, which were done *in vivo*, usually in small rodents, employ several techniques such as cell line injection tumor bioassays, effects on genetic material by joint chemical and RF irradiation, etc. Animals with no previous tumors are investigated (induction), as well as animals with tumors previously induced by known carcinogenics (promotion). The appearance of cellular molecular



predecessors of tumorigenesis can also be investigated.

Initially, it seemed that non-thermal effects of RF could indeed be associated with experimental teratogenesis in experimental animals, because hyperthermia normally doesn't increase in tumorigenesis (Dewhirst et al, 2003). One of the first animal experimental studies along these lines was widely publicized (Chou *et al*, 1992) and reported a small increase in overall tumor incidence in rats irradiated for two years with RF. The authors considered that these results might not be biologically significant, since the survival of animals was not affected. Another study was carried out by Repacholi *et al* (1997) in Australia, found a higher incidence of follicular lymphomas in transgenic mice exposed to RF for 18 months. At this point, a review of the literature on cancer induction and promotion by Repacholi (1997) concluded that the situation was still very contradictory and inconsistent, and that more research was needed. Methodological issues regarding the exposure parameters arose, however, and replication studies by Utteridge et al. (2002) and Oberto et al (2007) failed to confirm these findings. Another investigation was carried out by Anghileri et al. (2005), who reported that RF exposure induced tumors in rats and increased their mortality, probably by causing cellular calcium alterations via non-thermal effects, as a possible triggering factor. Their results, however, could not be confirmed or replicated by other researchers, since they did not report on exposure levels, and used a small number of animals in the experimental group.

Following Repacholi's suggestion, a number of investigations followed and another review in 2003, by Elder, concluded that "*the weight-of-evidence of 18 studies shows that long term, low level exposure to RF energy does not adversely affect survival and cancer in laboratory mammals.*" Even so, the initial positive results on cancer induction in animals provoked a flurry of other studies in succeeding years. According to the review by Swicord & Balzano (2009), 40 such studies have been published since 1990. The duration of exposure ranged from a few weeks to more than two years, and most of the studies investigated continuous exposure (20 to 22 hours per day, 7 days per week) to RF frequencies, such as those commonly used for mobile communications, with various frequency and amplitude modulation schemes. The power densities and SARs employed in most studies were comparable to that generated by cell phone handsets close to the head (1 to 4 W/m<sup>2</sup>).

Despite using SARs far above what normal users are exposed to, in terms of accumulated duration along a lifetime, and taking into account the quite different RF distributions in the crania of experimental animals compared to humans, 92.5% of the studies showed no significant effect on tumor formation.

### **Long Term Survival**

Since no significant short term effects of RF on animals were confirmed, with the

exception of intense brain and body heating by RF, other studies tried to investigate the effects of lower levels of RF exposure on the long term survival of laboratory animals. Instead of looking for specific changes in organ systems, they investigated detrimental effects in terms of reduced longevity by comparing them to non-exposed animals (control group). Chronic continuous low-level RF irradiation was employed, *i.e.*, simulating conditions similar to those of organisms living near base stations. The average survival of irradiated groups of animals was not affected in 95,8% (23 out of 24 studies), therefore no non-thermal effects could be demonstrated at this level.

## **Latin American Research**

As expected, we could find only a very few published RF animals studies, all from researchers from the same Brazilian state (Rio Grande do Sul).

Ribeiro et al (2007) investigated the effects of subchronic exposure to 0,8 GHz RF emitted from a conventional GSM cellular telephone on the testicular function in adult rats 1 hour daily for 11 weeks. No statistically significant differences were found for rectal temperature measured before and after the exposure period, testicular and epididymal weight, lipid peroxidation levels in these organs, serum total testosterone and the epididymal sperm count, maturation phase spermatid retention at stage IX-X, interstitial infiltration, cellular vacuolation and multinucleate giant cells. The authors concluded that exposure didn't impair testicular function in adult rats.

Ferreira et al (2006a) investigated the occurrence of chromosomal damage in red blood cells in rat offspring exposed in utero to low level RF used in GSM communication, by using the micronucleus assay. The activity of antioxidant enzymes, total sulphhydryl, protein carbonyl groups and thiobarbituric acid-reactive species were evaluated in the peripheral blood and in the liver. The authors noted a significant increase in micronuclei occurrence, but no alteration in oxidative metabolism, so they concluded that RF had genotoxic potentials in rat embryos exposed during embryogenesis, but with no explainable mechanism.

The same group (Ferreira et al, 2006b) investigated the effect of acute RF exposure on non-enzymatic antioxidant defense and lipid and protein oxidative damage in the rat frontal cortex and hippocampus, by performing malondialdehyde (MDA) and carbonyl assays to assess lipid and protein oxidative damages, respectively. No changes in lipid and protein damage, and also in non-enzymatic defense were found in frontal cortex or hippocampus.

## **Conclusions**

The effects of RF irradiation seems significant only when heating of internal tissues is achieved, *i.e.*, when SARs and power densities are much above safety

thresholds. Since below these levels no significant heating occur, especially in the well-protected human head. It was to be expected that any observed and consistent effects on animals could be explained on the basis of putative non-thermal effects.

The general conclusion after 20 years of animal experimentation studies is that no effects could be demonstrated. There is a remarkable consistent absence of effects of RF on intact animals, at least at RF levels below international standards. The few studies reporting effect on the BBB, cancer induction and promotion and overall survival of chronic exposure to RF were lacking, or were due to thermal effects.

With regard to possible mechanisms of interaction of RF fields, both in *in vitro* and *in vivo* experimental studies, ICNIRP (2009) has concluded that the examination of a very large literature database led to the conclusion that finding any low-level non-thermal effect between 150 MHz and 150 GHz is very unlikely and that finding such effects between 10 MHz and 300 GHz may not be possible.

## **Human Health Studies**

### **Experimental Studies in Humans**

Concerns have been expressed about the possible interactions of RF with several human organ systems, such as the nervous, circulatory, reproductive and endocrine systems, particularly those emitted by wireless communication handsets, such as mobile phones (IEGMP, 2000). One way of investigating causal-effect relationships in this area is to perform experiments with voluntary human beings in controlled circumstances (so-called provocation studies). Most of these experiments use short- to medium-term exposures to RF fields, within the same frequency range and at levels equal or below the safety standards, so as to rule out thermal effects. Therefore, they assume that non-thermal effects might be present. In the present chapter, we will review the recent literature on experimental studies in humans, with a focus on certain organ systems. The large majority of papers address radiofrequencies and modulations used in cell phone communication systems, due to its ubiquity.

Experimental results published so far have used several designs, such as self-controls, non-randomized and randomized controls, crossover, blinded and non-blinded designs, etc. (see the Annex I of this chapter for a brief methodological explanation on these designs). The quality and strength of evidence varies a lot among these designs, so that sometimes it is difficult to compare experimental results among different studies and arrive at unequivocal conclusions.

What we have observed also is that, despite the large number of published studies, the proportion of them that have high quality designs are still rare in the RF

literature. Most of the studies have focused on mobile telephony, so other kinds of exposures, occupational or not, have not been adequately covered in the literature. In addition, due to ethical limitations, only a few organ systems and functions have been studied, and few long-term exposure experiments have been completed, so little information is currently available on potentially slow-acting effects.

### **Nervous System and Behavior**

Several reviews of the literature on RF acute exposure on the nervous system of human beings have been published. (e.g. Valentini *et al*, 2007, Hossmann & Hermann 2003; D'Andrea *et al*, 2003a and 2003b, IEGCP, 2001). The most frequent experimental studies on central nervous system (CNS) functions can be classified into the following groups:

- Spontaneous and stimulation-induced electrical activity of the brain, such as in the electroencephalogram (EEG) and event-related potentials (ERP)
- Blood flow and tissue metabolism
- Cognition and attention, reaction time
- Sleep and wakefulness

D'Andrea *et al* (2003a and 2003b) reviewed the effects of RF exposure on the nervous system in general, and on behavior and cognition. They found that it is difficult to draw a consistent set of conclusions concerning hazards to human health, due to the variations among studies including exposure parameters such as frequency, orientation, modulation, power density, and duration of exposure. Adverse and non-adverse behavioral and neural consequences of exposure to high power RF, with sufficient energy to induce thermal effects inside the human brain, are real and well documented (Goldstein *et al*, 2003), and have served as a firm base for establishing safety standards and limits since the 1980s. Hyperthermia, of course, has several deleterious effects on nervous tissue in general and on peripheral nerves in particular, so that high-level exposure in occupational accidents can promote reversible and irreversible injury. Hocking & Westerman (2003) in a review of EMF effects on pain, have found from studying several such cases, that after very high exposures, nerves may be grossly injured, resulting in dysesthesia. Fortunately, only a small proportion of similarly exposed people develop symptoms.

However, the first question should be: is there a heating effect of low-level RF irradiation of the head? The majority of users report a heating sensation in the skin of the face after a minute or more using a standard cell phone close to the head. This increase has been objectively determined to be in the order of 2 to 30C after 6 minutes of use, most of it due to heat trapped by holding the phone with a plastic case in contact with the head and not by RF absorption within the head (Anderson & Rowley, 2007). Experimental studies using high precision thermography on both

sides of the head of volunteers, however, have shown that the insulation, heating by battery currents and the electrical power dissipation of the handset led to statistically significant rises in the skin temperature, while the RF exposure did not (Straume *et al*, 2005). Curcio *et al*. (2004) measured the ascending rate of tympanic temperature with exposure to a standard GSM cell phone in a double-blind experiment, and found a correlation with an increase in reaction time. Since heat can be perceived by users with an active cell phone, it is doubtful, therefore, that RF effects might be the real effective variable on cognitive effects. So, the effect of heating on brain tissue inside the RF plume of a cell phone used against the skull should be a better variable. The same group (Curcio *et al*., 2009) tested this by using near-infrared spectroscopy of the brain, and discovered that the hemodynamics of the frontal cortex was the only parameter to increase slightly with exposure times of up to 40 min to a GSM cell phone.

One way to document this for the head's interior would be to carry out functional brain imaging studies which label regional cerebral blood flow (rCBF) responses using PET (Positron Emission Tomography). Radioactive labeling of red blood cells provides this measurement, allowing for a medium-resolution mapping, *i.e.* it is able to show the location of the alterations. Haarala *et al* (2002) and Aalto *et al* (2004) were the first to use this approach. They demonstrated a decrease of rCBF in the temporal lobe near the antenna, but an increase in a more distant area, the frontal cortex. Huber *et al* (2005) also investigated in healthy young men the effect of a 'base-station-like' and a 'handset-like' exposure using PET, They observed an increase in rCBF in the dorsolateral prefrontal cortex on the side of exposure. Only 'handset-like' RF exposure affected rCBF. This parameter may reflect two phenomena, however: local heating, with the subsequent increase in compensatory blood flow, or an increase in functional activity of the nervous, tissue, which leads also to rCBF. Since other areas of the cortex were not activated, probably the PET study reflected a functional change in an area related to emotional processing and not localized heating. If heating provoked by proximity to the RF source was to be observed, a temperature gradient emanating from points nearest the source and decreasing through the scalp, skull bone, meninges and then brain tissue adjacent to the source of emission near the ears, was to be expected. This gradient correlates well with the thermographic studies of the surface of the head and the temporal bone, but not within the brain tissues.

The most important research question is whether RF levels below those producing thermal effects could induce changes in the nervous system and its activities. D'Andrea *et al* (2003a) concluded that at least for the review period, no firm evidence existed for such subthermal effects and that nearly all evidence was related to the generation of heat in the nervous tissues.

### **Cognition, Memory and Attention**

A small number experiments have been carried out before 2000 (Preece *et al*.,

1999, Koivisto *et al*, 2000, 2001) and were reviewed in detail by the so-called Stewart Report (IEGCP, 2001). The objective of such studies was to detect deleterious effects of RF fields on cognitive functions such as short- and long-term memory, attention, reaction time, concentration, etc.

There are several reliable methods to record and quantify such behavioral and cognitive variables using standardized, instrumented or computerized techniques. These experiments recorded a large set of such variables (14 to 30) in subjects under a crossover design and low-level radiation power densities, by using cell phones used near the head.

Slight differences were observed during the irradiation versus the sham exposures in one or two variables, such as simple reaction time, a mental digit subtraction task and a vigilance task. Surprisingly, in all of them RF increased cognitive and attention processing times, such as a consistent decrease in reaction time (RT) up to 20-36 milliseconds, which is quite a large figure, without a reduction in accuracy at the expense of speed, and sometimes with an increase in accuracy. Both groups of investigators suggested that exposure to mobile phone signals at power levels within existing exposure guidelines had demonstrated biological effects that were of sufficient magnitude to influence behavior. They proposed that the probable mechanism could be the effect of small temperature increases on synaptic transmission in the region of cerebral cortex directly under the headset antenna. Other papers have provided more data in favor of the existence of this effect on attention. For example, Papageorgiou *et al* (2006) reported that the RF emitted by mobile phones affect pre-attentive information processing as reflected in the P50 evoked potential.

A significant number of contradictory studies exist, however, particularly when using better designed experimental studies, such as differential exposure to both sides of the head, and double-blind randomized cross-over designs. Under these conditions Haarala *et al*, (2004, 2005, 2007), Curcio *et al* (2008), Besset *et al* (2005), Krause *et al*. (2007) and Russo *et al* (2006) could not find any evidence for a differential effect of exposure to mobile phone signals on several cognitive, memory and attention tasks, including the first studied by Preece and the Koivisto and Papageorgiu groups. Haarala *et al* (2005) concluded that a standard mobile phone has no effect on children's cognitive function as measured by response speed and accuracy. Using adolescents too, Preece *et al* (2005) were unable to replicate their own 2001 experiments, denying evidence for cognitive effects of cell phones.

It was suggested by the reviewers that although in some studies shorter response times were obtained, this should not be interpreted as a beneficial effect of cell phones, since in more complex situations, they might be detrimental. In addition, since no long term experiments were carried out, there is limited relevance of such studies for the question of whether mobile phone use is detrimental to health.

Studies in children are also lacking (Sienkiewicz *et al*, 2005)

### **Electrophysiology and Sleep**

Several electrophysiological studies on the effect of acute RF fields on the human EEG and ERP have been performed, with somewhat mixed results. Some studies have been unable to demonstrate any effect, while others reported mild effects on these parameters, mostly by subtle alterations of some parts of the EEG spectrum. For example, d'Costa *et al* (2003), Huber *et al* (2002) and Curcio *et al* (2005) did blinded acute exposure experiments to ascertain if resting wakefulness EEG spectral power was influenced, and all found a small increase in the alpha band. This effect was recently confirmed by a double-blind counterbalanced crossover design with 120 volunteers (Croft *et al*. 2008). Pulse modulation of RF was necessary to induce waking and sleep EEG changes. Loghran *et al* (2005) showed a decrease in rapid eye movement sleep latency and increased electroencephalogram spectral power in the 11.5-12.25 Hz frequency range during the initial part of sleep following exposure. Together with the studies that showed that RF from cell phones induced mild relaxation, and a quicker induction to REM sleep (which is associated to dreaming in humans) in the first period of sleep, no detrimental effects on sleep health could be demonstrated.

More recent experimental studies using better methodology, such as sham-controlled, double-blind, crossover designs, have determined that, although these effects on EEG exist, they are rather modest and that “the effects on the EEG were varying, unsystematic and inconsistent with previous reports. The effects of RF on brain oscillatory responses may be subtle, variable and difficult to replicate for unknown reasons” (Krause *et al.*, 2007, Hinrikus *et al*, 2004).

In relation to the previous studies that apparently had shown effects on the nervous system (cognition, EEG and sleep), the 2001 review by the Stewart Report suggested that “exposure to mobile phone signals at exposure levels that fall within existing exposure guidelines have biological effects that are of sufficient magnitude to influence behavior. The causal mechanism is unclear, but could include a small, localised heating effect. The question of the effect on the safety of mobile phones is uncertain.” In another review of the literature of the previous decade, Valentini *et al* (2007) concluded also that RF may influence normal physiology through small changes in cortical excitability. The significance of these results for the health of users is unknown, and there is considerable controversy on their existence and meaning, because better controlled studies carried out in 2007 and 2008 were unable to provide any confirmation. Uncontrolled variables and random fluctuations due to small samples might be responsible for observed positive responses. So, the proposal of a specific mechanism now seems unwarranted.

Even these conclusions have been challenged by better controlled, double blind, more recent studies. For example, Inomata-Terada *et al* (2008) investigated

whether pulsed RF emitted by a mobile phone had short term effects on the human motor cortex, by measuring motor evoked potentials (MEPs) elicited by single pulse transcranial magnetic stimulation (TMS), before and after mobile phone exposure (both active and sham). No short-term effects were detected.

In relation to sleep, Mann & Röschke (2004) reviewed the scientific literature on the effects of RF fields. They found several past studies that revealed a number of slight sleep-promoting effects and an increase in the alpha power of the sleep EEG induced by RF, which were consistent with resting EEG experiments. They concluded, however, that “at the present level of knowledge, no final conclusions can be drawn from the available data concerning potential health hazards. Although there seem to be some biological effects, these do not provide evidence for any adverse health consequences.” A demonstration of such effects for heavy use of cell phones during the day would have potential consequences in terms of health, since sleep is very important for overall well-being and its disruption might lead to impairment of cognitive functions, memory and stress.

Recent, better designed studies have been unable to prove any effect of low-level exposure to RF from mobile phones on sleep function. Fritzer *et al* (2008) investigated the effect of exposure during six nights not only on sleep parameters evaluated by polysomnography, but also on an array of neuropsychological tests. Data analysis was done by comparing the baseline night with the first and last exposure night and the first two sleep cycles of the respective nights. They did not find “significant effects, either on conventional sleep parameters or on EEG power spectra and correlation dimension, as well as on cognitive functions.” Their opinion was that “previously realized sleep studies yielded inconsistent results regarding short-term exposure. Moreover, data are lacking on the effect that short- and long-term exposure might have on sleep as well as on cognitive functions.”

Other negative results were reported by Kleinlogel *et al* (2008) for EEG and visual, auditory and attention-task related ERP in a randomized, crossover, double blind study.

One possible explanation for slight alterations in the levels of consciousness, reaction time and cognitive processing by some studies has been overlooked and merits further research, viz., the possibility that some people have higher sensitivity to otherwise subtle sensory clues emanating from the real RF emitting devices, as compared to the sham ones. These could be, for example, ultrasound buzzing, a higher temperature sensitivity of the skin, or other. It has already been proved that younger people have a hearing threshold for sound frequencies with a much higher pitch (up to 24 kHz) than older people, which might introduce an age-related bias into the results (Corso, 1963). It has been proved, also, that a phenomenon called “microwave hearing” can be observed in some animals and human subjects. Apparently, it is related to the expansion of fluids in the inner ear caused by heating (reference) and this could explain a lot of positive behavioral and neural



effects related to alertness, both in animals and humans.

### **Vision, hearing and vestibular systems**

There are few experimental studies published in these areas. Two Brazilian physicians, Balbani & Montovani (2008) reviewed the literature on cell phones, hearing and vestibular system. They argue that, since cell phones are very close to the user's ear, the skin, inner ear, cochlear nerve and the temporal lobe surface might absorb a part of its radiofrequency energy, so that effects could be expected. In addition, an increase in the temperature of the inner fluids of the vestibular apparatus theoretically could induce neural responses in the receptor cells, such as vertigo and nystagmus. Vertigo is one of the complaints frequently made by people who are allegedly hypersensitive to RF radiation emitted by cell phones. The proximity of a mobile phone to the human eye also raises the question as to whether RF could affect the visual functions.

In the auditory system, Uloziene *et al* (2005) investigated the acute effects of RF on auditory perception, using standard audiometry to evaluate hearing. They concluded that a 10-min exposure of RFs emitted from a mobile phone had no immediate after-effect on measurements and no measurable hearing deterioration was detected. The exposure was too short, however, and hearing deterioration can be observed only after long term stimulation with high sound intensities, so any possible effect would not be detected by these experiments. In other studies using auditory evoked responses and brain-evoked response audiometry (BERA), a more objective measure of the integrity of the auditory system, Hamblin *et al* (2006), Stefanics *et al* (2007), Cinel *et al* (2007), Oysu *et al* (2005) and Sievert *et al* (2005), assessed short term effects of cell phone emissions under normal use conditions on the auditory evoked potential, auditory threshold and BERA, respectively. None of the studies found any significant effect.

In the vestibular system, Sievert *et al* (2007) employed video-nystagmographic recordings, BERA and otoacoustic emission recordings, with and without a mobile phone in use. Thermographic investigations suggested that the mobile phone does not induce any increases of temperature which would lead to a relevant stimulus for the auditory and vestibular system, and that RFs generated by using the mobile phone do not have an effect on the inner ear and auditory system to the inferior colliculus in the brainstem and on the vestibular receptors in the inner ear and the vestibular system. In another paper (Pau *et al*, 2005) the same group recorded intra-temporal bone temperature elevation during cell phone use and could find none above 0.10C, suggesting that mobile phone RF transmitting power is not sufficient to cause significant heating. More recently, Bamiou *et al* (2008) also reported not finding any effects of 30 min GSM radiation exposure on vestibular function, using transient evoked otoacoustic emissions (TEOAE) and video-oculography (VOG).

The literature review by Balbani & Montovani (2008) concluded that acute exposure to mobile phone RF signals do not influence the cochlear outer hair cells function in vivo or in vitro, the cochlear nerve electrical properties nor the vestibular system physiology in humans. There seems to be no evidence of cochleo-vestibular lesion caused by cellular phones.

In the visual system, Schmid *et al* (2005) tested 58 human volunteers for four different visual function parameters, using a double blinded, crossover study, and found no statistical differences between acutely exposed and non-exposed. Interestingly, they measured power density distribution in the visual cortex, and determined that in the high exposure condition the resulting average exposure of the test subjects in the cortex of the left temporal lobe of the brain was 0.63 W/kg (1 g averaged SAR) and 0.37 W/kg (10 g averaged SAR). The low exposure condition was 1/10 of high exposure and sham was at least 50 dB (corresponding to a factor of 100,000) below the low exposure. Irlenbusch *et al* (2008) investigated a sensitive parameter of retinal function, the visual discrimination threshold (VDThr). No statistically significant differences in the VDThr were found in comparing the data obtained for RF exposure with those for sham exposure.

No published experimental research in major journals covered by MEDLINE were found in respect to the chemical senses systems (taste and olfaction) and RF exposure

### **Endocrine System**

The endocrine system is particularly sensitive to many environmental physical agents, Radiofrequency at high powers provoke heating and can affect adversely the endocrine glands (Black & Heinick, 2003). The action of high frequency electromagnetic waves could theoretically be mediated in two ways: first, by direct action on the glandular tissue; and second, by action on the basal brain and hypophysis (or pituitary gland), thus modifying the secretion of hypothalamic releasing factors and/or hormones secreted by the neuro- or adeno-hypophysis. In any case, target glands, such as the thyroid, adrenal cortex, ovary and testicles could be affected. Growth hormone, prolactin, oxytocin, ADH and others might be affected too. There are many studies with experimental animals, but studies with human volunteers using low-level power densities below the ICNIRP safety levels are rare.

Djeridane *et al* (2008) investigated the effect of exposure to 900 MHz GSM RF on steroid (cortisol and testosterone) and pituitary (thyroid-stimulating hormone, growth hormone, prolactin and adrenocorticotropin) hormone levels in healthy males. Exposure was daily, for one month and hormones were measured by blood samples every hour before the beginning, at the middle, and at the end of the exposure period. The study reported that all hormone concentrations remained within normal physiological ranges, and that the circadian profiles were not

disrupted. For growth hormone and cortisol, there were significant decreases of about 28% and 12%, respectively, 2 and 4 weeks after exposure, but no difference persisted in the post-exposure period, but factors other than RF could be responsible for this (no control group was set up). No disruptive effect was found in melatonin secretion by GSM cell phone exposure (Bortkiewicz *et al* 2002, de Seze *et al*, 1999). It appears that there is no evidence for effects of RF on endocrine functions in man.

### **Cardiovascular System**

Although some experiments have been carried out in connection with possible effects of non-occupational, low level RF emitted mainly by cell phone handsets (Braune *et al*, 1998), the general conclusion is that there is no evidence for documented effects on heart rate and arterial blood pressure. In a double-blind, crossover study, Barker *et al*, (2007) studied mean arterial pressure (MAP), heart rate variability (HRV) and plasma catecholamine levels in health volunteers. Despite the high statistical power of the study, which could discriminate changes of 1 mmHg in MAP, no difference was found between the exposed and unexposed groups to GSM and TETRA cell phones. Nam *et al* (2007) didn't find any differences in several cardiovascular parameters between CDMA exposed and non-exposed adolescents (systolic and diastolic blood pressures, heart rate, respiration rate, and skin impedance), except for a brief decrease in skin impedance.

Heart rate variability (HRV), a measure of autonomic nervous system activity, did not change significantly in exposed adults (Ahamed *et al*, 2008; Parazzini *et al*.2007). However, in newborn incubators this was observed, but was found to result from fields produced by motors and electric pumps (Bellieni *et al*, 2008). These devices emit many kinds of RF fields, ranging from extremely low (50 to 60 Hz) to high frequency, with different contributions and powers.

### **Electromagnetic Hypersensitivity Syndrome**

Electromagnetic energy outside of the visible spectrum and the infrared is not, under normal circumstances, detectable by human beings, since we don't have specialized receptors to transceive directly its specific frequencies. Furthermore, devices used by the public, such as pagers, cordless telephones, bidirectional radio sets and mobile telephones transmit at very low levels (a typical GSM or UTM enabled handset has an radiating power of 250 to 300 mW). Radiofrequency signals transmitted by broadcast terrestrial and satellite-based radio and TV have very low power densities at the level of human habitation, as well as digital base stations and wireless access points (typically a few  $\mu$ W/cm<sup>2</sup>).

Despite this, a subgroup of the population reports being sensitive to these RF fields, alleging being able to detect when they are near them, or to discriminate

when a cell phone is on or off. This has been called electromagnetic hypersensitivity and is not necessarily detrimental to such persons. The pathological phenomenon in this respect consists of individuals who, being sensitive or not, report a number of distressing subjective symptoms during and after using a cell phone and other radiofrequency-emitting devices, or when they are near an RF antenna site. These symptoms are quite nonspecific and are present in many diseases, such as cold and flu-like symptoms (headache, nausea, fatigue, muscle aches, malaise, etc.). In the absence, so far, of a mechanism for explaining them and of an indisputable causal nexus in relation to RF radiation, this constellation was initially named electromagnetic hypersensitivity syndrome, or EHS, but recently the World Health Organization, at a workshop devoted to studying this topic, decided to rename it Idiopathic Environmental Intolerance with Attribution to Electromagnetic Fields (IEI-EMF). The new name positions it within a wide host of other recognized/provisional environmental intolerances to ambient chemical and physical agents, with or without a proven etiology. In fact, the phenomenon was considered serious and prevalent enough to have WHO call for an international conference in Prague, Czech Republic, in 2004, to examine and discuss it (Mild *et al*, 2004). More recently one country (Sweden) has recognized the existence of the EHS phenomenon and has provided state-funded disability pay to some workers with EHS (Grandlund-Lind & Lind, 2004).

The prevalence of EMF sensitivity is not small: Eltiti *et al* (2006), in a survey carried out in the USA reported that 4 in 100 people report being electrosensitive, and that these people suffer more frequently from ill health than the general population. In Switzerland, Schreier *et al* (2006) found a prevalence of 5%. The most common health complaints were sleep disorders (43%) and headaches (34%), which were mostly attributed to power lines and mobile phone handsets. In addition, 53.5% were worried about adverse health effects from EMF, without attributing their own health symptoms to them. The phenomenon is real, and the quality of life of these individuals suffers greatly with debilitating symptoms, to the point that work and recreation becomes difficult (Bergqvist & Vogel, 1995, Irvine, 2007).

It is noteworthy that such unspecific symptoms are very common in many diseases and are extremely prevalent in the population. The problem is that most well-conducted studies have shown that there is no association at all between RF exposure and the EHS symptoms. In a systematic review of 13 IEI-EHF investigations carried out between 2000 and 2004 (Seitz *et al*, 2004) arrived at the conclusion that “based on the limited studies available, there is no valid evidence for an association between impaired well-being and exposure to mobile phone radiation presently. However, the limited quantity and quality of research in this area do not allow to exclude long-term health effects definitely.”

In the most recent meta-analysis, performed by Rööslü (2008), the results of seven experimental studies were pooled, and the conclusion was that “there was no evidence that self-declared IEI-EMF individuals could detect presence or absence

of RF-EMF better than other persons. There was little evidence that short-term exposure to a mobile phone or base station causes symptoms based on the results of eight randomized trials investigating 194 EHS and 346 non-EHS individuals in a laboratory.”

The most recent systematic review of all studies has also concluded that EMF exposure is not associated with EHS symptoms (Rubin, 2009). So, it seems from the available evidence that most of the uncertainty surrounding IEI-EMF has been reduced and the phenomenon is largely regarded today as due to other factors, a conclusion of the WHO 2004 report on IEI-EMF (Mild *et al*, 2004):

*“The majority of studies indicate that IEI individuals cannot detect EMF exposure any more accurately than non-IEI individuals. By and large well controlled and conducted double-blind studies have shown that symptoms do not seem to be correlated with EMF exposure. There are also some indications that these symptoms may be due to pre-existing psychiatric conditions as well as stress reactions as a result of worrying about believed EMF health effects, rather than the EMF exposure itself. It was added that IEI should not be used as a medical diagnosis since there is presently no scientific basis to link IEI symptoms to EMF exposure.”*

The WHO experts also recommended at the same meeting that the victims of the IEI-EMF should receive medical treatment for their conditions, even though the causal link with RF has not been established. This should include a medical evaluation to identify and treat any specific conditions that may be responsible for the symptoms, an assessment of the workplace and home for factors that might contribute to the symptoms (air pollution, excessive noise, poor lighting) a psychological evaluation to identify alternative psychiatric/ psychological conditions that may be responsible for the

### **Comments on Human Experimentation Results**

It is remarkable the change that has occurred in expert opinion about putative health effects of RF below the safety levels, in the last five years. By the end of 2001, a most respectable group of experts in the UK, the Independent Experts Group on Mobile Phones (IEGMP), issued an extensive literature review, which was promptly dubbed The Stewart Report, and which achieved great impact in the specialized as well as in the mass media. The Report made a call for adopting more stringent precautionary approaches by government and public, by expressing the opinion that

“The balance of evidence to date suggests that exposures to RF radiation below NRPB and ICNIRP guidelines do not cause adverse health effects to the general population. There is now scientific evidence, however, which suggests that there may be biological effects occurring at exposures below these guidelines. This does

not necessarily mean that these effects lead to disease or injury, but it is potentially important information and we consider the implications below. It is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects, and that the gaps in knowledge are sufficient to justify a precautionary approach. We conclude that the balance of evidence indicates that there is no general risk to the health of people living near to base stations on the basis that exposures are expected to be small fractions of guidelines. However, there can be indirect adverse effects on their well-being in some cases.”

Since the levels of RF radiation at which these investigations were made were below the international levels that are considered safe, *i.e.*, no heating of tissues could be possible, the Stewart Report was effectively suggesting that a non-thermal action of RF of sufficient magnitude to cause observable effects might be possible. In the ensuing years, however, better designed, better controlled experimental studies in humans were carried out and have refuted most of the IEGMP conclusions, not supporting the hypothesis of a non-thermal effect causing adverse health effects. Current science-based evidence points to there being no adverse effects in humans below thermal thresholds, no hazardous influences on the well being of users and non-users of cell phones and people living near base stations, and that no convincing evidence for cognitive, behavioral, and neurophysiological alterations exists.

A number of organizations have reviewed the effects of EMF-RF on human health recently, and have concluded:

**World Health Organization (2010) – Fact Sheet 193**

<http://www.who.int/mediacentre/factsheets/fs193/en/index.html>

- *“A number of studies have investigated the effects of radiofrequency fields on brain electrical activity, cognitive function, sleep, heart rate and blood pressure in volunteers. To date, research does not suggest any consistent evidence of adverse health effects from exposure to radiofrequency fields at levels below those that cause tissue heating. Further, research has not been able to provide support for a causal relationship between exposure to electromagnetic fields and self-reported symptoms, or “electromagnetic hypersensitivity”.*

**Human Experimental Studies in Latin America**

We have not found any significant human experimental study on the effects of RF fields on human health in Latin America.

Main conclusions and statement of the Latin American Committee on Human Experimental Studies

Experimental studies with humans have been performed with the intent of investigating possible acute effects of RF fields, particularly those emitted by mobile phones in close contact with the body, on several organ systems of healthy human volunteers. The majority of good quality studies have shown negative results or insignificant alterations in physiological and behavioral parameters of interest.

In the nervous system, many cognitive and behavioral functions have been investigated both in children as well as in adults and it is now generally accepted that there are no significant effects of cell phone usage on cognitive and behavioral parameters. In regard to alterations in the resting EEG, although initial studies showed a mild increase in alpha and REM frequencies, more recent and better designed studies using polysomnography could not demonstrate any effect on the EEG and sleep patterns. Other investigated effects of low-level RF emitted by mobile telephones on sensory systems, such as pain, vision, hearing and the vestibular systems, as well as on the endocrine and cardiovascular systems were all negative. We may conclude therefore that except for small, inconclusive variation in cognitive task performance and on EEG, the exposure of cell phone users within normal range of intensity and frequency does not affect the central nervous system.

Even in those studies that were able to demonstrate a mild effect, they were not detrimental to health, and their significance in long term exposure could not be verified. Studies using functional imaging of the brain and deep thermography have shown that there is no significant heating which is caused directly by RF irradiation either in the bone or in the brain.

In relation to the so called electromagnetic hypersensitivity syndrome, the conclusion is that self-declared sensitive individuals cannot detect RF exposure any better than non-sensitive individuals, and that their symptoms are not due to RF exposure, but to other factors.

## **Epidemiological Studies**

Due to ethical and methodological difficulties in studying long term exposure in humans to electromagnetic fields using experimental approaches (Repacholi & Cardis, 1997), observational research is key, *i.e.* epidemiological studies.

The objective of epidemiological studies is to test statistically whether a causal nexus between exposure to an environmental agent and its putative effects on the health status of the exposed subjects can be found. They use specially designed studies that try to determine statistical associations between independent (level of exposure) and dependent variables (health status, development of disease, etc.) by collecting data from population samples. The three most frequently used

research designs are cohort, case/control and cross-sectional studies. In relation to RF-based wireless communications, in addition, there are two different exposure situations: to RF in the far field, emitted by base stations, WiFi access points, etc. and to RF in the near field, emitted by handheld devices (e.g. mobile phones).

In this section we will review the state of knowledge provided by epidemiological research projects on health risks incurred by exposure to RF fields in several settings, covering the published literature until May 2010. A critical analysis of the methodological issues and summary of current of epidemiological research as well as a short summary of conclusions by expert review groups is presented.

### **Methodological issues in RF epidemiology**

Although epidemiological investigations can be carried out in many areas of environmental health, RF research presents particular methodological challenges. Before going into our literature review, we will briefly discuss them. A more detailed discussion and proposals for solutions will follow the review.

According to the World Health Organization publication on *Electromagnetic Fields, Environmental Health Criteria* series (WHO, 1993),

*“epidemiological studies on the association between cancer and adverse reproductive outcomes and RF fields are made difficult by a number of factors: most members of any population are exposed to levels of RF that are orders of magnitude below thermally significant levels, it is very difficult to establish RF exposure in individuals over a meaningful period of time, and control of major confounders is very difficult.”*

Despite having being written in 1993 our opinion is that this statement is still valid.

Epidemiological research should allow for sufficient latency, sufficient range of exposure, including high exposure, and ability to accurately classify individuals into several exposure groups.

Despite these difficulties, its high costs and long duration, epidemiological studies are crucial for proper risk assessment. The active database of registered scientific papers of the Electromagnetic Fields and Health Group of the World Health Organization (WHO-EMF) listed until the first quarter of 2010 about 383 published epidemiological studies, of which 147 dealt with mobile telephony and wireless data communication. Of these, 65 were case/control and 15 were cohort studies, comprising about 50% of published papers. Thirty two epidemiological studies investigated the association between RF exposure in this sub-area with subjective symptoms (21), nervous system and behavior (8), and teratogenicity, reproduction and development (3).



## **Ecological Studies: The Extent of EMF Irradiation**

Epidemiological studies, since they are carried out in natural settings, must take into account the degree of exposure to all sources of radiofrequency and the contribution of each frequency. Until recently, very little was known about the average exposure of human beings in urban environments to artificial radiofrequency fields used in telecommunications, particularly mobile telecommunications. One study, by Frei *et al* (2009) used personal dosimeters worn continuously by Swiss volunteers during one week to evaluate the degree of exposure. They discovered that the mean exposure was low (0.13 mW/m<sup>2</sup> ranging from 0.014 to 0.881 mW/m<sup>2</sup>). This mean level corresponds to a field gradient of 0.22 V/m, well below the safety limits of 10 V/m). Exposure to frequencies used in mobile telecommunications was mainly due to cell phone base stations (32%) and handsets (29%), and DECT cordless phones (22%). The highest exposures were recorded inside closed transportation vehicles such as trains (1.16 mW/m<sup>2</sup>) and tramways or buses (0.36 mW/m<sup>2</sup>) and airports (0.74 mW/m<sup>2</sup>), and were in average double in daytime than in nighttime (0.08 mW/m<sup>2</sup> only).

Besides mobile voice communication, recent concern has been expressed on the degree of daily exposure to wireless data communication devices, such as WLAN (Wireless Local Area Networks) and Bluetooth. Other common sources of RF exposure have been little investigated are baby surveillance devices (electronic babysitters), domestic cordless telephones and wireless headphones for indoor usage. Schmid *et al.* (2007a) have measured combined exposures for all these indoor devices in homes and offices, arriving at the conclusion that they are low, the average being approximately 0.1% of the ICNIRP power density level safety limit. WLAN exposures were in the order of 20 mW/m<sup>2</sup>. None of the devices, even those near the body, exceeded these limits. Outdoor measurements of LAN wireless base stations resulted 2 or 3 orders of magnitude lower than indoor levels, resulting negligible in relation to safety levels.

Joseph *et al.* (2008) estimated SARs (Specific Absorption Rates) for outdoor exposure of the general public for several locations and scenarios. The average level of GSM base stations was 0.26 V/m, generating a 95<sup>th</sup> percentile SAR of 2.08  $\mu$ W/kg (the ICNIRP recommended safety level being 4 W/kg for the whole body). In other words, observed SAR is approximately 5 tenths of a million times less than the safety level.

## **Information Sources for the Review**

Two main databases were used for finding the sources of information used in the present review: MEDLINE (US National Library of Medicine, searched on-line via PubMed), and the database of papers maintained by the WHO-EMF Project. We complemented the search with news alerts from various news services, such as

RF Gateway.

We consulted also the main comparative surveys of the literature, in order to better filter the large number of papers as to relevance: Krewski et al. (2007), Hardell et al., (2007), Lahkola et al. (2006), Moulder et al (2005), Ahlbom et al. (2004, 2009), Kundi et al. (2004), Elwood (2004), Breckenkamp et al. (2003), Rössli et al (2009). Important methodological issues in regard to large scale epidemiological studies of exposure to radiofrequency (RF) have been posed by Ahlbom et al (2004), Kühnlein et al (2008), Morrissey (2007), Neitzke (2007), Schüz & Mann (2000), and Rothman et al (1996), which we have used for the present review.

Two reviews by Ahlbom et al (2004, 2009) examined the published literature on epidemiology of the effects of RF from 100 kHz to 300 GHz on human health, dividing it into studies of RF exposure from occupational sources, from transmitters, and from mobile phones; and covering possible effects of long-term exposure on the risk of diseases, such as cancer, heart disease, and adverse outcomes of fertility and pregnancy. These reviews were important because they were commissioned by ICNIRP and carried out by its group of experts in epidemiology.

In addition, we have studied closely and taken into account the expertise of international and national committees that have carried out extensive reviews of the literature, such as ICNIRP, the Independent Expert Group for Mobile Phones (IEGMP), the former United Kingdom Radiological Protection Board (now Health Protection Agency), and others. For example, an expert group from the European Commission called SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks), has produced an opinion on the “*Possible Effects of Electromagnetic Fields (EMF), Radio Frequency Fields (RF) and Microwave Radiation on Human Health*”, which updates that provided by CSTE (Scientific Committee on Toxicity, Ecotoxicity, and the Environment) in 2001; both evaluations were based primarily on peer-reviewed articles. Recent board reviews by the Swedish Radiation Safety Authority (SSM, 2009) were especially considered for the present literature review.

## **Cancer Incidence and Mortality**

### ***Community Exposure Studies***

This is the category of epidemiological study that lacks good quality data. Small, low quality studies, published in non-peer reviewed journals, or as technical reports or conference abstracts, and which lacked proper controls and significant number of subjects, were excluded from the present review, since the quality of evidence they provide is very low.

Of the eight epidemiological studies on cancer mortality and incidence, published

on exposure on the general population until 2001, as examined by Ahlbom *et al* (2004), all of them focused on the possible effect of radio and TV transmitters on brain tumors and childhood leukemia. All had a small number of cases and typically involved less than five observed cases of cancer. Distance from the source antenna was the main criterion of classification of exposure. Risk ratios were small, near unity, so that no association between proximity to an antenna and cancer incidence or mortality could be demonstrated. The assessment by Ahlbom *et al* (2004) clearly states:

*“To date no acceptable study on any outcome has been published on this. On the one hand, results from valid studies would be of value in relation to a social concern; on the other hand, it would be difficult to design and conduct a valid study, and there is no scientific point in conducting an invalid one.”*

This situation has not changed until the date of the present review and no new significant community exposure studies has contributed to the scientific knowledge. For recent studies in children see section below.

More robust and extensive studies are clearly needed in this area. A group of experts has recently analyzed the feasibility of such studies (Neubauer *et al*, 2007), by examining the critical methodological issues, and concluding that they are feasible, but the exposure contributions from all relevant radio frequency sources would have to be taken into account, not only those used in mobile telephony, for instance.

However epidemiological investigators seem reluctant to pursue them, due to several reasons, the main ones being that proper instruments, capable of measuring personal exposure have only recently been developed. Schüz *et al* (2000) have demonstrated that

*“studies at the population level on suggested adverse effects of radio waves from mobile phone base stations are not feasible since no valid metric for estimating historical exposures is currently available. The pace of radio infrastructure development is also such that today's measurements are unlikely to be good proxies for either past or future exposures. The complex propagation characteristics affecting the beams from base station antennas include shielding effects and multiple reflections from house walls and other buildings. These factors, combined with the presence of other environmental sources of radio waves, cause distance from a base station to be a poor proxy for exposure to radio waves indoors.”*

Furthermore, field power densities of typical antennas are very low so that a biophysical effect is highly unlikely to occur (Repacholi, 1998). Thus, investigators have concentrated on epidemiological studies of cell phone and other users of RF devices.

## ***Studies with Users of Cell Phones***

Ahlbom *et al.* (2004) examined 10 epidemiological studies related to cancer carried out between 1999 and 2003, being three in Sweden (all from the same authors, led by L. Hardell), one in Finland, one in Denmark, and the rest in the USA. Only those studies with well-defined exposure groups, for a sufficient time span (at least 2 to 3 years) were included. Lakhola *et al.* (2006) performed a meta-analysis of 12 original epidemiological papers reporting on brain tumor incidence with a total of 2,780 cases, the majority of the reviewed studies overlapping with those by Ahlbom, but they improved on the statistical methodology, by carrying out a meta-analysis, recalculating odds ratios (OR) for better precision and pooling results for the same kinds of histological tumors. Kundi *et al.* (2004) reviewed almost exactly the same set of epidemiological studies reviewed by Ahlbom (2004) and Lakhola (2006), but came to different conclusions. Ahlbom *et al.* (2009) reviewed more recent epidemiological studies, including most of the joint INTERPHONE studies published by 2009.

Except from two cohort studies, all the other studies used the case-control methodology. The number of cases studied were larger than those for community exposure to transmitters. Outcomes studied were mainly tumors of the CNS and eye, such as high-grade and low-grade glioma, acoustic neuroma, uveal melanoma and meningioma. The rationale for this is that modeling studies have shown larger absorption and distribution of RF energy from cell phones around the head and neck regions, at least for those who do not use a hands-free device. One study covered tumors of the salivary glands, and five analyzed tumors of all kinds. Fourteen independent calculations of risk ratios (RR) were below or equal to 1, meaning that no risk was found for cell phone users for those studies. Five studies had RR slightly larger than 1 (between 1.1 and 1.5), but these were also non-significant differences. One study by Hardell *et al.* (2003) had a significant RR of 3.5 for acoustic neuroma incidence in patients using analog cell phones, and reporting at the same time a laterality effect (incidence of tumor was higher for the side of the head reported to be the dominant one by cell phone users). This last study made headlines all over the world, despite the fact the nine other showed no associations. According to an analysis on laterality of effects carried out by the SCENIHR EMF Health Group and published in a report in 2009, this parameter is highly susceptible to reporting bias as cases know which side of their head is affected by the tumor, whereas controls do not know which side of their head will be relevant for analyses (in a matched study, it is the side of the head where the tumor occurred in their corresponding matched case). Therefore overreporting of the affected side of the head among cases may occur.

The two only retrospective methodologically sound cohort studies were carried out in the USA and in Denmark.

The first cohort study, (Dreyer *et al.*, 1999, Rothman *et al.* 1996) analyzed 1-year

follow-up of mortality in a cohort of 285,561 non-corporate users of mobile phones in the USA, with no evidence of general mortality (RR of 0,86). This study is not meaningful as the latency is not sufficient for any mortality outcome. It was the first study to demonstrate that the overall mortality of the cohort was less than in the general population, a finding that was confirmed by other studies with specific causes of mortality, such as cancer. If this finding were to be interpreted in the light of what relative risk means, one would have to assign a “protective” or “risk decreasing” characteristic to the fact of using a cell phone. Of course this is hard to believe, most probably it is due to the a confounding variable, such as those that the Danish cohort study was able to demonstrate, like a better income, with corresponding better general health, a higher level of education, with corresponding awareness about health, better prevention, etc. This should serve as a lesson to those epidemiologists who accept this explanation for RRs smaller than unity, but tend to assign risk to cell phones when the RR lies above unity, at the same level of variation.

Two earlier case-control studies with a smaller data set in Denmark had demonstrated no evidence of increased risks for cell phone users in regard to the incidence of acoustic neuromas (Christensen *et al.*, 2004), meningioma and low- and high grade glioma, even for users with more than 10 years of continuous use (Christensen *et al.*, 2005). The cohort study, by Johansen *et al.* (2001), was the first nationwide cancer incidence study of cellular phone subscribers that examined records up to 15 years of usage, and reported an overall Standardized Incidence Ratio (SIR) of 0.89 (within a very narrow 95% confidence interval of 0.86 to 0.92) for all types of cancer. SIRs are calculated by dividing the number of observed cancer cases in the cohort by the number expected in the population. Overall, 3391 cancers were observed with 3825 expected by chance. The apparent protective effect of using cell phones was interpreted by the authors as a decrease of lung cancers possibly associated with a larger reduction in smoking among older subjects. The same group (Johansen, 2002b) published an expanded sample of the same study, including 420,095 private cellular network subscribers (80% of all subscribers in the country). They compared cancer incidence rates in phone users with national rates, according to gender, age, and period. Of the 15,000 cases of cancer expected by chance, some 14,250 were observed. The epidemiological study showed no relation to risk of brain and nervous system cancers [SIR 0.95], in relation to age at, or time since, first subscription, phone type, or tumor location. The Danish study was recently updated with follow ups of cell phone subscribers reaching back up to 21 years (Schüz *et al.*, 2007), with the first cellular telephone subscription between 1982 and 1995 and who were followed through 2002 for cancer incidence of all types of tumors. Cellular telephone use was not associated with increased risk for brain tumors (SIR = 0.97), including gliomas (SIR = 1.01) and meningiomas (SIR = 0.86) acoustic neuromas (SIR = 0.73), salivary gland tumors (SIR = 0.77), eye tumors (SIR = 0.96), or leukemias (SIR = 1.00). Among long-term subscribers of 10 years or more (more than 56,000), cellular telephone use was not associated with increased risk for brain tumors (SIR = 0.66, showing a

strong protective effect), and there was no trend with time since first subscription. Since a cause-effect relationship in this case is highly improbable, *i.e.*, using cell phones per se would not be expected to increase good health, the observed reduction in relative risk below 1 could be attributed to confounding variables, such as: long term users started to use cell phones when they were very expensive, so a higher income was required (Rothman *et al*, 1996). People with higher income are known to have better general health, take preventive care of themselves and go more often to physicians and hospitals than younger and less affluent people (although these differences are less relevant for highly developed countries such as Denmark and Sweden). The authors reported that “*no evidence was found for an association between tumor risk and cellular telephone use among either short-term or long-term users. Moreover, the narrow confidence intervals provide evidence that any large association of risk of cancer and cellular telephone use can be excluded.*”

The Danish study had some peculiarities. It was carried out entirely by doing record linking analysis, which has been possible only due to the excellence and completeness of population records (cell phone subscriber, National Population Registry and the National Cancer Registry), using a nationwide ID number.. Second, the cohort was very large and extensive in time, as well as comprehensive (80% of all Danish cell phone subscribers). There was no assessment of degree of exposure, frequency of use, use of hands-free, etc, and there was no way of ascertaining for sure whether subscribers actually corresponded to users Corporate user subscriptions (a large number, more than 200,000) were not included in the study, which might be a potential source of selection bias.

Except for acoustic neuromas, all the other studies reviewed by Ahlbom *et al* (2004) showed no association between cell phone use and parotid gland tumors, uveal melanoma, meningiomas and leukemias.

Interestingly enough Kundi *et al*. (2005), reviewing almost exactly the 9-10 studies reviewed by Ahlbom (2004) and Lakhola *et al*. (2005), arrived at the opposite conclusion, *i.e.*, that “*all studies approaching reasonable latencies found an increased cancer risk associated with mobile phone use. Estimates of relative risk in these studies vary between 1.3 and 4.6 with highest overall risk for acoustic neuroma (3.5) and uveal melanoma (4.2), and there is evidence for enhanced cancer risk with increasing latency and duration of mobile phone use.*”. The results are largely based on a studies of a single research group, headed by Hardell in Sweden, which are not consistent with the other 6 studies from other groups.

Another review published by Valberg *et al* (2007) on scientific evidence about exposures and health consequences of base stations and wireless networks arrived at the same conclusions as Ahlbom *et al* (2004).

The most important and recent set of systematic epidemiological studies, however,

was the INTERPHONE Project, which deserves a separate discussion, as follows.

### ***A review of the INTERPHONE studies***

Beginning in 2001, a series of ambitious, well designed, large case-control epidemiological studies coordinated by the International Agency for Research on Cancer (IARC) were started in 13 countries (Australia, Canada, Denmark, Finland, France, Germany, Israel, Italy, Japan, New Zealand, Norway, Sweden, and the United Kingdom) using a common protocol. Named INTERPHONE, this international effort started publishing preliminary data in 2004, and in 2007 the first paper describing methods appeared in print (Cardis *et al*, 2007). The first complete publication reporting the pooled results for two types of brain tumors, glioma and meningioma, was published in May 2010, after a protracted period (The INTERPHONE Research Group, 2010). The final publication for two other types of tumors, acoustic neuroma and tumors of the salivary gland, was still pending at the time of submission for publication of this review.

The INTERPHONE study focused on tumors in locations most likely to be affected from higher exposure to RF fields during mobile phones use: it included 2,765 cases of glioma, 2,425 of meningioma, 1,121 of acoustic neuroma, 109 of malignant parotid gland tumor and 7,658 controls). Detailed information about the history of mobile phone use, and a number of known and potential risk factors were collected by means of an in-person computer assisted interview (CAPI) conducted by a trained interviewer. Most significant is the fact that for the first time, several preparatory validation studies and refined epidemiological and statistical techniques were used in order to understand better and to decrease the influence of biases and confounding variables which operated in previous case-control studies. The INTERPHONE studies have been eagerly awaited, and ICNIRP, WHO and other agencies have postponed their official statements about RF and health in expectation of these results, based on its design characteristics and size. We review them here briefly.

One of the first INTERPHONE studies examining the incidence of acoustic neuromas (Shoemaker *et al*, 2005) used a pooled set of 6 separate case control studies carried out in Nordic Europe and UK under the common protocol. It found that the risk of this tumor in relation to regular mobile phone use in the pooled data set was not raised (OR = 0.9), and that there was no association of risk with duration of use, lifetime cumulative hours of use or number of calls, for phone use overall or for analogue or digital phones separately. They found however, a small elevated risk of a tumor on the same side of the head for use for 10 years or longer (OR = 1.8). The study suggested that there is no substantial risk of acoustic neuromas in the first decade after starting mobile phone use. The Japanese INTERPHONE branch of the same study reported essentially the same results (Takebayashi *et al*, 2006). The French INTERPHONE study (Hours *et al*, 2007) also reported no significant increased risk for glioma, meningioma or neuroma,

although glioma patients had a slightly positive, non significant OR among heavy users. The UK part of the study of gliomas had completely negative results, ascribing a higher but non-significant ipsilateral risk to recall bias (Hepworth, 2007). The result confirming no association of glioma and meningioma incidences to cell phone exposure under 10 years was confirmed by a Nordic INTERPHONE study in 5 countries (Lakhola *et al*, 2008).

Lönn *et al* (2005) in Sweden, did a case-control study of 644 brain glioma and meningioma cases and 674 controls, and concluded that for regular cell phone use, the odds ratio were 0.8 for glioma and 0.7 for meningioma, with similar results for more than 10 years of mobile phone use. Likewise, no risk increase was found for ipsilateral phone use for tumors located in the temporal and parietal lobes, type of tumor histology, type of phone and intensity of use. This study included a large number of long-term mobile phone users, and the authors conclude that the data do not support the hypothesis that mobile phone use is related to an increased risk of glioma or meningioma, thus being the first one to directly contradict the publications of their countryman L. Hardell.

Another INTERPHONE study was completed and published in 2008, which analyzed the risk of parotid gland tumors in cell phone users in Israel (Sadetzki *et al*, 2008a). Lönn *et al* (2006) had previously reviewed the epidemiological evidence on salivary glands cancer and cell phone use in Denmark and had concluded that the data did not support such an association (for regular mobile phone use, regardless of duration, the risk estimates for malignant and benign tumors were 0.7 (95% confidence interval: 0.4, 1.3) and 0.9 (95% confidence interval: 0.5, 1.5), respectively. Similar results were found for more than 10 years' duration of mobile phone use. The Sadetzki study, however, found an elevated risk of ipsilateral benign and malignant tumors (ORs in the highest category of cumulative number of calls and call time without use of hands-free devices were 1.58 (95% confidence interval: 1.11, 2.24) and 1.49 (95% confidence interval: 1.05, 2.13), respectively), provoking a lot of controversy and misleading statements in the press. Parotid cancer is very rare (2-3 cases per million). Carcinogenesis induced by long term smoking has been suggested as a risk factor for some head and neck tumors (Marur & Forastiere, 2008), including parotid cancer (Sadetzki *et al*, 2008b).

The final publication of INTERPHONE pooled results for glioma and meningioma case/control studies in 13 countries (The INTERPHONE Research Group, 2010), arrived at the conclusions that a below-unity odds ratio (OR) was obtained for glioma [OR 0.81; 95% confidence interval (CI) 0.70-0.94] and meningioma (OR 0.79; 95% CI 0.68-0.91), in relation to being a regular phone user anytime. The authors interpreted this OR as possibly reflecting participation bias or other methodological limitations and not of real protective effect. No increased OR was observed 10 years after first phone use (glioma: OR 0.98; 95% CI 0.76-1.26; meningioma: OR 0.83; 95% CI 0.61-1.14). ORs were below one for all deciles of



lifetime number of phone calls and nine deciles of cumulative call time. In the tenth [highest] decile of recalled cumulative call time, the OR was 1.40 (95% CI 1.03-1.89) for glioma, and 1.15 (95% CI 0.81-1.62) for meningioma. However, the authors noted highly implausible values of reported phone use in this group, such as 12 hours of use per day, potentially biasing the results and rendering them artificially high. Regarding location of the tumor, ORs for glioma tended to be greater in the temporal lobe than in other lobes of the brain, which corresponds to the part of the brain more exposed to the cell phone RF radiation, but the confidence intervals for lobe-specific estimates were wide. ORs for glioma tended to be greater in subjects who reported “usual” phone use on the same side of the head where their tumor was located, than on the opposite side, but on basis of the methodological studies already cited above, this results might be explained by a recall bias, since diseased individuals tended to assign their preferred mobile phone use side of the head to the one they sustained the tumor.

Another key finding of the Interphone study was that it did not matter whether the person was an analogue or digital cell phone user the study found no increased risk of brain tumours.

The WHO has published soon after a fact sheet on EMF and health (WHO, 2010), stating about the INTERPHONE final publication:

*'A retrospective case-control study on adults, INTERPHONE, coordinated by the International Agency for Research on Cancer (IARC), was designed to determine whether there are links between use of mobile phones and head and neck cancers in adults. The international pooled analysis of data gathered from 13 participating countries found no increased risk of glioma or meningioma with mobile phone use of more than 10 years. There are some indications of an increased risk of glioma for those who reported the highest 10% of cumulative hours of cell phone use, although there was no consistent trend of increasing risk with greater duration of use. Researchers concluded that biases and errors limit the strength of these conclusions and prevent a causal interpretation.'*

The results of INTERPHONE have been challenged by some science advocacy groups, such as BIOINITIATIVE, and by some epidemiologists, as having a number of significant methodological flaws (Sarrachi and Samet, 2010), including selection, recall biases, exclusion of young adults and children, and of brain tumor cases because of death and illness, all of which might lead to artificially low ORs. The critics have also called attention to INTERPHONE's failed definition of regular user (a regular user was defined as one call per week for at least 6 months, an exposure so low that might severely under-estimate risk in the exposed population).

Although many comments on the May 18, 2010 publication emphasized the

inconclusiveness of the study, we don't think this conclusion are entirely warranted. In fact, INTERPHONE is the largest and most carefully controlled case control, with the largest number of long-term cell phone users on brain and head tumors. Odds ratio were universally low, hovering around unity,. The INTERPHONE results are in agreement with most other *in vitro* and *in vivo* studies, as well as with other case-control and large register-based cohort studies with more than 400,000 participants.

Therefore, overall conclusions by highly respected institutions, ICNIRP (See: <http://www.icnirp.de/documents/ICNIRPnote.pdf>). "Overall, the study did not find an increase in the risks of glioma or meningioma in relation to mobile phone use. "...ICNIRP agrees that the biases and errors in the study precluded a causal interpretation of the results."

WHO (<http://www.who.int/mediacentre/factsheets/fs193/en/index.html>), in their respective statements published in 2009 and 2010, that there is no evidence for detrimental health effects on human beings by low-power radiofrequency devices used for mobile communications, are amply justified, despite contrary positions by a few groups and individuals.

In addition the US Food and Drug Administration (FDA) (<http://www.fda.gov/downloads/ForConsumers/ConsumerUpdates/UCM212306.pdf>) has stated that "The recent Interphone findings, posted online in the June 2010 International Journal of Epidemiology, did not show an increased risk of brain cancer from using cell phones. Although some of the data suggested an increased risk for people with the heaviest use of cell phones, the study's authors determined that biases and errors limit the strength of conclusions that can be drawn from it. According to WHO, cell phone use has become much more prevalent and it is not unusual for young people to use cell phones for an hour or more a day. This increasing use is tempered, however, by the lower emissions, on average, from newer technology phones, and the increasing use of texting and hands-free operations that keep the phone away from the head."

No epidemiological studies with long term exposures larger than 15 years have been published so far. Considering that even very aggressive environmental agents, such as UV radiation by solar exposure, display proven latencies of 20 years or more, the state of knowledge of RF exposure has a large gap here. It may be the case that effective latencies for cancer causation may exceed the average lifetimes of people who are currently adults, but might be relevant for users who are children or young today. Unfortunately, there are still no large epidemiological study for this age bracket, despite that children, adolescents and young adults constitute a larger, and increasing part of heavy users of cell phones, PDAs and notebook computers with wireless data access.

## ***Systematic reviews based on meta-analysis***

An important technique for the systematic review of the literature is meta-analysis, which uses special statistical methods to combine and to compare different studies with a common outcome and similar research design. The selection criteria for studies that compose the meta-analysis is an important consideration because to any statistical analysis biases can be introduced by this selection and influence the results. In addition, sometimes it is difficult to draw conclusions from meta-analysis due to the heterogeneity of the studies that were included (Croft *et al*, 2008).

In the period 2006 to 2009, four meta-analyses were published on epidemiological studies of brain tumors in relation to cell phone radiation exposure: Lakhola *et al*. (2006), Hardell *et al*. (2007), Kan *et al*. (2007) and Khurana *et al* (2009).

A recent meta-analysis covering long-term use of cell phones (equal or more than 10 years) conducted by Khurana *et al* (2009) reported for ipsilateral use an OR of 1.9 (95% CI = 1.4-2.4) for glioma, 1.6 (95% CI = 1.1-2.4) for acoustic neuroma, and 1.3 (95% CI = 0.9-1.8) for meningioma. The authors concluded that *“using a cell phone for more than 10 years approximately doubles the risk of being diagnosed with a brain tumor on the same (‘ipsilateral’) side of the head as that preferred for cell phone use. The data achieve statistical significance for glioma and acoustic neuroma but not for meningioma.”* Although the authors stated that *“this is a meta-analysis incorporating all 11 long-term epidemiologic studies in this field,”* in fact only 5 of the studies -- 2 by the Hardell group and 3 from the INTERPHONE Study -- were included in the quantitative analysis.

The meta-analysis by Lakhola *et al* (2006) for studies with more than 5 years follow-up, on the other hand, reported a pooled odds ratio (OR) of 0.98 for all intracranial tumors related to mobile phone use, which is close to unity, i.e. there is no evidence for a differential risk. For gliomas, the pooled OR was 0.96, for meningiomas it was 0.87, and for acoustic neuromas it was 1.07, all within the 95% confidence interval.

## ***Epidemiological Data on Exposure of Children***

The fact that more and more children and adolescents have become users of cell phones (the prevalence is already more 40% in children under 15, and more than 90% among adolescents in some countries) and wireless computers has raised strong health concerns, to the point that public authorities in some countries have passed legislation prohibiting base stations near schools, something that has no scientific basis (antenna far fields power densities are too small; furthermore, the exposure of children out of school is not controlled by such legislation. Ironically, the prohibition of use of cell phones by children, however, has not been the subject of legislation).

It has been argued by some investigators that children could be more vulnerable to RF, because they have developing organisms and that their head structures might be penetrated more deeply by RF fields (see review by Otto & von Mühlendahl, 2007). In addition, the use of mobile phones between today's children and adults is the longer lifetime exposure of children when they grow older, due to starting to use phones at an early age (Schüz, 2005).

While there are no scientific data that developing organisms are more vulnerable than adults to low-level, RF fields (Kheifets *et al.*, 2005) there are presently no epidemiological studies addressing children and adolescents cancer risks of exposure to RF. One of the reasons is that this is a very recent phenomenon. The other reason is that most cancers are extremely rare in young people. The third factor is that epidemiological investigations that require recall of information by users are not easy to do with children. It has been suggested, however (Kheifets, personal communication, 2010), that they might be in the same order of magnitude, *i.e.*, also not very high, than in adults). Two international studies of brain tumors in children and adolescents are underway (CEFALO and MOBI-KIDS).

In conclusion, according to Martens (2005), "*all this makes a definitive answer to the question if children are more sensitive to electromagnetic fields than adults impossible. More consistent research will be needed.*" A precautionary approach, especially with small children, could be the cheaper and more effective option, for now.

Although there is insufficient data to conclude anything about the use of mobile phones by children and its effect on health, some studies indicated an increased risk of leukemia in children living close to strong radio or television broadcast transmitters (Ahlbom *et al.* 2004, Schütz & Ahlbom, 2008). In one case-control study carried out in South Korea involving 1,928 childhood leukemia cases (Ha *et al.* 2007) no association was seen between childhood leukemia risk and the predicted field strengths (OR=0.83, 95% CI: 0.63-1.08). A second case-control study conducted in German municipalities surrounding 16 AM radio and 8 frequency-modulated (FM) radio and television broadcast transmitters (Merzenich *et al.* 2008) involved 1,959 childhood leukemia cases and 5,848 population-based controls. No increased risk was seen for the first exposure decade alone (OR of 0.86, 95% CI: 0.67-1.11), and no distance effect was observed (OR = 1.04 (95% CI: 0.65-1.67) among children living within 2 km of the nearest broadcast transmitter compared to those living at a distance of 10-15 km.)

### **Occupational Studies**

Intuitively, it is easy to infer that occupational exposure to RF might be a much more serious problem for public health than exposure of the general public, because many workers are exposed on a daily basis to much more intense RF

fields, for longer times, so that they receive a far higher “dose”. Examples of these workers are installation and maintenance technicians of RF antennas, amplifiers and transmitters, radar operators, including police and transit radar operators, operators of microwave plastic welding machines, technicians and health care professionals who employ microwave and RF therapy devices and high field imaging devices. So evidence of a causal relationship for cancer would most likely appear in these settings than in others.

While dozens of occupational studies on RF using case-control, cohort and correlation studies were published in the last 50 years, there have been few, if any, well conducted and extensive epidemiological studies on occupational exposure. Most of the studies reviewed by Ahlbom *et al.* (2004) were conducted in the 1990s and early 2000s and had many methodological deficiencies. In almost all of them no or few RF exposure measurements were made, and the group of exposed subjects was categorized only in terms of its job description, duration of exposure and/or distance from transmitters.

The main occupational health outcomes published were:

***Total mortality***

**Neoplasias:** incidence for brain, breast, testicular, ocular melanoma, lung cancers and leukemia

**Other health outcomes:** incidence of ocular (cataracts), cardiovascular and reproductive health

Breckenkamp *et al* (2003) evaluated the methods and results of nine cohort studies dealing with various effects on human health from exposure to RF, published between 1980 and 2002. The size of the cohorts varied between 304 (3,362 person years) and nearly 200,000 persons (2.7 million person years). The occupational exposure groups were workers with dielectric heaters in plastic manufacturing plants, workers with radio devices (professional and amateur), production workers of wireless communication technologies, users of radar devices of the Canadian police and those used by the military. Total mortality, cancer mortality, cancer incidence or other outcomes were estimated. In some of the studies an increased risk for various types of cancer was found in exposed participants, although in different organs. The review concluded that, due to methodological deficiencies of most of the cohort studies, no conclusion could be reached whether an elevated risk for cancer existed for these occupational exposures.

Ahlbom *et al* (2004) similarly reviewed 10 cohort studies, carried out from 1988 to 2002 (with a large overlap with Breckenkamp’s review) and examined brain tumors, incidence of leukemia and relative risk in professionals of several work

sectors. Risk ratios for both outcomes were mostly under or around unity, with only 2 out of 14 studies on brain cancer having RRs slightly above unity. They also reported that 6 out of 12 leukemia studies had large RRs, varying from 4.4 to 7.7, two of them Polish studies about military people living near high power transmitters. According to the reviewers, these large RRs could be explained by rather gross biases and errors, or by confounding factors such as the presence of chemical contaminants. The number of cases also varied widely, ranging from 1 to 69 cases of leukemia and 1 to 44 for brain tumors. The authors also reviewed 3 case-control studies on occupational exposure to RF in relation to brain tumor and leukemia. The majority of RR and SIRs were below or around unity, showing no association.

More recently, the German branch of the INTERPHONE case-control study carried out an occupational case-control study (Berg *et al*, 2006). No significant association between occupational exposure to RF and brain tumors was found (OR for glioma of 1.21 and for meningioma 1.34, both not statistically significant).

So far, the balance of these epidemiological studies suggest higher risks of occupational cancer risks due to chronic exposure to apparently higher power densities of RF, for diverse groups such as radar operators, telecommunication installation and maintenance technicians, and others. The outcome that causes most concern is an increased rate of leukemia. No consistent effects have been demonstrated, but they could not be refuted either, due to the low quality and short duration of the cohort and case-control studies carried out so far. The feasibility of carrying out cohort studies of occupational risks, however, is low (Breckencamp *et al*, 2009), due to the small numbers of exposed subjects or due to exposure levels being only marginally higher than those of the general public, small duration of exposure due to job changes or technological changes, and the impossibility of separating RF exposure from other environmental risks (such as in industrial plastic sealers, which are also exposed to plastic vapours).

In Latin America, there is currently a growing concern about the health of technicians who do maintenance work very near “live” antennas. First- and second-degree burns by touching waveguides have been reported. Although required by law to cut off power to the antennas during this work, telecom operators usually ignore it, due to the fear of provoking an imbalance in the network service architecture. There seems to be little danger, however, if a modicum of caution and use of individual protection were adopted, such as heavy clothing, gloves, helmets and insulated materials. Alanko & Hietanen (2007) surveyed and evaluated RF power in transmitting antenna arrays for mobile phone networks, radio and digital TV sub-stations and amateur radio, close to the access ladders. They reported that all measured values where workers would normally be located were below ICNIRP occupational reference levels.

Curiously, but easy to understand why, is the position of occupational physicians in

charge of RF occupational hygiene programs in companies. A survey with more than 200 occupational physicians in Brazil (Sabbatini *et al.*, 2008, unpublished manuscript, personal communication) showed that: 1) the concept of non-ionizing radiation for most physicians is related to occupational exposure to excessive heat and light, to the sun, to coherent light (therapeutic and industrial laser), microwave plastic welding, industrial use of UV, arc welding, etc. 2) few physicians have any knowledge about occupational exposure to RF used in radiocommunication and its risks, even those who work in this industry; 3) They consider that this physical agent is too weak, compared to other much more aggressive and dangerous ones, to worry about them.

### ***Analysis of time trends***

Some would say that the extraordinary growth and spread of mobile communications is the largest experiment ever made by humans. This means that billions of people are exposed daily to cell phone and base station RF fields, and that millions have been doing so for 20 years or more (albeit at much lower levels than present use).

One of the useful by-products of estimating risk ratios and incidence ratios by means of methodologically rigorous and highly consistent cohort studies is the possibility of predicting the absolute number of disease cases that could be found now or in the future. This has been done successfully with tobacco smoking, for instance, and it was of great value for many public health and prevention programs, as well for planning cost of service, impact of preventive measures, and so forth.

Curiously, this has been remarkably absent from epidemiological RF studies. We should try to test if the predictions underestimate or overestimate reality. One of the few examples of this kind of analysis is a study of the time trend of incidence of uveal melanoma by Johansen *et al.* (2002), which, despite a four-fold increase in the incidence of this tumor in Denmark in the preceding decade, did not find a correlation with increase in the use of cell phones

So another tool of epidemiology comes to rescue: the analysis of time trends of selected diseases. Brain cancer is still a rare disease when considered in relation to the overall population. In the USA, for example, Deorah *et al* (2007) did such an analysis for all kinds of brain cancers, adjusted for age. Its incidence increased until 1987, when the annual increase (as percent) decreased from 1.68 to 0.44%. This period coincided almost exactly with the large scale introduction of mobile telephony in the country, but this probably has no meaning if the latency period of brain cancers is longer than 20 years.

A few recent studies have addressed this point. For instance, Muscat *et al.* (2006) analyzed the incidence rate of cancers of the CNS from 1972 to 2002. They

concluded that these rates did not change appreciably during this period, despite an exponential increase in mobile phone subscribers since 1984.. The results by Deorah *et al.* (2006) also failed to support the hypothesis that a risk of brain cancer and survival in the USA would add more cases due to the increase of the exposed population. In Switzerland, brain tumor mortality rates, as in many other countries, have remained stable in all age groups (Röösli *et al.*, 2007). Age-adjusted incidence and mortality of CNS cancers are actually falling in most countries. In the Röösli study cited above, the annual rate of new cases of brain cancer from 45 to 59 years of age in the period of 1987 to 2002 was -0.3% for men and -0.4% for women. There is, however, a slight increase in the incidence of brain cancer among younger people, but the reason for this is presently unknown.

Deltour *et al.* (2009) examined the time trends in brain tumor incidence from 1974 to 2003, using data from the national cancer registries. The incidence rate of glioma increased 0,5% per year (C.I. 0.2-0.8%) among men and by 0.2% per year (C.I. -0.1-0.5%) among women, and that of meningioma increased by 0.8% per year (95% CI = 0.4% to 1.3%) among men, and after the early 1990s, by 3.8% per year (95% CI = 3.2% to 4.4%) among women. The authors concluded that “*no change in incidence trends were observed from 1998 to 2003, the time when possible associations between mobile phone use and cancer risk would be informative about an induction period of 5-10 years.*”

It is important to note, however, that the calculus of statistical association between time trends of relevant variables is fraught with difficulties. Any two variables that go up or down in synchrony will generate a spurious high association or correlation, without necessarily being causally related. In addition, since the time delay of cancer causation is usually very large, an upward surge of cancers putatively caused by increasingly massive populations exposed to RF due to mobile communication would occur, if ever, still somewhere in the future.

### ***Conclusions from Cancer Epidemiological Studies***

From our review of the literature on epidemiology, there seems to be a scientific consensus that there is no firm evidence for an increased cancer risk and mortality among cell phone users. Regarding cancer incidence, the recent results (2007 and 2008) of extensive cohort studies and case-control studies (the INTERPHONE project), have provided us with the best epidemiological evidence so far for an absence of any risk, up to 10 years of continuous use of cell phones. But the data for long term heavy users (brain cancers may have long latencies of 30 years or so) is still lacking.

Regarding the possible association between exposure to base station RF and health effects, this has been impossible to prove or disprove so far, due to the lack of good quality and extensive studies, and substantial methodological difficulties. Unfortunately, the scientific status of epidemiological research in this area rests on



very shaky and unwarranted ground, because, in contrast to other better established areas of investigation, *“the RF research questions are not driven by a specific biophysical hypothesis but rather by a general concern that there are unknown or misunderstood effects of RFs”* (Ahlbom et al, 2004).

The conclusions are best expressed by statements by the following authors and expert committees:

**Ahlbom et al, 2004 (ICNIRP):** *“Overall, although occasional significant associations between various types of brain tumors and analog mobile phone use have emerged (often seen after multiple testing), no single association has been consistently reported across population-based studies. The timing of epidemiologic studies and the lack of knowledge about actual RF exposure to the brain from mobile phone use to date (...) militate strongly against current ability to detect any true association. Thus current evidence is inconclusive regarding cancer risk after heavy RF exposure from mobile phones. (...) Results of epidemiologic studies to date give no consistent or convincing evidence of a causal relation between RF exposure and any adverse health effect. On the other hand, these studies have too many deficiencies to rule out an association.”*

**Ahlbom et al, 2009 (ICNIRP):** *Despite the methodological shortcomings and the limited data on long latency and long-term use, the available data do not suggest a causal association between mobile phone use and fast-growing tumors such as malignant glioma in adults (at least for tumors with short induction periods). For slow-growing tumors such as meningioma and acoustic neuroma, as well as for glioma among long-term users, the absence of association reported thus far is less conclusive because the observation period has been too short.*

**SCENIHR (2007):** *The epidemiological evidence indicates that mobile phone use of less than 10 years does not pose any increased risks of brain tumors or acoustic neuroma. For long term data are sparse and the conclusions are therefore uncertain and tentative – however, from the available data it does appear that there is no increased risk for brain tumors in long term users, with the exception of acoustic neuroma for which there is some evidence of an association. (...) In conclusion, no health effect has been consistently demonstrated at exposure levels below the ICNIRP limits established in 1998. However, the data base for this evaluation is limited especially for long term low level exposure*

**WHO/IARC (International Agency for Research on Cancer) World Cancer Report 2008.** <http://www.iarc.fr/en/Publications/PDFs-online/World-Cancer-Report>  
*“Radiofrequency radiation emitted by mobile telephones has been investigated in a number of studies. There is some evidence that long-term and heavy use of mobile/cellular phones may be associated with moderate increased risks of gliomas, parotid gland tumors, and acoustic neuromas; however, evidence is*

*conflicting and a role of bias in these studies cannot be ruled out.” (p. 170) “With reference to radio frequency, available data do not show any excess risk of brain cancer and other neoplasms associated with the use of mobile phones.” (p. 170). Concerning brain tumors: “After 1983 and more recently during the period of increasing prevalence of mobile phone users, the incidence has remained relatively stable for both men and women.” (p. 461)*

The INTERPHONE studies which were published so far mostly do not support associations between brain tumor and use of phone cells handsets. Large scale cohort studies should be the next big project to solve lingering doubts about risk assessment in various age groups, particularly children.

### **Other Symptoms and Diseases**

There are extremely difficult methodological problems to surmount for epidemiological studies aiming at evaluating risks related to RF exposure and other common diseases. An important reason is that, as opposed to cancer incidence studies, most of the candidate diseases are not subjected to mandatory registration, and that patient medical records are incomplete, often inaccurate and contributed to by so many health care providers, that retrospective data based on patient information are generally unreliable and inaccurate.

Cardiovascular, gastrointestinal, endocrine, nervous system, and reproductive disorders are the main areas of interest, but have not been adequately investigated.

Ahlbom *et al.* (2004) have reviewed the effect of several kinds of occupational exposure to far electromagnetic fields on other diseases than cancer. The main independent variable was job description in most of the studies, and the number of subjects per study was usually very small.

In another recent review of epidemiological studies of the effect of exposure to electromagnetic radiation emitted by base stations of cellular antennas, Rösli *et al* (2009) analyzed 17 articles that were considered of satisfactory scientific quality, of which 11 were epidemiological studies and six were of controlled exposure. Most articles (14) examined the association between exposure and well-being or nonspecific symptoms of ill health (malaise, headache, fatigue, nausea, etc.), as reported by the patients. Most studies that attempted to study the acute effects of exposure found no association with symptoms during or shortly after exposure to radiation from base stations. Studies conducted in the laboratory found no consistent patterns of response, suggesting that the reported symptoms had nothing to do with the exposure itself. Epidemiological studies have shown no evidence that people living near base stations are different from those who do not live near them. The authors claim that the exposure of humans under these conditions of fields above 1 V / m almost never occurs, so it is not possible to

attribute effects.

**Cataracts:** They are a plausible health outcome due to heating, and several previous studies had reported a possible increase in incidence of cataracts in several kinds of workers that deal with high intensity RF pulses, such as radar, TV and radio transmitter. The quality of such early studies, however, was low (WHO, 1993). In Ahlbom's review, four of these earlier studies from 1965 to 1984 provided no evidence of an increased risk for cataracts in the studied categories. Confounding effects, such as chronic exposure to sunlight without protective eyeglasses (a well-documented risk) were not controlled for.

**Reproductive risk:** Several parameters have been evaluated in relation to occupational RF exposure in 17 studies from 1975 to 2000: quality of semen, fertility, spontaneous abortion, stillbirth, low birth weight and birth defects. In 10 studies, cases were physical therapists, both male and female, who often used microwave ovens and RF heating devices without any protective measures. Radar operators and military personnel using high power RF emitters comprised the rest. No studies on maintenance technicians of RF antenna arrays were investigated. The majority of studies could not prove any large effect, and showed relative risk ratios under 1.3, except for some evidence for a reduction in the number of spermatozoa in three studies. According to Ahlbom, "*given the well-known susceptibility of spermatogenesis to even subtle heating, the possibility of reduced fertility in exposed men is reasonable to evaluate*".

**Cardiovascular disease:** A large cohort study with almost 200,000 Motorola employees (Morgan *et al*, 2000) potentially exposed to RF showed, as expected, healthy worker effect.

**Behavioral changes:** Due to the highly unreliable self-reporting outcomes, very few case-control and cohort epidemiological studies have been carried out on behavioral changes. One exception is Divan *et al* (2008), who examined the association between prenatal and postnatal exposure to cell phones and behavioral problems in young children within a prospective/retrospective large cohort study. Mothers of 13,159 children in Denmark completed questionnaires on their use of cell phones during pregnancy, as well as current cell phone use by the child. The authors reported adjusted OR ratio of 1.8 for behavioral problems observed in children who had prenatal and postnatal exposure to cell phone use. The conclusion was that "*exposure to cell phone use was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.*" The authors state "*observed associations are not necessarily causal (...) and confounding by unmeasured causes of behavioral problems could have produced these results. Furthermore, this is the first study of its kind (...) and awaits replication.*"

**Nonspecific symptoms:** Diverse groups of people living near base stations for

mobile telephony have reported on a wide range of symptoms, such as fatigue, unwellness, vertigo, dizziness, sleep disturbances, headaches, gastrointestinal symptoms such as nausea and diarrhea, loss of appetite, visual symptoms, decrease in libido, loss of memory and concentration and depression. It must be noted that these are very common symptoms for many diseases or as isolated events without a specific cause. They have also been associated with mild mental disturbances, stress, anxiety, depression, psychosomatic manifestations (somatization) and other affective disorders. Experimental designs (called provocation studies) are better suited to investigate the appearance of these symptoms in relation to RF exposure in individuals, but are able to evaluate only short term exposure. The epidemiological investigations suffer from several methodological problems which usually invalidate its results, mainly due to sampling errors, strong recall bias, and others, which are discussed below. Nevertheless several such low-quality cross-sectional studies have been carried out (Santini *et al*, 2002, 2003; Navarro *et al*, 2003), causing considerable alarm among the population and eliciting responses from public authorities. No case-control or cohort studies on this subject have been published. Cross-sectional studies are inadequate. In addition, the studies were not blinded, opening the opportunity to several bias errors. The survey carried out by Hutter was a little better designed than Santini's and Navarro's .

More recently, a research group in Germany has carried out a population-based, cross-sectional study investigating adverse health effects of mobile phone base stations (Berg-Beckoff *et al.*, 2009). In phase 1 of the study, a national survey of more than 30,000 respondents to a postal questionnaire were investigated as to general health and complaints in relation to proximity (up to 500 m) to base stations. About 18% of respondents were concerned about possible health effects, while an additional 10% attributed their health problems to the base stations. In the second phase of the study, a field measurement of RF fields was performed for about 3,000 respondents. No correlation was found between proximity to base stations and health complaints, but those who had sleep disturbances complained more.

Schüz *et al.* (2009) evaluated nervous system conditions, other than cancer, in the Danish cohort study of more than 420,000 inhabitants, both short- and long-range phone users, by using hospital-based records. Phone users had a 10 to 20% higher risk of migraine and vertigo, and a 30 to 40% decreased risk of epilepsy, dementia and other degenerative disorders of the nervous system, such as Alzheimer, Parkinson, amyotrophic lateral sclerosis, multiple sclerosis, etc. The results are difficult to interpret however, because only a fraction of patients with prodromal symptoms show up in the hospitalization records (simple vertigo and headaches are not usually diseases that require hospitalization), and because several biases could be in operation in regard to the reliability of subscriber records of cell phone use.

## **The Nocebo Effect**

In fact, concern about health effects from EMF seems to result from media reports, eliciting in some persons a number of psychosomatic symptoms and signs which are similar to other anxiety disorders, such as the panic syndrome (Röösli, 2008). This is a kind of nocebo effect (Bonneux, 2007) is opposite of a placebo effect and it is sometimes extremely detrimental to the quality of life of affected persons, sometimes impeding normal work. Röösli (2008) concluded that

*“the health hazards due to the maintenance of environmental scares by false-positive studies have been neglected. The nocebo hypothesis states that expectations of sickness cause sickness in the expectant individual. Maintaining anxiety by fostering doubts in gullible populations about the quality of the environment they live in may cause serious mental illness. Anxiety caused by health scares is an increasing public health problem, which should be addressed in its own right.*

Using a personal RF dosimeter would permit a better measure of RF exposure allowing for correlations with subjective symptoms, in a way very similar to the Holter ECG recorders used in cardiology diagnostics. Recently the first study using this approach was published (Thomas *et al*, 2008). It did not find any statistically significant association between RF exposure and chronic symptoms or between the exposure and acute symptoms.

## **Epidemiological Studies in Latin America**

We have not found any significant epidemiological study on the effects of high-frequency electromagnetic fields on human health. In São Paulo, Brazil, a multi-institutional research group has been established for the Extreme Low Frequencies (ELF).

## **Main Conclusions and Statement of the Latin American Committee about Epidemiological Studies**

We conclude, therefore, that current published RF epidemiological studies published so far have not shown any reproducible adverse health effect, and that numerous methodological flaws, along with only the few outcomes examined so far, do not allow for firm conclusions, particularly as it relates to children. Our conclusions are in line with those from other august international and national bodies of experts, as official statements such as:

**European Commission (2009).** Health Effects of Exposure to EMF. Opinion of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (p. 4).

[http://ec.europa.eu/health/ph\\_risk/committees/04\\_scenihr/scenihr\\_opinions\\_en.htm](http://ec.europa.eu/health/ph_risk/committees/04_scenihr/scenihr_opinions_en.htm)

- *“It is concluded from three independent lines of evidence (epidemiological, animal and in vitro studies) that exposure to RF fields is unlikely to lead to an increase in cancer in humans.”*

**The Netherlands, Health Council (2009)** Annual Update 2008:

- *“The Committee further discusses the relationship between electromagnetic fields and brain activity and that between electromagnetic fields and health symptoms. In both cases the Committee concludes that there is no scientific evidence that exposure to environmental levels of radiofrequency electromagnetic fields causes health problems.”*  
<http://www.gr.nl/index.php>

**ICNIRP (2009):** ICNIRP statement on the “Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)”

- *“..it is the opinion of ICNIRP that the scientific literature published since the 1998 guidelines has provided no evidence of any adverse effects below the basic restrictions and does not necessitate an immediate revision of its guidance on limiting exposure to high frequency electromagnetic fields.”*  
<http://icnirp.org/documents/StatementEMF.pdf>

**French Agency for Environmental and Occupational Health and Safety (2009)**

- *“..the currently available experimental data do not indicate short-term or long-term effects from RF EMF exposure, nor do current epidemiological data point to effects from short-term exposure. Questions remain for long-term effects, the group states; however, no biological mechanism has been established to support the presence of long-term harm.”*  
[http://www.afsset.fr/upload/bibliotheque/964737982279214719846901993881/Rapport\\_RF\\_20\\_151009\\_1.pdf](http://www.afsset.fr/upload/bibliotheque/964737982279214719846901993881/Rapport_RF_20_151009_1.pdf)

And finally, from the most authoritative source, the WHO EMF Project, which has reviewed thousands of published papers on all aspects of EMF fields and health:

**World Health Organization (2007)**

- *“Despite extensive research, to date there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health.”* (Key Point #6) <http://www.who.int/peh-emf/about/WhatisEMF/en/index1.html>
- *“To date, all expert reviews on the health effects of exposure to RF fields have reached the same conclusion: There have been no adverse health consequences established from exposure to RF fields at levels below the*

*international guidelines on exposure limits published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998).” Children and Mobile Phones: Clarification statement (second paragraph)*  
[http://www.who.int/peh-emf/meetings/ottawa\\_june05/en/index4.html](http://www.who.int/peh-emf/meetings/ottawa_june05/en/index4.html)

**Fact Sheet #304: Electromagnetic fields and public health: Base stations and wireless technologies**

<http://www.who.int/mediacentre/factsheets/fs304/en/index.html>

- *“Conclusions: Considering the very low exposure levels and research results collected to date, there is no convincing scientific evidence that the weak RF signals from base stations and wireless networks cause adverse health effects.”*

**Fact Sheet #193: Electromagnetic fields and public health: mobile phones**

<http://www.who.int/mediacentre/factsheets/fs193/en/index.html>

- *“Several large multinational epidemiological studies have been completed or are ongoing, including case-control studies and prospective cohort studies examining a number of health endpoints in adults. To date, results of epidemiological studies provide no consistent evidence of a causal relationship between radiofrequency exposure and any adverse health effect. Yet, these studies have too many limitations to completely rule out an association (...) The increasing use of mobile phones and the lack of data for mobile phone use over time periods longer than 15 years warrant further research of mobile phone use and brain cancer risk. In particular, with the recent popularity of mobile phone use among younger people, and therefore a potentially longer lifetime of exposure, WHO has promoted further research on this group. ”.*

Strong evidence and knowledge about the relationships between personal exposure to EMF, such as those used in RF broadcasting and communication, is still limited, mostly due to the relative lack of extensive and well controlled epidemiological studies, a restricted set of health outcomes that have been studied so far, and significant methodological difficulties posed by such studies. Studies that have indicated a positive association are sparse and are outweighed by studies with negative results. There is no satisfactory consistency among studies. Well conducted meta-analyses in relation to the incidence of head and brain cancer suggest no risk exists (e.g., Lakhola *et al.*, 2006),

This applies to neoplasia-related outcomes, such as brain and head/neck cancers, for adverse reproductive outcomes, as well as for other symptoms and detrimental effects on health that were studied, such as cardiovascular, reproductive and ocular disorders, effects on the nervous system and the so-called Electromagnetic Hypersensitivity Syndrome (EHS). Empirically calculated risk ratios have been in

its majority below unity, or, if positive, with relatively low values, which are difficult to interpret due to the low incidence of these diseases in the samples studied.

This lack of evidence is particularly acute in long term epidemiological studies relating to exposure to base stations. The low levels of RF used by modern digital devices suggest that extremely long latencies for any health manifestation from chronic exposure are to be expected, but no study has so far been completed to address latencies longer than 20 years. Thus, longitudinal, prospective epidemiological studies spanning decades of high quality observation will have to be carried out before any evidence is provided in this respect. Furthermore, there are no epidemiological data about specific groups of users, such as children.

The members of the Committee concluded that, in view of the methodological difficulties and great costs involved in this kind of research, that it is not a priority for the region right now, and that they could be pursued by more resourceful countries, such as is being done within the INTERPHONE project. It is clear that their results could be extended to Latin American countries. The Committee suggests that the health priorities for funding research and care are in a different direction, due to the huge human and economic costs of diseases such as dengue fever, malaria, Chagas disease, tuberculosis, AIDS, malnutrition, developmental disorders, and others, which are still prevalent, but poorly funded and neglected by pharmaceutical companies and the medical establishment of the more developed countries.

### **Methodological Issues of Epidemiological Studies**

Ahlbom *et al.* (2004) called attention to the many difficulties that surround observational epidemiological studies of adverse health outcomes of medium to long term exposure to RF fields. Other authors, such as Auvinen *et al* (2006) have also commented on these points, arguing that considerable improvements must be made in the factors that affect the validity of epidemiological studies on health effects of mobile phone use, such as in study design, risk assessment and exposure assessment.

For the sake of qualifying the reviewed epidemiological studies, we will briefly mention some of the main points here.

**Diversity and contribution of exposure sources:** Valberg *et al* (2007) indicated that the human body absorbs about 5 times more of the RF energy from FM radio and television frequencies (around 100 MHz) than from base station frequencies (around 1–2 GHz). There are few reasons for a study to single out a certainty of exposure to a mobile phone base station, except exposure prevalence, but this does not rule out other sources unless a detailed spectral analysis is carried out prospectively during the time of exposure. Thus, there is little evidence that presently justifies epidemiological studies being restricted to adverse effects of



radio waves from mobile phone base stations while neglecting radio waves at other frequencies produced by different transmitters (Schüz *et al*, 2000). Assuming that groups differ in this exposure only by the proximity to a base station mast, for instance, is unwarranted if the power distributions for other frequency bands are not actually measured in the locations where each patient lived. In addition, since subjecting people to a single frequency band for any significant length of time is impossible, the determination of the contribution of each band to overall risk remains a difficult proposition at best (Neubauer *et al*, 2007). In fact, some authors suggest that “*it is virtually impossible to eliminate exposure to RF from other sources for studying the isolated effects of cell phones on health.*” (Kohli *et al*, 2009); hence a causal nexus cannot be inferred at all for a specific effect of RF due to a single source (e.g.. mobile telephones or base stations).

**Poorly estimated population exposures:** this is the single most criticized methodological weakness of epidemiological studies. With the techniques used by the studies reported so far, particularly for community and occupational exposure, it is exceedingly difficult to determine with any degree of reliability the intensity of the independent variable, which is Specific Absorbed Rate (SAR) for different parts of the body, even when field power densities are measured. Many studies simply used a job description as an indicator of exposure (Ahlbom *et al*. (2004), or were based on distance to the nearest RF source to determine cases and controls, or relied only on theoretical calculations. Large ranges of variation of exposure, either in intensity or time were combined, even in apparently well designed studies. Therefore, the reliability and strength of evidence of these epidemiological investigations is very low and cannot be trusted as firm evidence. Breckenkamp *et al* (2008) carried out a comparison between calculated exposures based on technical data of base stations nearby the subjects and the measured levels using dosimeters and concluded that there is a low correlation (0.28), specificity and sensitivity, that calculated distances from maps introduced a higher uncertainty than actually measured ones, and that only individual dosimetry should be used in epidemiological studies of community exposure, due to the large errors introduced by other proxies of exposure. Auvinen *et al* (2003) suggested that observed “effects” or “no effects” could have been mostly random in several studies. In addition using more objective data than self-reported cell phone use is critically important for experimental as well-designed epidemiological studies. The number and duration of calls made, by retrieving information from the telecom providers is such a measure, but it is difficult to ascertain who was actually using the phone when the call was made, or if the call was made using a earphone or a loudspeaker (hands-free) away from the head. Schüz & Johansen (2007) found a 60% agreement between self-reported use (a measure which suffers from other kinds of recall bias itself) and subscriber records, which represents a sufficiently large margin of error for calculating risk ratios with small number of subjects. Another person might be using the cell phone, too.

**Variation of transmission power:** The power emitted by the cell phone might also

vary substantially from call to call, depending on the distance to the base station at the time of the call. For instance, Lönn *et al* (2004) measured output power of handsets in zones of different degrees of urbanization. In rural areas where base stations are sparse, the output power level used by mobile phones are on average considerably higher than in more densely populated areas. The same applies for community exposure studies: several studies have shown that it is totally unwarranted to assume that any given building has even approximately the same power density in all locations inside it: people moving around a house or apartment will be subjected to continuously and widely fluctuating exposures.

**Inadequacy of proxy measures:** Several methodological investigations have challenged the adequacy of proxy or surrogate measures of exposure, such as time of use, average number of calls, and even duration. Morrissey (2007) for example, found that they correlate rather poorly with RF exposure, because there is a large variability during a single call, between calls, between individuals, different age groups and geographical locations. Inaccuracy of recalling time of use can be as large as 60%. For community exposure studies, determining the power density of RF fields is also essential, because some field surveys have shown a very large variation between different living areas (e.g. Neitzke *et al*, 2007).

**Other forms of mobile communication:** Using a cell phone is a catch-all term which may not reflect the degree of direct exposure to RF. Not only it is impossible to know from company records, or from proxy reporting how often people make or receive hands-free calls (thus decreasing exposure of the head), but how often they are using text messaging, Internet navigation, emailing, listening to music with earphones, or whatever other uses that avoid close contact and are increasing at very fast rates, particularly among the younger generations. Since these other uses vary enormously with time Different among age groups, socio-economic and educational levels and even among individuals, often being influenced by subtle factors such as cost, matching may not be possible and randomization may not be guaranteed in epidemiological studies.

**Multiple and unaccountable sources of exposure:** Other biases that are difficult to control for, particularly for register-based retrospective cohorts, are caused by another major trend in mobile communication; many users have multiple cell phones in their names (or not) or under unnamed corporation accounts, and use them in a haphazard, impossible to track, manner. In many countries, prepaid, unidentified cell phones represent more than 80% of all lines, and a large part of the population of users owns both post-paid and pre-paid phone lines, or may operate with two providers, and even have two-chip cell phones. Record linkage procedures will not work in all these cases, and evaluating exposure using company records will invariably under-estimate exposures.

**Long-term temporal changes in exposure levels:** Poor exposure assessment has also been due to another factor that has been often ignored by researchers in

mobile communication: the rapid change in telecommunication technologies. A person who has used a mobile phone for 10 years or more has probably been the owner of several handset models with very different exposure parameters along this time. Recent data show that two thirds of American users substitute their phones after an average of less than two years use, and that this pace is accelerating, being higher for the younger generation (International Communication Research, 2010). For instance, in Brazil, 70% of users in a national survey said they wanted to buy a new phone in 2010. In 2008 this percentage was 32%. (Gilsogamo, 2010). First-generation (analog) cell phones were in wide use until late nineties and exposing users to RF fields which were 5 to 20 times more intense and employed larger external monopole antennas compared to the latest all-digital models, and, as technology evolves, the trend is towards even lower exposure levels.

In some places analog phones are still used; or this mode is entered automatically when in roaming mode in certain places, but the largely complete global change to GSM, CDMA, TDMA and other digital transmission technologies took place in less than ten years. In the United States, AMPS analog technology was commercially introduced in 1983, iDEN and CDMA, the first digital technologies, in 1994 and 1996, respectively, and second generation (2G) phones in 1997. The GSM standard of digital mobile telephony started in 1992 in several European countries, and within two years it had achieved a global reach, arriving in the USA in 1997. Third and fourth generation mobile technologies were launched worldwide in 2003 and 2009, respectively, and use remarkable lower RF fields and its base stations are also less intense and more closely spaced. Micro- nano- and femto-cells, with very low radiation, are now becoming the norm.

Adding to the complexity of exposure assessment, mobile communication the number of users has increased many times the total time of phone use in the last 20 years. For example, in 1998 the average consumer used his or her phone 122 minutes per month. Two year later, this had almost triplicated to 320 minutes per month, and now may be above 600 minutes per month for some heavy users, such as the new category of “cell phone junkies”.

The conclusion is that the high inaccuracy in measuring the real values of the independent variable with such a wide margin of error make most of the studies difficult to interpret and to reach the truth, Furthermore, the exposure assessment picture is very complex and will become more so in the future. Since rate of adoption and cultural differences are wide, pooling results of several countries by using only self-estimates of time and frequency of use, or even company records, such as in the INTERPHONE studies, may not provide an appropriate estimate of phone use.

**Unmatched control groups:** Conducting epidemiological research that compares

cell phone users to non users will become impossible in the future, because there is an increasing difficulty in finding people who are not users of this ubiquitous communication technology, particularly among the youth. Sabbatini (2010). A recent survey of cell phone users in three cities of different size in Brazil, found that penetration is lower among the very poor and the very old, and it is now more than 100% in the age bracket from 18 to 30 years. In this situation, unavoidable selection biases will introduce large errors, since control groups will be different from cases in many ways, regardless of efforts to match them according to major variables.

**Small numbers of cases:** except for two large cohort studies, most of the epidemiological investigations were made using case-control approaches, which use a smaller number of cases (subjects with the disease). Although the later methods can be sensitive enough to detect significant associations even with relatively small numbers of subjects, there are several possible biases and statistical anomalies when investigators have been unable to gather sufficient case data, such as when the incidence of cancer investigated was very rare (some studies were based in 1 to 3 cases only). Many statistical tests become unreliable with such exceedingly low numbers, and risk ratios slightly above unity might turn out to be significant by pure chance or, more likely, large effects can be missed. Monte Carlo simulations have shown that highly asymmetric contingency tables are very sensitive to small variations in the numbers of patients who presented the disease.

**Small number of spatial samples:** Some of the community exposure studies which have been published were not included in our review due to the fact that they investigated cases of cancer clusters in one single location around the cell phone masts, only, and compared them with controls in a different location, quite away from a mast. Of course, if care is not taken to exclude or to match for other factors, such as ionizing radiation seepage, toxic dump remains, age, inheritance, etc, the results cannot be adequately interpreted (CDC, 2010). In one of the papers recently published by an Austrian researcher, a spatial association of cancer incidence and living proximity of affected subjects to a base station was discovered. Unfortunately, it was announced that the antenna in question was disconnected, and the paper had to be retracted. This exemplified the hazards of careless epidemiological research and statistics with a small number or a single location.

**Selective investigation in response to the appearance of cancer clusters.** Cancer clusters are known to occur, as the result of random spatial and time phenomena. Thus, reacting with retrospective studies prompted by community reaction to these clusters, a very frequent response, is a bad research practice, because a causal-epidemiological nexus is very difficult to arrive by. Not to mention that they often do not have an underlying cause.

**Small number of outcomes:** Most of the published studies have focused on a small number of health outcomes, such as tumors of the head, neck and central nervous system. The selection of these outcomes may leave out other outcomes or endpoints that might be significant (Ahlbom *et al.* (2004) . In fact, rarer tumors may have been left out of the epidemiological studies, although their incidence might be better correlated to power density distribution in the brain. According to the INTERPHONE October 2008 summary by IARC, *“because exposure to RF from phones is localized, if a risk exists it is likely to be greatest for tumors in regions with greatest energy absorption. The spatial distribution of RF energy in the brain was characterised, using results of measurements made on over 100 phones used in different countries. Most (97–99% depending on frequency) appears to be absorbed in the brain hemisphere on the side where the phone is used, mainly in the temporal lobe. The average relative SAR is highest in the temporal lobe and the cerebellum and decreases very rapidly with increasing depth, particularly at higher frequencies. Analyses of risk by location of tumor are therefore essential for the interpretation of results studies of brain tumors in relation to mobile phone use* (Cardis *et al.*, 2008). Therefore studies purporting to better characterize the three-dimensional location of brain tumors in relation to RF exposure should be carried out in the future.

**Multiple hypothesis testing** is common in cancer epidemiological studies related to EMF exposure. However, this increases the chance of obtaining false positive associations and should be avoided. Another bias is created when Investigators often focus on the most significant associations generating further biases. Particularly in small studies, apparently strong associations may be spurious and not supported by subsequent studies. (Pocock *et al.*, 2004).

**Differential effects of confounding variables:** This factor may be, in some measure, a consequence of others, such as small sample size, because the large diversity of potential confounding variables makes reliable stratification, matching or selection, the classical devices for reducing variability, a difficult task (Breslow & Day, 1980). Modern statistical methods such as conditional multiple regression analysis may alleviate the problem, but the fact still remains that investigators are often unable to determine if case and control groups differ from each other in terms of the operation of confounding variables. One example of how these variables can distort results has been the INTERPHONE validation study in Germany (Schlehofer *et al.*, 2007), which discovered that exposure to loud sounds, smoking and hay fever were significant risk factors for acoustic neuromas, but not exposure to ionizing and non-ionizing radiation (except for people who were irradiated for medical purposes on head and neck, with an OR of 6.05 (Blettner *et al.*, 2007)). A case control study by Edwards (2006) confirmed the higher risk (OR of 2.12) of acoustic neuroma for people hearing loud music for 13 years or more. Studies such as those by the Hardell group, which did not matched these and other variables in the control and case groups might thus reach false conclusions.

**Latency bias:** Besides the latency between start of exposure and diagnosis of disease, which is inherent to many diseases, including cancer, another methodological difficulty in epidemiological studies is the latency between start and detection of disease (by mean of its manifestation and subsequent diagnosis, which may also introduce a delay). This can be very large in cancer due to exposure to environmental agents (e.g., Gofman, 1990). In some cancers it may actually exceed the life span of subjects, depending on their age at the start of the study. Due to difficulties in determining the true latency period, usually the two latencies are combined into one. This latency bias, therefore, as a failure to adjust for the latent period in observational studies (Gail & Bénichou, 2001), may introduce differential systematic errors into the study and affect the results in several ways. For example, in cohort studies, the study may finish before cancer is detected in the exposed group, thus decreasing the magnitude of effect (relative risk), particularly for lower exposure subgroups. Also in cohort studies, the tumor in the exposed group may have started to grow well before or just after exposure took place, increasing the magnitude of effect, particularly for very long latencies. Case-control studies are less sensitive to latency bias because of randomization and matching, but differential effects of latency are expected to be present. A number of biases can be caused in case-control studies when data from cases and controls are collected after too short a period of exposure to EMF (cell phone usage, for instance) and pooled with cases and controls after exposure to longer periods.

A multistage model of cancer causation, such as that proposed by Armitage & Doll (1961), should be used in the design of cancer epidemiological studies. The investigators should lag the observations in relation to exposure, taking into account the known or calculated average time latency for the particular kind of cancer (Gail & Bénichou, 2001), a value that is often unknown or has not been observed.

Epidemiological studies over extended periods of time are difficult to carry out and most of the cell phone users in the world have less than 5 years of usage, so this is not easy to solve. Furthermore, the relevant lag periods for health effects of RF are presently unknown, but should be very long, and hence missed by current studies.

**Selection bias** is very common in retrospective case-control studies and may operate by either by conscious or unconscious inclusion or participation of subjects. Another selection bias is created by leaving out the data of people who refused to participate or who dropped out of the study, because they may have done this due to some reason that will introduce a systematic error in the sampling. Potential for selection bias has been evaluated in an INTERPHONE study (Vrijheid *et al*, 2009b) by using information from non-response questionnaires (NRQ) completed by a sub-set of non-participants. Regular mobile phone use was reported less frequently by controls (56%) and cases (50%) in the non-participants. than by those who participated (controls, 69%; cases, 66%). The

results suggested that *“refusal to participate is related to less prevalent use of mobile phones, and that this could result in a downward bias around 10% in odds ratios for regular mobile phone use”*. In addition, a low response rate, particularly among controls, introduces bias if participation is related to mobile phone use (Cardis *et al.* 2007). This is likely to be a partial explanation for why many relative risk estimates in the Interphone study are actually below 1.0 (SCENIHR, 2009). Other examples of selection bias are leaving out corporate users of cell phones, excluding people with certain kinds of ailments, and others.

**Recall bias:** For questionnaire-based retrospective studies, this can be an important and common source of bias, since self-reported use of cell phones is not a reliable measure, particularly for long term use. Timotijevic *et al.* (2008) have examined the factors influencing self-report of mobile phone use, such as response prompting, time reference and others. A correlation study by Parslow *et al.* (2003) indicated that over-reporting is more common than under-reporting (70% more for the number of calls and 180% more for the duration of calls). Most validation studies report overestimate of duration by a factor of 1.4 and underestimation of number of calls by a factor of 0.81 (Vrijheid *et al.* 2008, 2009).

The INTERPHONE study group went to great lengths to investigate, for the first time, how prevalent and serious is recall bias (Vrijheid *et al.*, 2006a, Samkange-Zeeb *et al.*, 2004). As suspected, they concluded that for 6 months only, *“volunteer subjects recalled their recent phone use with moderate systematic error and substantial random error. This large random error can be expected to reduce the power of the Interphone study to detect an increase in risk of brain, acoustic nerve, and parotid gland tumours with increasing mobile phone use, if one exists.”* and that although reported number of calls correlated rather well with the golden standard provided by telecom records of calls, within a 3 months period, this was not so with reported duration of calls. These results were extended in a publication by the same group in 2009, where it was found that *“for cases, but not controls, ratios increased with increasing time before the interview; however, these trends were based on few subjects with long-term data. Ratios increased by level of use. Random recall errors were large (...) apparent overestimation by cases in more distant time periods could cause positive bias in estimates of disease risk associated with mobile phone use.”*

In another validation study (Berg *et al.*, 2005), emitted power by mobile phones was correlated with user's reports of intensity of usage (number and duration of calls made). The correlation was significant, but low (0.5 and 0.48 for number and duration respectively). Recalls for longer periods were not investigated, but surely they would be even less correlated. The impact of selection and recall biases on epidemiological studies of RF and health was also studied quantitatively by means of simulations by Vrijheid *et al.* (2006b, 2009), who arrived at the same conclusions. Recall bias for estimates of cell phone usage using self-report in a case/control study versus telephone subscriber data submitted by companies in a retrospective

cohort study permitted Schütz and Johansen (2008) to compare their reliabilities. The result was a low agreement (0.3), very low sensitivity (30%) and good specificity (94%). Odds ratios calculated for both data sets resulted in a difference of up to 0.2 points.

**Differential recall bias:** people who have a tumor or health ailment, for example, which they believe or are led to believe by the investigators themselves or mass media, tend to recall with bias. Recall bias might be particularly strong for the side of head (laterality) of phone use, since subjects have a tendency to point to the side of the tumor, when asked about what side they used the handset more.

**Reporting bias:** two problems may occur in retrospective studies with cases going back many years in the past, especially with fatal diseases such as neoplasias. Firstly, a considerable amount of data about exposure in people who are deceased is based on second-hand reporting by close living relatives. This is called reporting by proxy. Surely this reduces greatly the accuracy of data and should be avoided, although this is impossible in some cases. It is a dilemma, because maintaining proxy interviewing introduces biases (since proxy reporting is more common in cases than in controls, due to mortality or severity of disease), while its elimination would introduce another kind of bias (better data quality in controls, exclusion of patients who are unavailable at the time of retrospective data collection,). Secondly (and more serious because it is difficult to detect and correct), brain, memory and cognition might be affected by disease, and introduce inaccuracies or false reporting by affected patients (Ahlbom *et al.* 2004).

**Non-blinded data collection and reporting biases:** In a study conducted in Germany, residents of a neighborhood were actually *communicated* to by the investigators that they were being recruited for evaluating bad health caused by an antenna situated near their homes, a fact that many ignored until then! Methodological, elementary errors such as these are actually very common, as blinding or double-blinding is not always entirely impossible. According to Valberg *et al* (2007), most of these epidemiological studies would be rejected for publication if they should follow the standards of quality demanded of clinical research.

In conclusion, there are many methodological difficulties which seem to affect epidemiological studies in this area, particularly of case/control designs. The most common problems to be considered here are:

- Poor estimation of exposure
- Differential action of recall bias
- Selection bias

The most difficult and most important considerations in planning the protocol of a case-control study are ascertainment of cases, selection of controls and the quality



of the exposure measurement (Wacholder, 1995). |

What can be done to improve the quality and resolution of epidemiological studies?

First of all, we need better methods as well as better reporting. Groups of concerned epidemiological investigators have dedicated their time to draw up better practice guidelines (e.g., Stroup et al., 2000; Blettner et al., 2001; Pocock et al., 2004). Systematic, transparency are now the aim of most reviews.

According to Auvinen et al (2006). *“the major opportunity to improve the quality of evidence is through prospective studies. The major limitation of epidemiological studies addressing the health effects of mobile phone use is related to exposure assessment. These limitations are inherent in case-control studies. Quality of evidence can be improved by conducting prospective cohort studies.”*

SCENIHR, the Scientific Committee on Emerging and Newly Identified Health Risks, a consulting body set up by the European Community has identified as the best way to fill the present research gaps in human epidemiological studies as:

*A long-term prospective cohort study is the next logical step in the hierarchy of evidence following inconclusive results of previous case-control studies. A cohort study overcomes shortcomings of case-control studies, such as recall bias and selection bias, as well as uncertainty due to self-reported retrospective exposure assessment. Such a study would also significantly expand the narrow scope of outcome in previous studies that were mainly limited to intracranial tumours. Additional outcomes include e.g. neurological diseases, cerebrovascular diseases, and other types of cancer. Prospective studies can consider not only the effects of current exposure but also exposure history incurred prior to start of follow-up as well as exposure from new technologies, developed during the course of the study. (SCENIHR, July 2009).*

In this respect, a number of prospective cohort studies with long duration (20 to 30 years) are beginning, such as COSMOS (International Cohort Study of Mobile Phone Use and Health), carried out by the Department of Epidemiology and Public Health at Imperial College London, UK and a number of other countries (Sweden, Denmark etc. The costs of these kinds of study are large, and its long term funding is usually not entirely assured, but they are certainly necessary to provide final assurance to science and the public of the long-term safety of cell phones.

In relation to children, SCENIHR (2009) also proposed in its report on current research gaps on EMF and health:

*Children are exposed to RF fields from mobile telecommunications equipment earlier and thus have longer life-time exposure than present day adults. They may also be more susceptible than adults due to anatomical*

*and morphological differences and as they are exposed during development. Available and ongoing research is mainly limited to case/control studies on childhood brain tumours. Hardly any research has been done on the effects of exposure to EMF on the development of the central nervous system, on cognitive functions in children, and on behaviour. More data are also needed on children younger than those who have been studied to date. Animal experiments on early brain and behaviour development can answer some of the questions related to effects on children.*

Elimination of exposure assessment errors will only be achieved by using personal dosimeters that are capable of recording the whole spectrum, and continuous, maintenance-free and reliable recording. This is the single most important technological innovation to change the current scenario, but its deployment with large number of participants is very costly (consider, for example, the comparison with radiodosimetry using photographic film badges for determining ionizing radiation exposure, which tags millions of occupational users every year around the globe, is very cheap, is easily quantifiable and reasonably reliable). In a meeting held in January 2008, titled “*Dosimetry Meets Epidemiology*”, it was confirmed that “*monitoring is a sine qua non to assess the public health situation and a parallel should be drawn in RF research, where the question should focus not only on mechanisms but indeed on public health. In addition, knowledge about the extent of public exposure will be mandatory if consistent evidence of adverse non-thermal effects of ELF and RF exposures may be established eventually*”.

The first studies are beginning to appear along these lines. In Germany, with users carrying a personal dosimeter for 24 hours and measurements every second, Kühnlein *et al.* (2008) determined that the overall exposure to RF fields of all assessed individuals was markedly below the ICNIRP reference level.

Another technical improvement that might render better exposure assessment on a continuous basis for epidemiological investigations on cell phone users are special handsets which were modified (SMP: Software Modified Phone) to record for every call the output power. Although it still is not a true measurement of SAR, the correlation could be good enough. An investigation using SMPs, comprising more than 60,000 calls, was carried out by Vrijheid *et al.* (2009a). They concluded that the average power used was 50% of the maximum, that output power varied by a factor of up to 2 to 3 between study centres and network operators, that in about 39% of the time, conversations were held at maximum power, and that this increased much when they happened in rural locations, due to a larger distance from the base station. They concluded that there appears to be little value in gathering information on circumstances of phone use

A good example of what resolute contributions such kind of epidemiological study can make is the longitudinal, prospective investigation of exposure to tobacco and health outcomes in 34,439 physicians of the UK National Health Service along five

decades (Doll *et al*, 2004). The degree of exposure was recorded with reasonable accuracy, without large reporting or recall biases, it was based on a known reliable relationship between exposure (smoke inhaling) and blood concentration of chemicals, risk assessment and recording of health outcomes with long latencies was close to ideal (98.9% of causes of death were identified), large numbers of participants and continuing adherence to the study (94%), and several other such features. Thus, a cause-effect relationship could be firmly established in a field fraught with uncertainties until then, and which changed forever public attitudes toward tobacco (by showing for example, that smokers had a relative risk of 3 dying earlier compared to non-smokers)

If we refer to the Bradford Hill's (1965) “nine points” for assigning a good chance of cause-effect to epidemiological studies, we can easily ascertain that the body of evidence so far does not satisfy them entirely, in regard to RF field exposure and possible effects on human health:

1. **Strength of association** measurements, such as RRs, ORs and SIRs are usually small, close to unity, so they do not point out a significant strength of association.
2. **Intra- and inter-studies consistency:** scientific controversy has been fueled by a notable inconsistency among studies for several health outcomes, reproducibility of positive results is low, and comparison is difficult due to large differences in study quality and methodology
3. **Specificity of the association:** although specific associations have been sought by epidemiological studies, they are still controversial since many studies contradict each other, and the independent variable (exposure) has been measured with a large margin of inaccuracy.
4. **Temporality:** most of the studies examined exposure before disease; but since the start of disease is not the same as first detection of disease, particularly in cancers with very long development times, the temporality of cause before disease is somewhat blurred.
5. **Dose-response relationship:** very few studies examined this parameter, in part due to methodological difficulties. In most community-exposure studies, such a relationship, assessed indirectly by distance from the base tower, was either not proved or unreliable data could explain better the slight variations observed. In studies of cell phone usage, the number and duration of calls were commonly used as a dosing parameter, but recall bias could have influenced its accuracy.
6. The very low levels of RF fields emitted by base stations do not support a **biological, physical and chemical plausibility**. Cell phones on the other

hand produce relatively high exposures, so this becomes more plausible, but the majority of published research have not provided a firm basis for such effects even at these higher levels of exposure.

7. **Biological coherence:** Contrariwise to ionizing radiation, RF rarely has biological and molecular counterparts that would explain damage to the cell machinery, and so disease mechanisms at very low levels are unlikely. It is doubtful whether non-thermal effects are a significant phenomenon for promoting disease.
8. There is no **consistent support for positive epidemiological studies from experiments**, either in animals or humans
9. An **analogy to other similar, discovered cause-effect relationships**, such as with ionizing radiation, has not been ascertained so far, and it is several orders of magnitude lower, if it eventually is proved to exist (one main reason being that RF has no cumulative biological effects). One possible analogy might be with extremely low frequency fields, such as are emitted by power lines, and which have been concluded by IARC as a possible carcinogenic agent. Entirely different biophysical mechanisms exist for ELF and RF.

## Indirect Effects: Interference With Medical Devices

Electromagnetic compatibility (EMC), *i.e.*, the use of RF spectrum separation and adoption of techniques and measures to avoid interference of an RF-emitting device function, that is potentially susceptible to RF, has been a major preoccupation of the telecommunication industry. This is called electromagnetic interference (EMI).

The possibility that medical devices could be adversely affected by RF emitted by the antennas of base stations and portable wireless devices in their proximity has prompted, in the 1990s, many engineering and clinical tests around the world.

Although initially deemed a rare event (very few cases were actually observed or reported), the potential impact on the well-being and lives of patients hooked up to these medical devices justified a cautious approach. The low frequency of such EMI events attests to its rare occurrence since only 5 reports in the MAUDE FDA database of adverse effects of EMI on medical devices have been reported since 1993 (<http://www.fda.gov/cdrh/maude.html>), none of which could be traced to the proximity of a telecommunications device. The most common EMI being caused by exposure to an electrocautery device. Indeed, an early experimental study with more powerful handheld phones (Irnich *et al.*, 1996) indicated that only 1 in 100,000 pacemaker patients were expected to suffer a clinically relevant

interference event in their lifetimes.

The interest in EMI was justified because this might be one of the few documented, albeit indirect detrimental effects of low level RF fields on the health of exposed people. This is especially the case for patients using implanted cardiac pacemakers or defibrillators, or hooked up to life support devices, such as mechanical ventilators, which are vital for their continued survival. Since its invention, these devices were known to be susceptible to external EMF, such as those used for metal detection in airports and for shop security against theft; and a number of warnings and protection measures were implemented since then (see ICNIRP, 2000, for a review).

Initial studies soon documented that these adverse effects of EMI were indeed possible, at least for the handsets in close proximity to medical devices and that there was almost no in-built protection from RF interference in current (i.e., 1980's generation) medical devices. The ongoing explosive growth in the use of mobile phones both inside and outside healthcare facilities was also a major motivation of such studies, because it could increase the incidence of heretofore-rare events of EMI. Due to the extremely low level of signals from base stations, however, most of experimental studies focused on EMI for handsets.

- Medical devices that might, in theory, be susceptible to RF emitted by communication equipment in its proximity, are legion. For example:
- Implantable: cardiac pacemakers, defibrillators, chronic neural and gastric stimulator packs, artificial cochleas, etc.
- Wearable: hearing aids, Holter and MAPA monitoring devices, TENS (transdermal electronic neural stimulator), etc.
- External: bedside signal monitoring equipment, anesthesia machines, renal dialysis and heart-lung pump machines, infusion pumps, external cardioverters and pacemakers, mechanical ventilators, signal recording equipment (EKG, EEG, etc.), imaging terminals, computers with telecommunication capabilities, telemetry equipment and several others.

Two kinds of research studies been performed: *in vivo*, with implanted or wearable devices used by patients, and *in vitro*, with detached or external devices. In both situations, mild to extremely deleterious interference events were observed during tests under laboratory and clinical conditions, such as the sudden malfunction of pacemakers, arbitrary and unexpected change of parameters and resetting of devices, triggering of false alarms, sensor artifacts, alteration of readings and tracings; many of which could cause serious harm or even death in case a real patient would be plugged to any of these devices.

But what was the prevalence of such events?

In 1995, the United Kingdom's Medicines and Healthcare Products Regulatory Agency (MHRA) conducted a large survey of provocation studies in 18 locations, including hospitals, based on data for 178 different models of medical devices, subjected to interference attempts by a wide variety of radio handsets. The startling result was that in 23% of tests medical devices suffered some kind of EMI from handsets, and that overall 43% of these interference incidents would have had a direct impact on patient care, and were rated as serious. Emergency and security communication two-way radios were the most deleterious, reaching 41% and 35%, respectively of EMI events at less than 1 m distance, with 49% of the events considered serious.

Thus, real concern increased in the mid-1990s, and reports started to leak to the mass communication media. This influenced heavily the perception of the public towards cell phones, when, in fact, they were much less effective in this respect, since in the MHRA study, only 4% of handsets caused interference at less than 1 m distance, with a negligible 0,1% being regarded as serious. At the time, most of the handsets tested were analogical, and thus had a higher power output than current CDMA, TDMA and GSM digital models.

Thus, it was discovered, not surprisingly, that distance between devices was the major factor for EMI, since, due to the law of inverse squares, mobile phones typically produce RF of up to 42 V/m at 0.1 m, dropping to below 7 V/m at 1 m. The US FDA established in 1979 a voluntary standard of a maximum 7 V/m for medical devices to become immune to EMI from wireless devices (FDA, 1979), but several studies (e.g., Clifford *et al*, 1994) had determined that analogue cell phones and two-way radios easily exceeded this limit at 1 m distance or so.

The first extensive experimental studies of EMI on pacemakers came out in 1995 and 1996. The first large scale *in vivo* study was published by Barbaro *et al.* (1995), in which the authors evaluated 42 different models of cardiac pacemakers implanted in 101 patients. The results were worrisome, since among pacemaker patients with a GSM cell phones activated in contact over the pacemaker pocket, 26% suffered an EMI event, a very large proportion. Clinically relevant anomalies were mostly ventricular triggering (20%), pulse inhibition (10%) and asynchronous pacing (8%), but pacemaker malfunction and physiopathological events were entirely temporary, reverting to normal after the cell phone was removed or disconnected. Fortunately, the authors determined that the maximum distance to achieve EMI was 10 cm only.

Similar results were confirmed by the large multicentric, prospective study by Hayes *et al.* (1997), who tested 980 patients implanted with 6 different models of pacemakers and four different types of cell phones. They observed an overall incidence per test of 20%, an incidence of symptoms of 7.2% and an incidence of

clinically significant interference of 6.6%. These were not present when the telephone was placed in the normal position over the ear. They were composed by 14.2% of atrial interferences, 7.3% of asynchronous pacings and 6.3% of ventricular inhibitions. The authors were the first to classify EMI interference clinical consequences into three levels: the level I included consequences that included symptoms, such as vertigo, dyspnea or cardiac syncope. Level II included interference of limited clinical importance, such as heart palpitation. Level III grouped all other consequences with improbable clinical importance. Of these, 1.7% were Class I, 4.9% Class II and 13.4% Class III interference. Therefore, interference that was definitely clinically significant occurred in only 1.7% of tests, and only when the telephone was held over the pacemaker.

In 1996, Irnich *et al.* published a large and influential *in vitro* experimental study where 231 different models of cardiac pacemakers of 20 manufacturers were tested with respect to interference by three signals: a 900 MHz analogue cell phone signal (C-Net), a 900 MHz digital pulsed signal (D-Net) and a 1,800 MHz digital pulsed signal (E-Net). The result was that 30.7% of the pacemaker models tested were sensitive to interference from the analogue signal, 34.2% from the digital 900 MHz signal and 0% from the 1,800 MHz signal. This sounded serious, but an essential discovery was that the maximum distance that caused EMI effects was less than 20 cm. This led to the recommendation that pacemaker-implanted patients should use the cell phone to the contralateral side of the head in relation to the side of the implant, since this assures the required safe distance.

Between 1995 and 1997, seven other well-designed experiments were published, all of them reporting between 18% and 37% overall EMI, both in relation to devices/patients or to tests (see Censi *et al.*, 2007 for a comparative review on cardiac pacemakers).

As a consequence, a number of national and international regulatory agencies began to examine closely the issue of EMI of wireless communication systems upon medical devices, and, recognizing the potential risks of adverse effects, started to publish around 1997 several technical reports, guidelines and recommendations to professionals and the general public on the subject. These early reports set an alarming tone and made a large number of restrictive and precautionary recommendations, which later proved to be unnecessary, as we will see, mostly due to the evolution of technologies and adoption of filtering and protection measures by medical equipment manufacturers.

For example, the MHRA published two device bulletins, one in 1997, and another in 1999. They were later supplemented by a document on new mobile communications technologies, such as Bluetooth, WiFi, etc., in 2004. Other authorities, such as the International Standards Organization (ISO, 2005), the American National Standards Institute (ANSI), the Association for the Advancement of Medical Instrumentation (AAMI) and the United States' Food and

Drug Administration (FDA) also issued a number of studies and recommendations. Following the initial wave of alarm, AAMI published a detailed technical report to its members (AAMI, 1997). In the same year, ANSI published its report on recommended practices for estimating EMI immunity of medical devices (ANSI, 1997).

Among these early recommendations, officials responsible for safety in healthcare facilities were urged to implement a serious and costly effort to curb the apparently mounting menace of RF “on the loose” in their institutions. For example, AAMI recommend that RF transmitters in use in the facility should have the lowest possible output power rating that could be used to accomplish the intended purpose, that electrically-powered medical devices should meet EMC standards, that electronic medical devices used in intense electromagnetic environments, such as near ambulance radios or in electrosurgery, should have EMC specifications suitable for these environments; that a system be implemented for tracking problem service calls by the location, date, and time of the reported malfunction, and that EMI problems should be reported to the manufacturer and to regulatory authorities.

Furthermore, AAMI recommended that “clinical and biomedical engineers should be the focal point for EMC, EMI mitigation, and EMC/EMI education/training within the health care organization (as well as the) purchase, installation, service, and management of all equipment (medical, communications, building systems, and information technology) used in the facility.” AAMI emphasized that the Safety Committee of healthcare organizations should take permanent responsibility for EMC/EMI, and coordinate educational and information to the public, and have a say on site selection, design, construction and layout of facilities. AAMI felt, at the time, that there should be an intention and effort to “designate areas of the facility where the use of common hand-held RF transmitters (e.g., cellular and PCS telephones, two-way radios) by staff, visitors, and/or patients was to be managed or restricted”. With this next to impossible task (how do you detect an active cell phone inside the pockets of visitors?), the recommendation actually resulted in the total ban of cell phones and base stations in the entire building by many health care facilities, and the passing of local legislation to enforce it. The air travel industry went through the same dilemmas, when suspicion was aroused that cell phones could interfere with electronic flight equipment, and the ban is still enforced today.

Particularly costly and difficult to implement was AAMI’s recommendation that “*ad hoc* radiated RF immunity testing should be considered when EMI was suspected, when RF transmitters are likely to operate in proximity to critical care medical devices, in pre-purchase evaluation of new types of RF transmitters to determine their effect on existing medical devices, in pre-purchase evaluation of new electronic medical devices, and when checking for age-related changes in medical device RF immunity”.



It was predicted that all these harsh measures would cause a high organizational and financial impact on healthcare organizations should they be moved to comply rigorously with such recommendations. The fact that the great majority of extant, potentially vulnerable medical equipment in most hospitals were relatively old, and designed without consideration to protection against RF interference coming from novel mobile communication devices, made a rapid response to AAMI's recommendations a virtually impossible affair.

As new engineering tests were carried out, and as the industry moved fast to incorporate filters and other RF protection circuits into medical devices, the situation changed considerably in the succeeding years. The initial alarm was relieved by the discovery that adverse events would occur only when RF emitting devices would be put in very close proximity to medical devices (less than 20 to 30 cm), and that beyond distances of 100 cm, no effects could be observed, at least with devices of medium wattage and greater prevalence, such as mobile phones. Newer models of implantable devices were rendered immune to RF interference within the RF spectrum, and the technical evolution of portable digital communication devices, which emit at very low output power, have now practically eliminated or reduced considerably the risk of severe interference. In fact, micro- and nanocells, and the widely prevalent use of mobile phones and wireless communication networks within hospitals around the world, has become exceedingly common, without any reported incidents.

According to the most recent FDA/CDRH report on EMC (FDA, 2008), a different stance has been adopted, which leans more towards social engineering, education and prevention, than towards prohibition and banning. The main CDR/CDRH recommendation for healthcare facilities are to inform and educate all professionals involved, as well as patients and visitors; to assess the RF environment of the facility, particularly with a higher concentration of vulnerable medical equipment, such as in emergency rooms, intensive care units, surgical theatres, etc., to manage such environment with the goal of reducing interference risks to a reasonable extent, including a policy to select, acquire and substitute older equipment; and to establish and implement written policies and procedures, and the systematic reporting of adverse effects related to RF interference with medical devices, implanted or not.

Many authorities, such as FDA, MHRA, ICNIRP, WHO and others have recognized recently that a total ban on mobile communication devices inside hospitals, even in critical care areas, would be very difficult to enforce and that it is not reasonable, or even necessary. One of the reasons is that it is increasingly difficult to pinpoint accurately which of the user's equipment has wireless communication capabilities (for example, PDAs with cell phone features, laptops with embedded WiFi interfaces, etc.). Another is the enormous growth of such devices in possession of visitors, patients and professionals working in the healthcare institutions and their reluctance to cease operation within its confines. Still another is that healthcare

professionals consider that pagers and cell phones are very important for timely communication and have a significant impact on quality of care in all areas of a hospital, so that their use should not be restricted.

Soto *et al.* (2006) did a survey in 2003 members of the American Society of Anesthesiologists and reported that cellular telephone use by anesthesiologists was associated with a reduction in the risk of medical error or injury resulting from communication delay (relative risk = 0.78; 95% confidence interval, 0.6234-0.9649). A review by Ruskin *et al.* (2006) on the use of wireless technologies by anesthesiologists has ascertained that the very low risk of EMI events in operating rooms is offset by a significant reduction in medical errors that results from more efficient communication.

Thus, in a 2005 technical report by ISO on the use of mobile wireless communication in healthcare facilities (ISO, 2005), it was recognized that

*“misinformation regarding mobile wireless systems, electromagnetic interference and management procedures has led to a broad range of inconsistent policies among healthcare organizations (and that) a balanced approach is necessary to ensure that all the benefits of mobile wireless technology can be made available to them. Overly restrictive policies may act as obstacles to beneficial technology and may not address the growing need for personal communication of patients, visitors and the workforce. At the other extreme, unmanaged use of mobile communications can place patients at risk (...). It may not be feasible for healthcare organizations to manage every mobile wireless handset that is randomly brought into their facility without certain restrictive limits.”*

More realistically, the 2004 MHRA recommendations classified risks of interference according to more recent knowledge, into three levels: high, medium and low. Analogue emergency service radios and private business radios (two way communication radios, such as those used by porters, maintenance and security staff), were classified as being at a high risk of interference with many medical devices, and MHRA recommended its use in hospitals only outside clinical areas, only in an emergency and never for routine communication. An experimental analysis of walkie-talkie radios by Stroud *et al* (2006) determined that these devices usually emit at a higher power output, typically 4 W or more, and that they interfere much more with medical equipment than cell phones, to the point that hardware component failure may occur. Thus MHRA recommended that these walkie-talkie radios should be changed to lower risk technologies, with a power below 2 W, such as mobile phones. These, together with TETRA (Terrestrial Trunked Radio Systems), laptop computers, palmtops and gaming devices equipped with higher power wireless communication devices, such as GPRS, 3G and HYPERLAN, were classified as having a medium risk of interference. MHRA recommended to use them only in designated areas and to switch them off near

critical care or life support equipment. Finally, cordless phones (DECT) and low power wireless networks, such as RLAN and Bluetooth have been classified as low risk of interference with medical devices, and require no action in relation to their use in the health care environment. These recommendations were supported by several studies, such as one carried out with several kinds of ventilators used in intensive care (Jones & Conway, 2005).

Many countries and regional governments now have adhered by revising their guidelines to this less restricted view of cell phones in healthcare facilities. As an example, we cite a guideline circular by the New South Wales government (NSW Health Dept, 2005) in Australia, whereby it is recommended that a general 2 m distance be observed at all times between RF emitting mobile equipment and sensitive medical equipment in certain areas, such as ICUs, ERs, OTs, etc., and a 0.5 m distance in wards and general areas, and that two-way emergency and security radios should not be turned off, but used only in required situations.

Another interesting recommendation by the ISO technical report (ISO, 2005) is to *“issue particular mobile wireless equipment to doctors and staff for healthcare-specific communication and health information access. This would allow the full benefit of wireless technology operating compatibly throughout the healthcare facility, even in sensitive areas in proximity of life-critical medical devices”*. This recommendation has probably been superseded by the new digital cell phones, which emit very low power at frequencies to which most medical devices are considered now immune, and which have largely substituted alphanumeric pagers used by medical personnel. Use of VoIP (voice over Internet Protocol) handset devices using very low power nanocell WiFi data communication networks are now being deployed, which will probably put the issue to rest.

Indeed, the evolution of wireless communication technology on the one hand, and of radiation protection of medical devices on the other, has greatly changed the situation. For example, in contrast to the HRMA and Irnich studies in the 1990s, Lawrentschuck & Bolton could demonstrate almost a decade later (2004) that the EMI risks were significantly reduced. They carried out a systematic review of 7 published research studies between 1996 and 2004 on EMI of cell phones on 28 different types of external medical devices. The authors found that clinically relevant EMI potentially endangering patients occurred in 45 of 479 (9.3 %) devices tested at 900 MHz and 14 of 457 (3 %) devices tested at 1800 MHz, mostly occurring when mobile phones were used within 1 m of medical equipment. Overall, the prevalence was low, but the authors observed that all studies still recommend some type of restriction of mobile phone use in hospitals, with use greater than 1 m from equipment and restrictions in clinical areas being the most common.

The trend continued, as demonstrated by an experimental study carried out by van Lieshout *et al* (2007), on a total of 61 medical devices in 17 categories and 27

different manufacturers. They studied novel digital transmission technologies, such as GPRS-1 and UMTS signals used by third generation (3G) cell phones. The distance to achieve an interference effect was reduced to 3 cm (i.e., with the handset practically in close contact with the medical device), with only one hazardous incident occurring beyond 100 cm.

More recent experiments with modern implantable stimulators, for instance, have demonstrated no effects of GSM cell phone transmissions nearby (Kainz, 2003, Tandogan, 2005; Calcagnini, 2006). Mechanical invasive and non-invasive ventilators have not suffered any malfunction from GSM cell phones, and a few effects with two-way communication radios at less than 1 m distance (Dang *et al* 2007). In Sweden, Wallin *et al* (2005) tested the interference of GPRS, UMTS, WCDMA and IEEE 802.11b (WLAN) signals on 76 medical devices, including during 11 surgical operations with a total duration of 100 h. They concluded that UMTS and WLAN signals caused little interference and that “devices using these technologies can be used safely in critical care areas and during operations, but direct contact between medical devices and wireless communication devices ought to be avoided. GPRS can be used safely at a distance of 1 m. Terminals/cellular phones using these technologies should be allowed without restriction in public areas because the risk of interference is minimal.”. The particularly large *in vivo* study by Tandogan *et al* (2005), which tested 679 implanted pacemakers, arrived at an overall 5.5% figure of incidence of EMI per patient.

Although Tri *et al* (2005) demonstrated that current cell phone technologies in use, such as GSM, CDMA, TDMA and IDEN are still able to cause malfunctions on external medical equipment over short distances, clinically relevant EMI occurred only 1.2% of the tests made. Only four years before that, the same authors (Tri *et al*, 2001) had detected a 7.4% incidence of clinically relevant EMI events in cardiopulmonary monitors. Finally, in 2007, the same authors again, working at the Mayo Clinic (Tri *et al*, 2007) determined, in more than 300 tests involving a total of 192 medical devices, that the incidence of clinically important interference was 0% (95% confidence interval, 0%-4.8%). Thus, they concluded that “although cellular telephone use in general has been prohibited in hospitals because of concerns that these telephones would interfere with medical devices, this study revealed that when cellular telephones are used in a normal way no noticeable interference or interactions occurred with the medical devices.”

A review by Francis & Niehaus (2006) of 14 published research papers on the effect of cell phones on implantable cardiac rhythm devices, arrived at the conclusion that “no dangerous malfunction was found in any of the analyzed studies, but most of the studies noted interference with device function when the phone was operated very close to the device. Interference was minimally in those devices with built in feed-through filters for eliminating electromagnetic interference. Device programming and interrogation were the most susceptible phases of operation.”

Other reviews of the literature by Boyle (2006) and by Lapinsky and Easty (2006) concluded that *“wireless technologies are deemed suitable for use throughout hospital areas including intensive care units and operating rooms, given that recommended separation distances from medical equipment are observed.”* And that *“medical device malfunction is extremely rare if the distance from the transmitting device is greater than 1 m”*.

Censi *et al* (2007) observed that older pacemaker models seemed to be more sensitive to EMI from cell phones, due to a lack of feedthrough filters. Feedthrough filters are broadband filters using ceramic capacitors that reduce significantly the influence of radio frequency sources on pacemakers. They discovered that modulated RF signals are demodulated by the pacemaker's internal non-linear circuit elements, if no feedthrough filtering assembly is incorporated to its circuitry. The problem is that digital cellular phones use extremely low-frequency modulation (as low as 2 Hz) can be mistaken for normal heartbeat. Therefore, healthcare institutions are urged to advise patients who still have implanted pacemakers dating before the year 2000, particularly in countries where analogue cell phones are still in use, that they incur unreasonable risks of EMI and adverse events. The use of two-way long range HT communication radios, used in entertainment, security and staff emergency communications is also dangerous, even for more recent pacemakers.

Finally, this review concludes with a note regarding the almost continuous state of technical evolution of both medical devices and wireless communication devices. Technologies that use very high frequency EMF, in the THz range, security imaging devices using RF fields, electrical power transmitted via wireless connections, and others, may pose risks for EMI on medical devices, both implanted and external, not yet foreseen. Thus, Gladman & Lapinsky (2007) conclude that *“increased use of cellular phones and ever changing communication technologies require ongoing vigilance by healthcare device manufacturers, hospitals and device users, to prevent potentially hazardous events due to EMI”*. Restrictive policies are also better facilitated when easily accessible areas are designated where mobile phone use is encouraged (Morrissey, 2004), obviating the problems and difficulties of following up all imaginable wireless technologies that will arrive in the future.

### **Review of Research in Latin America**

This review regards that there are particular circumstances in Latin America that have caused a disproportionately large number of experimental and review papers on the subject of electromagnetic interference on medical devices:

Hospitals in the region have a higher proportion of old medical equipment which has not yet been technically screened against the RF fields used by modern wireless technologies, such as GSM, 3G and WiFi; therefore, the situation favors a

higher number of EMI incidents. Analogue phones are still in use in many regions of Latin America, and most of digital mobile phones using CDMA and TDMA technologies automatically shift to analogue mode when roaming outside their home areas, without the user being aware of this. The overall result is that the situation is partially similar to what happened in the 1990s, in other countries, and thus a higher number of EMI events can be expected.

Furthermore, the ignorance of medical and technical staff about medical devices susceptibility to EMI is also higher in the region, and the absence of hospital security committees with organized plans of RF protection is very common.

On the other hand, the experimental and exact nature of testing for EMI, at least in laboratory conditions, and the fact that “technology poses problems that can be solved by technology itself”, make this field of study an easy one to tackle, as well as free of polemical issues. Guidelines for minimal distance and restriction policies can be easily established and applied.

Thus in a literature survey using MEDLINE and LILACS (Latin American Literature on Health Sciences, available at <http://www.bireme.br> ) we were able to locate nine published papers by Latin American authors between 1970 and 2008. Six of these papers were related exclusively to implanted pacemakers and defibrillators (Ferreira *et al.*, 1988; Mateos *et al.*, 1996; Gauch *et al.*, 1997; Muratore *et al.*, 1998. Santomauro *et al.*, 2002 and Fernández Banizi *et al.*, 2004). Most of these papers were reviews of the literature and guidelines. The two other published papers were related to EMI on electromedical devices (Cabral & Mühlen, 2002) and equipment used in surgical rooms (Hermini, 1996).

One of the earliest and few *in vitro* experimental studies published by Latin American researchers was carried out by Cabral & Mühlen (2001), from the State University of Campinas' Center of Biomedical Engineering, Brazil. The effect of a single RF source at 900 MHz (an analogue cell phone) was investigated using 31 medical devices of 14 different manufacturers: infusion pumps, pulse oxymeters, non-invasive blood pressure device, multiparametric vital signal monitors and cardiac monitors. The authors were careful to note the year of manufacturing of the devices, the majority being before 2000. A proportion of 55% of equipments manifested any form of EMI in distances up to 0.5 m in this study. This dropped to 11% up to 1.3 m of distance.

Another, more recent experimental study by Calvo *et al* (2008) was carried out in Colombia. They examined EMI generated by four models of GSM cell phones and one Motorola radio communicator, on 16 types of medical equipment (ventilators, infusion pumps, defibrillators, incubator, lighting chamber, pulse oxymeter, EEG recorder, multiparametric vital signal monitors). The authors observed that 87% of all equipments tested presented some form of interference with their function. Of these, 19% regained normal function after interruption of the EMI disturbance, 25%

required the intervention of a clinical operator to return to normal function, 12% required specialized technical intervention, and 31% of the equipments presented data display interferences. However, these effects were obtained in general at very short distances between source and medical equipment, usually below 10 cm, and in several cases in close contact only. Worrysome to the authors, 11% of the equipments presented interference with distances around 100 cm from the source, 14% of the equipments presented interference below a field gradient of 5 V/cm, *i.e.*, below the international EMC standards, and 75% of the failures were clinically significant and might have caused death or injury to patients.

## **Conclusions and Recommendations**

1. Wireless communication technologies with enough output power and very close proximity to medical devices of several kinds, including implanted devices, has the possibility of causing electromagnetic interference with potential hazardous effects on the well being and critical life support of patients;
2. The low power technologies and frequency spectrum used by present-day digital wireless communication devices, such as mobile phones, laptop and palmtop computers, base stations and access points, and electronic filters installed on modern medical devices have reduced to practically zero the chance of occurrence of such hazards, when they are used normally;
3. Large mobile telephony base stations outside the healthcare institution, or smaller micro- or nanocell base stations and wireless data communication network access points inside the institution have presently too low power density microwave electromagnetic fields to cause any significant interference with all kinds of medical devices;
4. Clinically relevant electromagnetic interference with medical devices is very unlikely to occur, particularly when a minimum distance of 0.3 m for implanted devices, and 0.5 m for external medical equipment is respected;
5. Therefore, scientifically and technically there is presently no restriction regarding the use of medium risk mobile phones and wireless data communication devices in any area of healthcare institutions, and no general ban policy is necessary, or legislation to this effect. Higher powered communication radios and data communication modems, which may pose a higher risk of interference, should be used sparingly and in emergency situations, only, very near to medical devices, implanted or not;
6. Patients implanted with pacemakers and similar devices should be oriented to always talk on cell phones at the contralateral side of the implant, and user the newer low power digital models;

7. Healthcare institutions should be encouraged to carry out a survey and maintain records of high EMI risk areas and equipments, and issue and enforce policies of monitoring and restriction of use
8. Healthcare institutions should be encouraged to set apart and signalize areas for the free use of mobile wireless telecommunications by professionals and visitors;
9. Further mitigation of potential EMI effects on medical devices can be achieved by installing special low-risk wireless communication systems inside healthcare institutions which are issued for routine use by its workers;
10. Safety norms at national, regional and local levels should take into account the current knowledge base about EMI on medical devices, and educate the healthcare professionals accordingly;
11. In Latin American institutions where a large part of medical equipment manufactured without filters for preventing RF EMI interference are still in use should be encouraged to gradually phase out and substitute these equipments in order to avoid potential hazardous events;
12. As wireless telecommunication technologies continue to evolve, scientists and technicians should keep vigilance and test them for potential EMI hazards on medical devices of all types;
13. National organizations in charge of establishing standards for electromagnetic compatibility should be urged to take into consideration the issue of EMI on medical devices;
14. Correct risk perception and acceptance by the general population in respect to EMI of wireless devices on medical equipment, pacemakers, etc., should be addressed,



## Chapter 2 - Social Issues and Public Communication

### Introduction

It has been suggested many times that the real issue behind the current controversy and fear by the public regarding RF mobile communication may not be whether there is a real and solid scientific basis for this fear, but rather a lack of **risk communication** and of understanding of public **risk perception** and **risk acceptance**. Also important is the **public's understanding of science**.

Mobile telecommunication is a complex engineering subject, which most of the population does not fully understand. In addition, lay people do not adequately realize that scientific studies on biological effects and health consequences of RF unavoidably have **uncertainty** and may provide conflicting results and trigger discussion among scientists. Finally, actions of various interest groups, and in some cases incompetent and irresponsible reporting by the mass media have exacerbated the controversies.

In summary, the nature of scientific endeavor and how knowledge is produced, and how uncertainty is treated and eventually overcome in science, is misunderstood by the general public and it is exceedingly difficult to communicate.

**Fear of technology** is common and not a novelty: reports from our past tell us of fear of detrimental effects by the public in several instances: trains, telegraph wires, telephones, TV sets, video monitors, power transmission lines, "frankenfoods", aspartame, silicone breast implants, and several others. Curiously, as observed by Dr. Michael Repacholi, former coordinator of the WHO EMF Project for 11 years, the public was not so much afraid of the dangers that we know about, such as glowing radioactive materials used in watches to see the time in the dark, medical x-rays, and spas with radioactive waters (both purported to be "curative"), ultraviolet tanning beds, etc. Understanding these different reactions is essential for communication of risks to the public.

Regarding the public understanding of science and the emotional reactions regarding mobile wireless communications, what happens when the object of fear is not perceptible to our senses, as in the case of EMF? Not only can our senses not perceive EMFs, but it takes quite an amount of education to fully understand what they are, how they are generated by different modern technologies or even natural sources, and how they interact with matter and living tissues. Certainly, this is not appreciated by most lay people. It is natural to fear the unknown, and once

you have acquired this feeling, it is very hard to remove it simply by rational discussion. An obvious way to cure fear and anxiety about EMF effects is to provide people with as much information as possible (**user education**). However, people providing such information should be very careful to present only well proven facts, making reference to recognized experts and organizations and, most of all, make every effort not to make the concerns worse. As an example of the latter, stressing scientific uncertainty and implementing precautionary measures may have a negative impact on the public's perception of risk or its trust in policies and government agencies.

The most important factor for the acceptance of new technologies seems to be **risk/benefit comparison**, which is not automatic. Of particular interest to users, industry and government stakeholders in the mobile communication sector, is the fact that apparently few studies have been made on risk/benefit ratios for these technologies, in comparison to many others that have a strong impact on society. Potential harmful effects of mobile phones, such as using them while driving, exploding batteries, deleterious interference with electronic medical equipment (e.g., heart pacemakers), and most of all short- and long-time effects of RF fields on the health of inhabitants and users (such as cancer and electromagnetic sensitivity) have been touted as possible by several researchers and special interest groups, as well as by the mass media. This has prompted an enormous body of research (e.g, Valberg *et al*, 2007), mostly in the last 10 years or so, with considerable expenditure of money that could have been better used in more serious and prevalent health issues, such as AIDS, dengue fever and malaria, and has caused a significant amount of concern and even panic among the population. Despite the existence of an overwhelming body of serious research showing that all these phenomena either do not exist or are seemly very rare *vis-à-vis* the enormous number of devices in use (with the possible exception of effects on the performance of drivers, Goodman *et al*, 1997), irresponsible or alarmist media diffusion have created a public view that is quite out-of-step with the scientific evidence.

Any and all technologies have their share of risks. They must be counterbalanced by a careful study of its benefits. Such is the case of automobiles, airplanes, chemicals used in agriculture, food conservation and cleaning, oil and coal combustion, nuclear power, genetically modified foodstuffs, etc. The society has recognized and accepted all of them, considering their usefulness and adoption rate, but at the same time has imposed risk management procedures, enforced maximum levels of exposure, encouraged technological improvements, required preventive measures, etc. In order to do the same for mobile technologies, more studies focusing on the social and economical benefits of mobile communication technologies are urgently required.

This section covers the report on social research and communication to the public, and addresses the following interrelated topics:

- Risk perception, risk acceptance and risk/benefit issues
- Social resistance against technology
- Understanding benefits: perceived and real impacts of mobile communication on health, wellbeing and security of the public
- Public understanding of science
- Scope and aims of public communication on EMF and health issues
- Communication of health risks to the general public
- Communicating scientific uncertainty
- Applying and explaining the precautionary principle
- Evaluating the quality of information to the public
- Assessing ethical and professional responsibility of the mass media concerning health and EMF

## **Risk Perception, Risk Acceptance and Risk/Benefit Issues**

The first study we highlight here tried to characterize risk perception in Chile using a psychometric paradigm (Cifuentes & Bronfman, 2003). Its goals were 1) to assess which hazards preoccupy the public, 2) to describe those attributes of risk that influence the populations' perception of them, 3) to explore differences between perceived social risk and perceived personal risk, 4) to explore risk acceptability issues, and 5) to study data variability when using disaggregate data instead of aggregate data. The survey considered a list of 54 hazards grouped in categories: environmental, technological, transportation, forbidden or addictive substances, chemical pesticides and substances, natural disasters and social ills, and others. Cell-phone antennas were included within technological hazards. The fact that it encompasses most hazards people may ever worry about helps put mobile telephony in perspective as an environmental problem

*What hazards preoccupy the public?* The highest social risk perceptions were of forbidden and addictive substances, natural disasters, social illnesses, and environmental hazards. Cell phones fell into a mid level, next to high voltage lines or genetic engineering; both in the technological group.

Some segments of the population are more risk-adverse, other are less so, so analyses about the hazards that preoccupy the public should take age, gender, schooling, socio-economical level and perhaps profession into account. For example, Martha et al. (2007) investigated how adolescents perceive health risks, driving while using cell phones and social risks (incivility) and concluded that they tend to disregard health risks, only. Older people, on the other hand, tend to perceive health risks much more acutely.

*Risk/benefit balance.* As we have remarked above, the benefit deriving from an activity, substance or technology plays a fundamental role in society's attitude toward it. As expected, environmental hazards, such as forbidden or addictive substances, are generally perceived as having a high risk and small benefit, resulting in a negative net balance. Technological hazards, like mobile telephony, were rated as presenting comparable risk and benefit, especially in personal terms, but were scored by users in the study with small deviations towards risk or towards benefits.

*Perceived social risk versus perceived personal risk.* The difference, defined as **risk denial** (because, although the risk is perceived by society as a whole, it is not perceived at the same level or manner at a personal level), is positive for almost all hazards, i.e. the first is larger than the second. Environmental hazards present a small risk denial, showing almost equal perceived social and personal risk. Forbidden or addictive substances cocaine, marijuana and HIV have the highest risk denial. Smoking has a very large risk denial among smokers, a well known fact. These observations reflect the fact that, in these cases, the individual can keep control and believe *"this may not happen to me"*. How is mobile communication risk denial considered? It depends on which part of the technology is being considered: base stations or handsets. For handsets it is high, since they are increasingly being bought and used, despite a high perceived social risk fueled by media information. Regarding base stations, risk denial cannot be assessed with a simple percentage or average, since there are people living near towers, and people living quite away from towers (or who don't see small microcell antennas, or antennas installed on rooftops) and this influences strongly the perception of personal risk.

*Acceptability and risk attributes.* As expected, the degree of acceptability of a risk correlated negatively with its perceived social risk but positively with its perceived social and personal benefit (Siegrist et al., 2005). In the Personal Benefits vs Dread Risk relationship, cell phones ranked more or less in the middle or, in other words, their potential risks are well compensated for by their evident benefit.

In this respect, Siegrist et al. (2005) in a study carried out in Germany showed that *"trust in authorities was also positively associated with perceived benefits and negatively associated with perceived risks. People who use their mobile phones frequently perceived lower risks and higher benefits than people who use their mobile phones infrequently. People who believed they lived close to a base station did not significantly differ in their level of risks associated with mobile phone base stations from people who did not believe they lived close to a base station."*

*Risk and benefit perception.* As in other studies, perceived social risk correlated inversely with perceived social benefit and the reverse with acceptability of a risk. This could imply that the perceived risk of a hazard may be decreased by identifying and emphasizing its benefits. However, the observed correlations do not

imply a direct relationship between the two variables, since there is no causal link between them. Instead, risk and benefit may be influenced by a third variable, “**social trust**” being a likely candidate. Although likely this hypothesis remains to be tested for mobile telephony. The perception of risk is also influenced by the public's trust in authorities (Covello, 1991).

This very general conclusion of the Cifuentes & Bronfman paper may well apply to mobile telephony. Concerns about cell phone masts may continue to occupy press space but in the meantime the number of mobile phones has increased in Chile (and in most of Latin America) to more than one per inhabitant, which speaks clearly in favour of acceptability versus potential health hazards.

Another paper (Barnett *et al*, 2007) reports the results of a nationally representative survey that explored public responses to a leaflet issued by the UK Department of Health (DoH) in 2000, providing information about the possible health risks of mobile phones. Their results are very informative of what can be done to evaluate the impact of a given action on social issues and communication with the public.

Two leaflets were produced by the DoH; one about mobile phones and the other about base stations. The focus of the study on public perception is that the leaflets simultaneously communicated uncertainty and precautionary advice. Assuming that more personal control would improve risk perception, the leaflet outlined that, in the face of uncertainties in knowledge, “*there are ways in which you can choose to minimise your exposure to radio waves*”. Three options of precautionary advice were outlined: keeping calls short, those under 16 years of age minimising non-essential calls, and consumers taking into account the SAR (Specific Absorption Rate) when purchasing a new handset.

The analysis of results of such dissemination efforts must take into account, however, that possible health risks from mobile phones are generally seen as rather less serious than a range of other risks, as described above. Available data also suggest that an appreciation of the benefits of mobile telephony offsets concerns about possible risks.

Often governments start initiatives towards responding to public concern about risks, feeling that “*something must be done*”, but then fail to evaluate (qualitatively) or measure (quantitatively) the impact of measures taken. They also fail in providing any information on benefits, probably because they feel that they are self-evident.

As discussed in more detail later, the results of surveys by Weidemann & Schütz, (2005) and Weidemann *et al* (2007) confirm the view that *precautionary advice is generally associated with increased concern rather than providing reassurance*. Interestingly, regardless of the initial level of concern about uncertainty, the general trend is towards increased concern triggered by government advice. This suggests

the need for care about the provision of precautionary advice as part of public health information. It seems clear that providing such advice as a response to public concern is unlikely to actually reassure. Even more, research suggests that for those who have strong concerns, information about uncertainty might provide support to their beliefs and result in new facets of the hazard.

## **Social Resistance Against Technology**

Since the textile workers led by John Ludd protested against the introduction of semiautomatic weaving machines in the 18<sup>th</sup> century, the resistance of certain groups in the population to the introduction of new technologies, which are felt to be disruptive to the social order, detrimental to the job market or threatening in some way, has been called *luddism*.

More than ever in the past, however, we are witnessing a popular movement which uses allegations about potential damage to health as the pretext to protest and to resist to a new technology (Burgess, 2003), or rather, to a very specific aspect of a new technology, which is the installation of large masts (called *Greenfields*) and sometimes rooftops, which support base stations in residential neighborhoods. This social movement, which in some Latin American countries, like Brazil, has reached the point of violent intervention by activists (masts were destroyed by angry mobs, and technicians have been physically assaulted and had to be protected by military police) is an interesting (and important) phenomenon and has been studied in detail by some scholars.

For example, Drake (2006) studied the attitudes and beliefs of one of these protest groups and examined “*how and to what extent health issues dominate the group’s concerns and how the campaigners have engaged with scientific knowledge to form their opinion.*” They discovered that, albeit most of the members of the group used cell phones, they had a militant and biased opinion on the health effects of base stations, and that they believed that the precautionary principles were not being applied by mobile telephony providers. They also felt that science and technology, at least in this case, was not leading to a better quality of life.

It is important to note that these protest groups form a tiny, but very vocal and exceedingly active minority. The “silent” majority, which is either indifferent to the issue, or oppose the minority’s views and positions, does not manifest itself. Politicians are therefore pressured by an unbalanced representation of the people’s views, an unfortunate fact, which is responsible for most of decisions that are not based on science.

In principle, social communication strategies for these groups, in order to induce more balanced views, seem to be not very effective. Although some of their members that have less firm convictions may be more receptive to rational,

science based arguments, their core is sometimes made of fanatical, inflexible individuals, who consider themselves as crusaders and evangelists. Since any technology can be accused by anyone at any time to be detrimental to humans, the only way to bring such groups to reason is to make them understand better how RF fields are used in telecommunications (public understanding of science) and to raise the balance of risks and benefits, by understanding better the benefits of mobile wireless communications, i.e., its positive social impact. It is what we discuss below.

## **Understanding the Benefits of Mobile Wireless Communication: the Social Impact**

Despite its social importance and phenomenal presence, telephone technology, since its invention and mass adoption in the late 19<sup>th</sup> century, received surprisingly little social research. According to Geser (2004)

*“no considerable efforts have been made to gain a synopsis of its multifaceted impacts on various fields of social life, and no integrated theory has evolved concerning the specific functions and consequences of phone communication (...) This deficit only illustrates the larger tendency to ignore the impact of technologies on the unspectacular aspects of everyday life (...) Evidently, the cell phone seems to evoke much less intellectual enthusiasm and scientific research endeavors than the World Wide Web. (...) Such views ignore the basic facts that in comparison with PC’s and Internet technologies, cell phones are used nowadays by broader strata of the population all over the world, and that for many users, they have stronger impacts on social life, so that most of them are ready to spend much larger sums of money on monthly phone bills than on Internet provider services (...) This diffusion has occurred worldwide, rather independently of different cultural habits, values and norms.”*

This impact is apparent in at least two levels of the social activity: personal and work. However, several authors have pointed out that *“the boundary between work and personal life slowly disappears as people can easily use mobile communication technology simultaneously for personal and business purposes in both social and work-related contexts.”* (Peters & ben Allouch, 2005). This has been called the *“always on” paradigm shift*, which previous communication media, such as fixed phones, did not allow. Several sociological studies have shown that private communications have invaded the workplace, and work-related communications have conversely invaded the private sphere of individuals (Geser, 2004).

A study funded by the European Commission regarding the use of information and communication technologies (ICTs) in European countries has suggested that

*“mobile communication (...) allows a more flexible form of communication. (...) It allows one to fit socialisation into the nooks and crannies of everyday life and possibly obviates the need for social contact in the context of other, more formal institutions.”* Sociological studies have shown an interesting “backtrend” provided by the highly personal way of wireless portable communication devices: *mobile phones are re-creating the more natural, humane communication patterns of pre-industrial ages* (Fox, 2001, *apud* Urry, 2007). According to Geser (2004), *“the cell phone gives rise to a new trans-spatial version of particularistic communalism: thus making the mobility enforced by modern urban living conditions compatible with the maintenance of rather primordial modes of social integration”*. In other words, mobile interpersonal communication networks are *the* real global village, as envisioned by Marshall McLuhan, not television and radio, as he originally stated, which are unidirectional.

What tangible benefits mobile communication could bring to individuals? Current research shows that the public has absolutely no difficulty in recognizing them at a personal level, while the benefits for society as a whole are not brought to mind so easily.

In regard to these overall social benefits, according to a 2001 review by the UK Office for National Statistics, personal communication devices, such as fixed and mobile phones, have had a large impact on outcomes related to economic growth, social inclusion, better health, safety and wellbeing (Haddon, 2002). This so-called *“social capital”*, according to a 2002 report by its Policy and Innovation Unit has shown positive impacts to varying degrees, as supported by empirical research. It may:

- facilitate better economic performance, for example through reducing transaction costs, enabling the mobilization of resources and facilitating the rapid movement of information
- facilitate the more efficient functioning of job markets, for example by reducing search costs.
- facilitate educational attainment;
- contribute to lower levels of crime;
- lead to better health;
- improve the effectiveness of institutions of government.

Since the early history of mobile communications using cell phones, anecdotal evidence of everyday life pointed out that, many times, having a cell phone at hand for urgent calls in road accidents, sudden life-threatening disease onset, or getting lost or having a punctured tire in a dangerous neighborhood, etc., has been a decisive factor for saving lives or improving safety and security (Geser, 2004). According to this author,



*“The cell phone can be extremely useful for interconnecting emergency agencies with their environment, by increasing the likelihood that somebody watching an emergency event has a phone and is disposed to make a call. In particular, cell phones can shorten considerably the time span for the arrival of institutional helpers like ambulances, fire workers or policemen: so that they have better chances for effective intervention: e.g. keeping the heart attack patient from dying, preventing the fire from spreading or intercepting flying burglars.”*

Of particular relevance for the present report, in the seminal study by the American research firm Frost & Sullivan in 2006, on behalf of the GSM Association (GSMA, 2006) on the social impact of mobile telephony in four countries of Latin America (Brazil, Colombia, Argentina and Mexico). Health and security were high on the list of applications with a large social impact in rural and semi-rural areas. About 35% of the users reported using cell phones for emergency calls, and 18% for calls to hospitals and physicians; but most significantly, 40% of users reported making more calls for each one of these compared to before they owned a cell phone. In other words, mobile telephony increased significantly the level of communication related to health and security. Community leaders of these areas, when asked what were the applications with higher social impacts, they chose security in first place, followed closely by health.

Although a direct link between the acquisition of a mobile phone and positive effects on overall quality of life has been hard to demonstrate in developed countries (where the quality of life is already very high), it is possible that mobile telephones are having a more pronounced impact in countries where communications infrastructure has hitherto been less extensive. For example, a Vodafone study in South Africa has demonstrated that 16% of users in that country report using the cell phone for calling police or security. Another example is a study on the use of cell phones by small entrepreneurs in extremely poor countries, such as Rwanda (Donner, 2004), which demonstrated a huge impact of cheap mobile communications on the social and economical viability of small enterprises.

The perception of cell phone users regarding its usefulness for security is also very high. In the Latin American survey cited above (GSMA, 2006), 67% of the users reported feeling safer when emergencies arose (the highest in the list of perceptions), and 38% felt more protected from robbery. The most cited uses for cell phones in this area were:

- To call the police in case of robbery and theft
- To call the police in cases of family violence
- To report robberies in the street or highway
- To call relatives for help in case of suspicious noises
- To call for help in cases of vehicle malfunction or flat tyre

- Health concerns are also a major direct benefit of owning a cell phone. The users researched by the Frost & Sullivan study (GSMA, 2006) reported the following main uses:
- To check on the health status of an ill relative
- To call the pharmacy for delivery of drugs
- To call for ambulances and medical help in cases of sudden illness or medical emergencies
- To consult a physician on modification of a therapy regime, to follow up a case, etc.
- To warn about accidents with victims on the road
- To communicate with hospitalized relatives or friends

In a small scale study carried out by Coates (2001) among university students, 33% of respondents gave calling in emergencies as one of the reasons they acquired cell phones. A high level of correlation was also reported between gender and the motivation to purchase a cell phone. Females purchased phones primarily for emergency usage. In another study in Africa, 16% of respondents reported having used mobile phones for notifying police or for personal security purposes (Samuel *et al*, 2007).

The final and most important research question regarding social impacts of cell phones when compared with other forms of telephony (private land line or public telephones) is whether there are applications that are *clearly unique* for mobile phones or *are more used* with cell phones than with other means. This question has been not been researched in depth in most studies so far: it could provide a very relevant input to risk/benefit analyses of mobile telephony in many settings. But there is no doubt that they are: as cell phone models advance in their capabilities, such as text messaging, electronic mail and internet access, embedded photographic and videocameras, GPS localization functions, etc, they depart more and more from common telephony and become clearly unique in their several novel applications and usefulness to the users. For instance, there are reports in the news that users who have been kidnapped by robbers and stowed away in their car's trunks, were quickly located and freed by police after receiving a distress call from the victim's cell phones, thus avoiding injury and possibly death, because her cell phone was fitted with GPS. The same happened with a couple lost in a forest trail.

Despite the sheer size and growth rate of this social phenomenon, there have been relatively few studies addressing the empirical evidence of the impact of cell phone usage on the health, safety and well-being of the population, particularly in developing countries (Donner, 2004).

A large social study on the impact and use of cell phones in Latin America has

been carried out by Sabbatini (2009, *in press*). Two independent, simultaneous surveys were conducted on the same populations, in the same period of time, in three cities in the state of São Paulo, Brazil: São Paulo City, Campinas and São João da Boa Vista with widely different sizes with a total of more than 3,000 respondents: a residential survey using randomized, prospective, continuous, stratified sampling, with the aim of determining general demographics and data about the ownership profile, intensity and variety of usage of mobile phones for emergency calls; and an exhaustive analysis of all incoming calls originating from cell phones to the emergency call centers of the Military Police of the three cities. Assessing the information provided by the two surveys, as well as correlating them with other statistical information available elsewhere, such as records of police stations, etc., improved the power of analysis and interpretation

Among the many conclusions of this study, we can highlight the following:

- Importance of owning cell phones and importance for their lives, as felt by users, were invariably high for all categories of users (age, gender, civil status, profession, education, socioeconomic level, and city size), with an average of 85% of opinions of the phones as important or very important;
- The feeling of importance increased sharply with increasing time of ownership;
- The feeling of importance also correlated highly with having made or not an emergency call.

The main conclusions regarding the use of cell phones to make calls related to safety and health were the following:

- Using a cell phone to make emergency calls, and the number of times it was used was about the same for people of different genders, civil status and city size, and on average was close to 40% among users;
- There was no difference regarding the use of a cell phone to make an emergency call, whether the user had access to a phone land line or not;
- This kind of usage was higher in younger people from 18 to 30 years of age, but increased also in relation to time of ownership, level of education and socioeconomic level;
- Socioeconomic level was a more influential factor than level of education;
- Users of prepaid phone used proportionally more cell phones to make emergency calls than users of postpaid phones.

Thus, some important facts arose from the study:

- It has clearly demonstrated that cell phones represent today a very important communication resource for preventing and maintaining health and safety of individuals, since almost 40% of its owners have already made use of them at least once for purposes that affect these areas. Cell phones are ubiquitous and an enormously widespread technology in the cities studied (more than 60% of individuals), so their role assumes greater importance. Their inherent mobility and individual use create new opportunities in the fields of security and health of its owner, relatives, friends, colleagues, etc., independently of time and location.
- The pattern of use for making emergency calls observed in the study was closely related to the ownership of a cell phone in several categories, i.e. it increased with higher socioeconomic class, higher education level, and younger age. However, it does not correlate, as ownership does, with gender, city size and married status.

We could interpret these results in the light of **perceived value of a technology**. It would be expected that users who acquire mobile phones attribute a high value to them; otherwise they would not buy them. This has been shown in an analysis of the importance of cell phones as indicated by users: they were invariably high for all categories of users (age, gender, civil status, profession, education, socioeconomic level, and city size), with an average of 85% of opinions rated as important and very important. The value of a technology increases automatically when one uses it at least once for some purpose. This is clearly apparent as demonstrated in this study, where users with a longer time of use (more than 2 years) value more (give more importance to owning a cell phone) and make more emergency phone calls. Then the difference appears, and people with a higher interest in having cell phones consequently use them more for making emergency calls.

It is noticeable also that although users tend to feel that cell phones are important, ( 85% of the users in the survey consider them important or very important for their lives), a smaller percentage have made use of them for really important, emergency or life-saving situations. This has been observed in other studies in Latin America (GSMA, 2006) and elsewhere. In the Frost & Sullivan survey, 86% of the users considered that mobile communication was important for their safety and health, and 67% felt more secure by having access to one, but only 35 % actually used it for safety and health purposes. This might be explained by social awareness phenomena (e.g., knowing about other people who made use for these purposes, rather than having a direct experience themselves).

Restating our initial question: what makes mobile telephony different from fixed line communication?

Mobile communication stands on its own name: **spatial mobility**, or freedom to be

in any location to be able to communicate. In this way, *“wireless transmission technologies are certainly at the root of all innovations that make communication compatible with spatial mobility. Seen in this very broad evolutionary perspective, the significance of the mobile phone lies in empowering people to engage in communication, which is at the same time free from the constraints of physical proximity and spatial immobility. As it responds to such deeply ingrained and universal social needs, it is no surprise to see the mobile phone expanding worldwide at breath-taking speed. In fact, there are reasons to assume that it would have been equally welcome in all human societies and cultures in the past: that is, under all imaginable specific cultural or socio-economic conditions.”* (Geser, 2004). The sense of freedom is one of the most important factors here. According to Spector (1993) *“In fact these technologies should be liberating, freeing users to communicate with anyone, from anywhere, at any time.”*

Many studies were able to prove that this freedom of communication provided by mobile cell telephony has a significant impact for individuals, particularly regarding its impact on health, safety and wellbeing, reproducing what other researchers found in studies in developed and developing countries.

According to Lacohe et al (2003), the ownership of a cell phone is nowadays seen as an essential tool for survival in a “risk society”. This term implies that in the last decades, violence, accidents, and general opportunity for mayhem has increased as a whole in most urban environments in the world (more in some, less in others). Families are increasingly acquiring mobile phones for women and children, in order to improve their safety and accountability. Location based services (LBS) based on wireless triangulation and GPS to pinpoint the location of a cell phone are now possible, and becoming popular as value-added services both for operators and users. As early as in 1997, in a survey of business and residential users of cell phones in the USA, Katz found the importance for the *“residential user (of) the readily recognizable effects of increases in convenience, personal efficiency and security, as well as more subtle effects, particularly in the psychological and interpersonal realm (...), such as the need to be in touch or being highly mobile;”*

It should be noted, however, that in large metropolitan areas, with million of inhabitants, cell phones may affect emergency institutions negatively insofar as they cause information overflows:

*“With a mobile phone, a driver can immediately call for emergency help or the 911 service (a safety function), this initially expedites the emergency service. Now emergency services are being inundated with multiple calls for the same emergency, slowing down response time and preventing other emergency calls from coming in.”* (Bautsch et. al. 2001).

Sabbatini (2009), while interviewing the commanding officer of the Military Police Emergency Call Center (COPOM), found that one of the problems they had was

how to pinpoint whether the calls referred to the same accident; for example, in order to be able to limit the response. Sometimes this is a difficult task due to incomplete information provided by callers, such as the exact spatial and temporal information. The US federal government is now contemplating mandatory GPS functionality in all cell phones, so that users with injuries and unable to discuss the emergency, have automatic location information.

Another disruptive consequence of widespread use of cell phones on emergency systems is that, in many countries (such as in the USA), the emergency number can be dialed free of charge from any cell phone, even from those that were connected to a line which has been blocked or deactivated, from discarded, lost, stolen or abandoned handsets, etc. This has led to a large increase of prank and unnecessary calls, flooding the calls centers, which are impossible to track (Michels, 2007).

### **The Issue of Public Understanding of Science**

The understanding of science and technology behind wireless communication by the general public is nowadays considered an essential ingredient for good communication of a new technology.

The terms “*public understanding of science*” or “*public awareness of science*” relate to the attitudes, behaviors, opinions and activities that comprise the relations between the general public or lay society as a whole to scientific knowledge and its management. This involves many activities and initiatives, and is a comparatively new approach to the task of promoting science, technology and innovation among the public and provides an integrated and results-oriented view, within a single framework a series of other fields, such as: science communication in the mass media, Internet, radio and television programs; science fairs, festivals and exhibits, education (children, adults and specific groups, such as consumers, physicians, industrial hygiene and safety, government officials, politicians.

Not only the very basic information about how wireless communications work, but the nature of the physical agents involved, and its interaction with living beings, must be properly understood and accepted by the population, before evaluation and acceptance of risk occurs among members of the public. In addition, in fields where near certainty has not been achieved in science, special care must be taken by social communicators how to disclose and how to consider scientific uncertainty. Most of the general public has not been trained or is unaware about how science works, how it arrives at a consensus, how knowledge and theories are provisory and continuously and inevitably change.

### **Disclosure of Scientific Uncertainty**

While lecturing on health effects of EMF to the public, Vanella *et al*, (2006) found that when mention of the International EMF Project, sponsored by WHO, was made to a lay audience, most reactions were negative. A typical "feeling" was that, *"if there are on-going studies it means that there are no conclusive results yet. And this is not good. It's better to stop everything (typically authorization of new communications installation or new regulations on he subject) until WHO presents good results!!"* Put in lay words, *"there is no smoke without fire"*.

At the same time epidemiological studies that are most often the most impacting source of information for the general public, since they often deal with cancer and other feared diseases, and use very large numbers of diseased individuals have sown confusion and uncertainty more often than not. Many studies directly contradict others, in terms of affirming whether there exists an association between EMF exposure and detrimental health effects, despite an enormous number of uncertainties, biases, and a lack of solid and incontrovertible scientific evidence. Results based on faulty designs, statistical artifacts and unjustified interpretations abound. According to Tauber (2001), *"many epidemiologists concede that their studies are so plagued with biases, uncertainties and methodological weaknesses that they may be inherently incapable of accurately discerning weak associations."*

This has been called the *"scandal of poor epidemiological research"* (van Elm & Egger, 2004), and physicians and researchers have called for more prudence when divulging results to the media (Hazinski *et al.*, 1995):

*"...concerning the public's confusion about the results of clinical trials, I think the public and the media would be better able to assess research results if medical researchers themselves were more modest and careful when discussing their results with journalists. The NEJM has led the way in embargoing research results until after publication, but such rules cannot prevent the ambitious or naive investigator (or the investigator's institution) from touting results and pushing conclusions beyond the limits of the data."*

The public at large is not prepared to accept scientific uncertainty and to understand epidemiological results in terms of probabilities, and will not be satisfied with a conclusion that is really the absence of conclusions. This justifies the need to provide information to society about the methodology of scientific work and the uncertainty that, within certain limits, it implies. At the same time, governmental agencies should adopt effective measures to verify compliance with regulations under strict control by independent parties (Vanella *et al*, 2006). It is well known that, even when the technique, equipment and expertise to perform measurements of EMF is available to almost everyone, results will be acceptable to the public only when they are not performed by parties who have a vested interest. In simple words, people will readily accept results provided by a university but will not trust results provided by a telecommunications company, even if they concern his own installations (Bruni *et al*, 2003).

## The Precautionary Principle and Cautionary Policies

What do we understand by precautionary principle?

As Wood (2006) noted, *"In the event of scientific uncertainty as to either the nature or origin of a risk to human health, responsible agencies may wish (...) to take protective measures without having to wait until the reality or seriousness of those risks becomes apparent"*.

There is an on-going debate about whether EMF exposure from communications, or other sources, has sufficiently consistent scientific evidence of hazard to actually trigger this "precautionary principle" (Foster *et al.*, 2004), and that its unjustified exaggeration for everything might be a kind of environmental extremism (Foster, 2003). Some authors (e.g., Eisinger, 2004, comments on Foster *et al.*, 2004) go to the length of stating that the precautionary principle might be self-defeating, since it has transfer of risks instead of risk prevention as the most probable outcome, and that therefore it might be dangerous in some situations.

Current advice by WHO is that *"Considering the very low exposure levels and research results collected to date, there is no convincing scientific evidence that the weak RF signals from base stations and wireless networks cause adverse health effects"* (WHO, 2006)

Nevertheless, everybody seems to be happier taking some precautions. As an example, in Australia and New Zealand, safety standards have a mandatory requirement to *"minimizing, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided that this can be readily achieved at modest expense"*

Enhanced precautionary measures for special groups, such as children, seniors, or for places which are deemed abnormally sensitive, such as hospitals and schools, have often been called for, and, in fact, have produced many laws supposedly trying to protect them, such as observing a minimal distance from base stations. This is a form of irrational behavior, based on cultural, emotional and political arguments, not scientific ones (Vecchia, 2005), since the ICNIRP, and other standards of protection in place were devised in order to protect everyone within a science-based framework, including special groups and places.

Phone manufacturers have responded to community concerns by making SAR values of their handsets available, to allow this to be a factor in consumer choice. Similarly, policies of co-locating antennas owned by several operators on a single mast and wherever possibly locating these masts away from schools, represents a prudent approach by industry.



On the government side, one possible response to public concerns is to conduct EMF surveys and to provide as much information to the community as possible, as done e.g. by the Health Protection Agency of UK ([http://www.nrpb.org/hpa/radio\\_surveys/](http://www.nrpb.org/hpa/radio_surveys/)) or the corresponding Australian agency, ARPANSA (<http://www.arpansa.gov.au/>). An example in Brazil, is the city of Americana, São Paulo State, where a survey has been done by CPqD (Centro de Pesquisa e Desenvolvimento: <http://www.cpqd.com.br/monitor/americana/>).

Regulations normally require measurements or theoretical estimations of EMF levels around antennas and other sources. Publishing those results may satisfy people living near these installations, but what about the majority of the population? This is the reason why many large-scale EMF surveys have been performed. From the results of similar surveys every citizen should ideally be able to pinpoint EMF values near their residence. In practice, large area surveys have proved costly if performed on every city block corner or road crossing, and even more so if a permanent monitor is to be left acquiring information at every site. An alternative has recently been reported by a university laboratory in Argentina (Taborda et al. 2006) which developed a method to survey EMF from a moving vehicle, adding GPS data in order to permit mapping of radiation levels. EMF data can be coupled to city maps, satellite images and adding specific data on existing communications installations. An added bonus is that this method allows detection of uncharted or undeclared installations by simply setting the EMF measuring range as a scale of colors to be assigned to each measurement point.

ARPANSA went even farther and, starting July 2003, commenced Australia's first centralised Electromagnetic Radiation (EMR) Health Complaints Register, thus opening the door to two-way communications between the community and the government agency. The Health Complaints Register collects reports of health concerns related to EMR field exposures in the range of 0-300 GHz. The register is not limited to telecommunications equipment and broadcasting transmitters but includes reports related to sources such as power lines, induction heaters, microwave ovens and other personal, industrial and scientific equipment producing electromagnetic fields.

The emphasis in the UK has been to make available to the public detailed data on the type and location of masts (see: <http://www.sitefinder.ofcom.org.uk/> ) in order to promote effective dialog between planners, operators and the community in decisions regarding installations location. In Italy, the Ugo Bodoni Foundation has established a nationwide EMF monitoring network (<http://www.monitoraggio.fub.it/>).

As mentioned often, the justification for invoking the precautionary principle is scientific uncertainty. The reason can be – and often is - political. Risk perceptions can become triggers for precautionary action. Experiments reported by Weidemann and Schültz (2005) intended to test two opposite hypotheses about the impact of precautionary measures on risk-related attitudes and beliefs. First,

precautionary measures will increase trust in risk management, which, in the end will be associated with lower risk perceptions. Second, the alternative hypothesis points to the possibility that precautionary measures will be considered a clue that the risk might be real. Hence, perceived risk could be amplified.

The conclusions of their experiment were that precautionary measures implemented with the intention of reassuring the public about EMF risk potentials seem to produce the opposite effect. They may amplify EMF-related risk perceptions and trigger concerns.

Public calls for precautionary measures have been increasing in all countries, particularly after the massive roll out of 3G technologies, despite a lack of evidence for it. Many have argued that international safety standards are inherently cautionary.

*“The precautionary principle is difficult to define, and there is no widespread agreement as to how it should be implemented. However, there is a strong argument that precautionary measures should not be implemented in the absence of reliable scientific data and logical reasoning pointing to a possible health hazard. There is also experimental evidence that precautionary advice may increase public concern. We argue that conservative exposure standards, technical features that minimize unnecessary exposures, ongoing research, regular review of standards, and availability of consumer information make mobile communications inherently precautionary. Commonsense measures can be adopted by individuals, governments, and industry to address public concern while ensuring that mobile networks are developed for the benefit of society.” (Dolan & Rowley, 2009)*

## **Communication with the Public**

Assuming that the public at large is not sufficiently informed about EMF, the obvious path of action to take is to provide people with as much information as possible (Vecchia. 2004). Naturally, information coming from an interested party, such as the communications industry, will be mistrusted. In contrast, government agencies, research institutes or universities may be accepted, provided they have no financial ties with involved companies.

Out of the many existing methods, we have chosen three to evaluate, with different degrees of efficacy. Firstly, the most popular and modern system is to use the Internet. It is low-cost and readily accessible, although web accessibility is not evenly spread among Latin American countries and is certainly more limited than in Europe or the USA. On the other hand it is relatively passive: the information will always be there, but not necessarily it is reached by the proper people.

A second method is the organization of events to reach the lay people, particularly at those places where situations of conflict have arisen. Experience in Argentina (Vanella et al., 2006) can be described as:

*Conflict situation → Urgency to implement a measurement campaign to assure the public that every EMF source (antennas) is within regulatory limits → Public presentation of results → Questioning of the measuring experts by the public and debate → Development of a standard,.*

More than 40 presentations lasting 1-2 hours, followed by debate and FAQ's (Frequently Asked Questions) were organized during a two-year period in a wide range of locations, from province capitals to small towns with less than 1000 inhabitants, so enough experience was accumulated to offer some conclusions. The method proved very effective at "defusing" conflict situations for several reasons: first, the project was conducted by a university research lab, therefore providing scientific and independence credibility; second, regardless of how informed was the public at the time of a presentation, nothing can compete for people's satisfaction better than first hand contact with experts; and finally, the presentations showed results of measurements made in the locations of the meetings a few days before. In fact, it is not helpful to show lay people results of measurements made far away from them, or even in foreign countries; it is more useful to show measurements made close to them.

Even when personal presentations by experts might be very effective, to have greater impact a large number of experts would be needed to perform extensive measurements in the area! While we may find many experts on communications and EMF with doctorate degrees, it is not that easy to find among them the ability to communicate with lay people in simple terms. The obvious conclusion is that this method is valid only for a few conflict locations within a region.

A third method could be named "back to basics" in communication technologies. Besides the internet, the media offer a wide selection broadcasting tools. Television is still one of the most popular vehicle of information, although EMF & Health is not a popular topic for TV.

Almost every review of the scientific literature includes a section on social research and communication to the public. A representative summary is provided by the following *Recommendations for risk communication* from the work by the Ministerio de Salud Pública y Consumo de España (2002):

- *Utilize a comprehensible and objective language in order to enable citizens to take well informed decision*
- *Warn that, even when exposure to EMF may come from many diverse sources, the risk probability of exposed people is very low, provided the*

*radiation levels comply with existing regulations*

- *Society must be informed in order to decide what risk level is ready to accept. This level must be the lowest possible that can still ensure proper use and safety of new technologies (please refer to above reference to earthquake in Peru, 2007)*
- *Inform over the high degree of safety guaranteed by present regulations or recommendations, whether national or international, without underestimating potential risks, regardless of how remote they might be*
- *Pursue and maintain a proactive policy, not reactive, towards documentation and scientific information, with a permanent update of results generated by present research under way and future developments*

Choosing the right language carefully is an important element in communicating with the public, and it is recommended that specific approaches be used with certain segments of the public, such as lay people, journalists, teachers, etc (see the WHO monograph on communication about EMF). For example, MacGregor et al (1998) tested the beliefs of a lay public about ELF-EMF risks for health before and after reading a brochure, and found that “*the naive beliefs about the potential of EMF exposure to cause harm were highly influenced by specific content elements of the brochure.*”.

## **Special Segments of the Public**

Besides the general, non-specialized, non-technical lay public, other more specialized sectors of the public need to be better informed about the science of EMF and health. These are physicians in general (occupational physicians in particular, since they are involved with environmental health and health risks posed by environmental agents), industrial hygiene and safety technicians and engineers, etc.

For these professions, the best approach seems to be courses. Sabbatini (2009b, submitted), has developed the first course of this kind in Latin America, specifically geared towards occupational physicians, and an on-line video lecture with the basics of EMF and health, and which are freely available over the Internet. These products were developed in reaction to a survey with more than 400 occupational physicians and industrial safety and hygiene technicians, which indicated that more than 80% of the participants wished to attend such a course (Sabbatini, 2008, submitted).

## **The Role of Governments and International Agencies**

Several international agencies deal with the subject of NIR, notably WHO, IRPA and ICNIRP. WHO is the only institution of the United Nations with a clear mandate to promote research over possible health effects of exposure to NIR and, through the International EMF Project, it compiles information and coordinates available resources from other international and national agencies and research institutions. Such an accumulation of scientific facts must be transmitted to the public at large in order to avert public apprehension to the widespread diffusion of new technologies. Now the fact is that very few people visit the EMF Project web page <http://www.who.int/peh-emf/en/>.

It should be normal that local agencies contribute to disseminating WHO-EMF Project results and fact data until information reaches the public. Nevertheless very few Latin American countries participate in the EMF project.

What is the situation in Latin America regarding the role of government?

The OAS, the Organization of American States, the local equivalent of the UN, has recognized the importance of Telecommunications and long ago established the CITELE, <http://www.citel.oas.org/>. CITELE is the main forum in the hemisphere for governments and the private sector to meet and coordinate regional efforts to develop the Global Information Society according to the mandates of the General Assembly of the Organization and the mandates entrusted to it by Heads of State and Government at the Summits of the Americas. CITELE meets periodically, and the proceedings of every meeting are the best compilation of up-to-date regulations and activities on Telecommunications in the Americas.

In the prologue to the most recent version (CITELE, 2003), Héctor Mario Carril, Vice President of the Permanent Consultative Committee II: Radiocommunications including Broadcasting, writes:

*“Growing deregulation of telecommunication services in the Americas has increased the number of operator companies and the development of radio systems with its consequent increase of EMF sources. Due to the generalized use of these technologies , public worry has also risen and accurate scientific studies are necessary to resolve any doubt and allow sustainable decision making in order to preserve public health while maintaining an effective communication among citizens, providers and authorities.*

*Said communication about the possible environmental risks posed by technology play an important role and should be an interactive process of exchange of information and opinions among all persons involved, scientists, government, industry, citizens.*

*Scientific information may help people to understand both the benefits and eventual complications of EMFs and may help regulators to evaluate different options regarding risk management and to establish safety measures allowing*

*assessment of the consequences derived from different decisions”*

Even when the message clearly states the importance of providing sound, science-based, information about EMF and health to the public, this is not provided with the compilation of Latin American regulations contained in the paper above. Also there is some reluctance (or perhaps simply negligence) to provide this information and communicating it to the population. This has been observed on the very few web pages of pertinent Latin American government agencies identified so far. Therefore, this message becomes a recommendation of what should be done rather than a statement of what is actually happening.

## **Ethical and Professional Responsibility of the Mass Media**

Mass media, such as radio, TV and the Internet are nowadays the most powerful way of capturing the mind and influencing large numbers of people. When well conducted, mass communication campaigns that utilize a combination of several media outlets simultaneously can be extremely effective. For example, in 2004, when a long drought and a lack of capital investments in power plants put Brazil in the delicate situation of having to curtail consumption of electric energy, the federal government launched a highly successful media campaign, complementing a number of other legal measures such as increasing billing for excess energy consumption and the encouragement of the wholesale substitution of incandescent lamps by long-life fluorescent ones. The result was a sudden drop of more than 30% of usage of energy which remained until the reservoirs of hydroelectric dams were full again, several months later.

Science reporting in the traditional Latin American media is very restricted and, with few exception, lacking in excellence standards. Most of the news about EMF repercussions on human health consists simply in uncritical translation or reproductions of press releases and news pieces from foreign media and news agencies. Original reporting in newspapers and TV and radio news programs is very rare, in the sense that the reporters go back to the original sources of information (scientific journals) and the number of scientific journalist who have the ability to scan the original literature and filter out papers with low methodological quality are exceedingly small.

The all important role of mass media can be clarified by fundamental behavioral and psychological issues relating to the fear of the public about health effects of mobile communication.

The public is not intrinsically afraid of using cell phone handsets, cordless phones, and other kinds of wireless radio communication devices, and it seems that no amount of alarmist theories, or even anecdotal reports of detrimental effects on health of users will substantially decrease their wide dissemination in modern society, as long as real and perceived benefits are large, irreversible and valued by

society as a whole. This has already been seen in other areas, such as the adoption of risky products and behaviors. In addition, no amount of information or campaigning will change this (unless the health effects were proved to be quite catastrophic, such as in smoking tobacco), and will make people feel that mobile phones are not necessary;

The public is somewhat afraid, or suspicious, of potential health effects of visible and large outdoor *towers* and *antennas* (base stations). We emphasize visible and large here on purpose. This is a kind of fear of the unknown, so that educational and informational campaigns *could* have an effect here. On the other hand, this fear will eventually disappear, due to two factors: the public will get used to the antennas, due to their ubiquity (as it happened with electric transmission wires in posts and large transformers), and the antennas will decrease in size and become unobtrusive (as already happens with WiFi access points and microcell base stations);

This fear has been fueled by media reports and activists, based more on ideology than on scientific facts.

Key points in the responsibility of mass media are: the uncritical acceptance and publication of all news from the international press and dissemination of results of papers with poor methodological quality or findings not confirmed by independent replication studies : amplification of position statements of ideologically-driven interest groups; and the lack of journalistic ethics when information in polemical areas is published without consulting opponents with differing views.

Therefore strong action towards educating journalists as well as ongoing debate with activists (legislators and the judiciary system) would achieve the highest impact. We feel that universities should strive to produce good science and technology reporters, with a multidisciplinary background, but mostly able to judge the quality of original papers and to criticize the published results.

## **Conclusions of Social Issues**

Latin American references on Public Communication and Social Research regarding EMF are scarce. Most of this review was based on references from country reports in Europe, the USA or other non American countries. The only ongoing research project we know about is, “An assessment of the social impact of mobile telephony in Brazil. I. Well being, Health and Security”, being conducted by Edumed, Brazil and so far no results have been published.

- There is a clear need to carry out more research concerning social aspects of EMF in Latin America, along the lines of studies conducted in Europe, Chile and Brazil. What is more important, is to gauge the impact of

measures taken, whether regulatory, precautionary or simply communicational.

- The public needs more information. It is astonishing, to say the least, that given the degree of conflict on the subject of EMF and health, there exists so few attempts to inform the public via the mass media or the Internet in Latin America. Obviously more effort is needed in every Latin American country.
- A sustained effort would be made easier if we build and sustain a reference location for Latin America. A repository of information could be maintained and research efforts coordinated for the region, establishing and maintaining at the same time fluid communications among anyone interested on the subject: researchers and professionals in engineering, biology and medicine, government agencies and telecommunications companies, etc...
- If we combine our previous comments into recommendations it would be to set up a national (or even better, a regional) web page specifically dedicated to EMF & Health. Returning to our Aims and Objectives section: **independent consensus** and **scientific quality**, it follows that the page should be based either in the appropriate government regulatory agency or in a prestigious university or research institute.
- Finally it has been well documented that attempts by overzealous governments *“to do something about people’s concerns with EMF & health”* should be carefully evaluated before proceeding, since excessive recommendations on precautionary actions or, even worse, implementing local rules for antenna deployment or lowering threshold limits for EMF with the idea of being more strict and safety conscious than others, tends to increase concern, confusion and mistrust in government instead of reassuring people.
- Having many different rules by municipalities only creates confusion and mistrust of government. On the other hand, adopting science based regulations recommended by international bodies such as ICNIRP countrywide should contribute to peoples’ reassurance. In turn, international bodies such as ICNIRP and CITELE are working hard to harmonize standards among countries.
- A larger participation of governmental agencies in international activities, including the International EMF project of WHO would sound to the public as a message of attention to the issue and would help increase trust in the authorities regarding this area of knowledge.
- We recommend also that focused seminars and conferences, as well as



several courses be developed and offered in Portuguese and Spanish to special interest groups, such as occupational physicians, journalists, bioengineers, industrial safety and hygiene, etc.

## **Chapter 3 - Non-Ionizing Radiation Protection Standards and Policies**

### **Introduction**

The purpose of this chapter is to provide information on standards and policies in Latin American countries. This will inform government and other authorities about policies and regulations in the region and about international standards recommended by WHO.

Research on non-ionizing radiation (NIR), particularly radiofrequency (RF) fields, started in the 1950's, just after the Second World War, but regulations limiting their exposure began a long time after.

The first significant effort to establish international limits on NIR exposure was by the International Radiation Protection Association (IRPA), which formed a working group on NIR charged to examine radioprotection issues. In 1977 this working group became the International Non-ionizing Radiation Committee (INIRC).

Within the framework of WHO's Environmental Health Criteria Program, the IRPA/INIRC developed several environmental health criteria (EHC) documents on NIR, each of which included overviews of the physical characteristics, measurement and instrumentation, sources and applications of various NIR, a comprehensive review of the literature on biological effects, and an evaluation of the health risks of exposure to NIR. These EHCs have provided the scientific database for the subsequent development of exposure limits and codes of practice relating to protection from NIR exposure.

In 1992 IRPA/INIRC became the International Commission on Non- Ionizing Radiation Protection (ICNIRP), a new independent scientific organization to assess research and develop international guidelines on NIR exposure limits. ICNIRP works cooperatively with WHO and the last revision of the ICNIRP guidelines was published in 1998. The ICNIRP 1998 guidelines have been endorsed by WHO, the International Labour Office (ILO) and the International Telecommunications Union (ITU), and they have been adopted as their national standard by more than 50 countries worldwide.

ICNIRP assesses all the peer-reviewed scientific literature, including those reporting both thermal and non-thermal effects and are based on evaluations of biological effects that have been established to have health consequences. The main conclusion from the WHO and all rigorous national reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health.

WHO's International Electromagnetic Fields (EMF) Project has been promoting the adoption of science – based international standards such as the ICNIRP (1998) guidelines.

One of the reasons for increasing public anxiety about EMF exposures has been the introduction of new technologies and the disparities in national EMF standards around the world. To encourage the development of exposure limits and other control measures that provide the same high level of health protection to all people, WHO has been promoting the harmonization of national standards.

In order to provide tools for the achievement of harmonization, WHO's International EMF Project has compiled a worldwide standards database [<http://www.who.int/docstore/peh-emf/EMFStandards/who-0102/Worldmap5.htm>] and has published two policy handbooks [WHO, 2007a, 2007b] that are very useful for countries developing NIR standards

The ITU has made recommendations on compliance of telecommunication systems with EMF exposure limits. At the regional level in Latin America the Inter-American Telecommunication Commission (CITEL) has compiled information and regulations of: the WHO, the Pan American Health Organization (PAHO), the ITU, the ICNIRP, the Mobile Manufacturers Forum (MMF), the Institute of Electrical and Electronics Engineers (IEEE) and the International Electrotechnical Commission (IEC), with respect to the effects of NIR and the established technical standards. CITEL has also compiled EMF regulations in force in Latin America and other Regions [Inter American Telecommunication Commission XXXX].

## **International Guidelines**

### **International Commission for Non Ionizing Radiation Protection (ICNIRP)**

ICNIRP guidelines (ICNIRP, 1998) are the most accepted guidelines for NIR world wide. The complete text of ICNIRP Guidelines can be found at the ICNIRP website [www.icnirp.org](http://www.icnirp.org)

#### **Basic Restrictions**

Basic Restrictions are restrictions on EMF exposure based on established health effects. These Basic Restrictions depend on the EMF frequency and are given in terms of current density, specific absorption rate (SAR) or power density. ICNIRP states that “protection against adverse health effects requires that these restrictions are not exceeded”

Following the determination of the threshold levels, the level of exposure at which the first established adverse health effects are produced, and dividing them by a safety factor of 10, leads to the value for the basic restrictions for workers. The

basic restrictions for general public exposure are obtained by dividing the threshold levels by a factor of 50. That is general public exposure limits are five times stricter than for occupational exposure. Fig. 1 shows the relationship between adverse health effects threshold levels and ICNIRP basic restrictions.

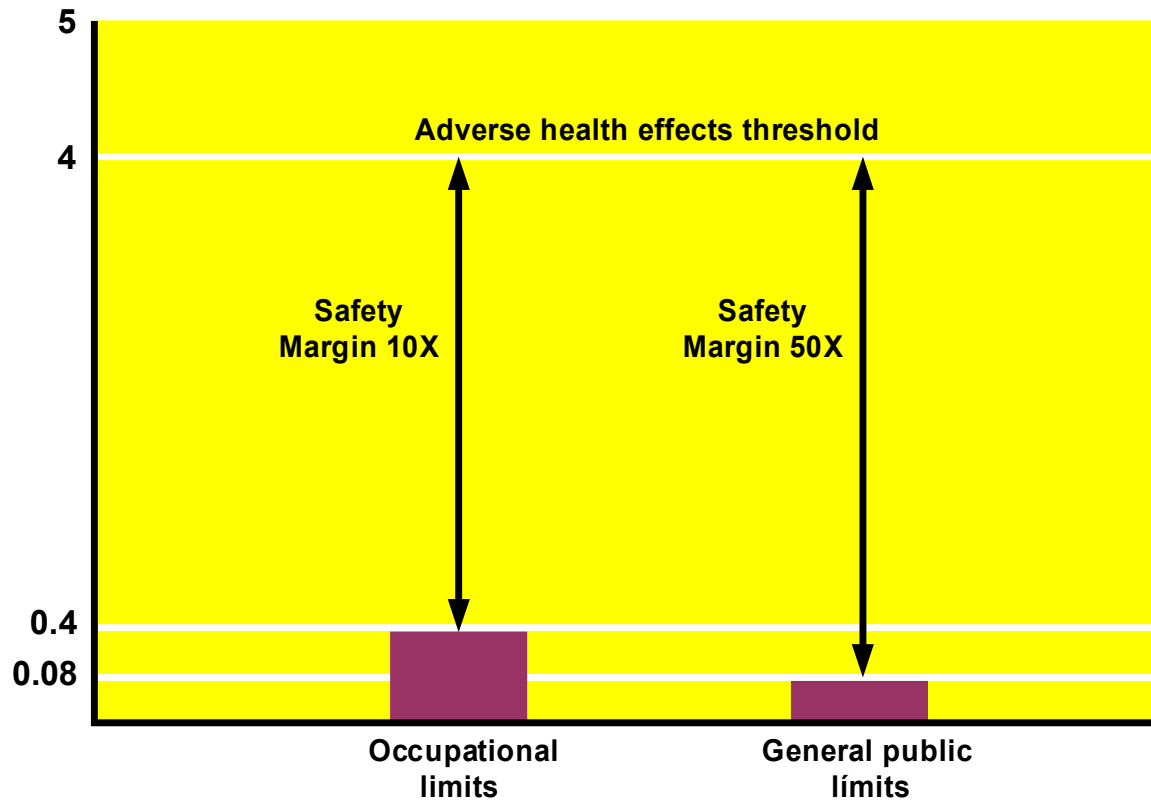


Figure 1 Safety factors for occupational and population ICNIRP basic restrictions in SAR

**Reference levels for field measurement**

The basic restrictions are physical quantities determined from the interaction mechanisms that produce adverse health effects. However they are difficult to measure in the field. This is why basic restrictions are related to equivalent reference levels that are easy to measure with instruments in the field. These reference levels are obtained from the basic restrictions by using computational models and measurement methods.

The reference levels are intended to be spatially averaged values over the entire

body, but with the proviso that the basic restrictions on localized exposure are not exceeded.

For frequencies up to 10 GHz the basic restrictions are given in terms of the current density and whole-body and localized SAR. Their corresponding reference levels are provided in terms of the easily measurable quantities, electric and magnetic fields, the magnetic flux density and the power density. For frequencies from 10 to 300 GHz the reference levels are exactly the same as basic restrictions, given in terms of power density.

For frequencies below 10 MHz the electric and magnetic fields are uncoupled from each other when the EMF is measured within about one wavelength from the radiating antenna, so both fields should be measured to determine compliance. At distances greater than about one wavelength from the radiating antenna the electric and magnetic fields have a constant relationship, and so only the electric or magnetic field needs to be measured.

Above 10 MHz the electric and magnetic fields are coupled and electric and magnetic field strengths are related by the medium impedance  $\eta_0 = E/H = 377$  ohms, which is valid for the far field. In the near field electric and magnetic fields are uncoupled and as a conservative approach the levels for the far fields could be used since the levels of electric and magnetic fields can not independently exceed the SAR restrictions.

### **Simultaneous exposure to multiple frequency fields**

In real situations the exposure to EMF includes more than one frequency, so ICNIRP has developed formulas to calculate both basic restrictions and reference levels to determine compliance for these exposure situations.

### **Basic restrictions for telecommunication services**

The main RF services include radio broadcast and mobile telephony (including PCS), whose frequency range goes from 50 – 2000 MHz. However, as wireless systems will play a very important role in the near future this frequency range will expand. ICNIRP basic restrictions for the main telecommunication services are shown in Table 1

**Table 1 ICNIRP basic restrictions for general public exposure to the main telecommunication services and systems**

Services/systems	Frequency range (MHz)	Whole- body average SAR ( $Wkg^{-1}$ )	Localized SAR (head and trunk) ( $Wkg^{-1}$ )	Localized SAR (limbs) ( $Wkg^{-1}$ )
FM broadcast	88- 108 MHz	0.08	NA	NA
VHF TV	54- 88 MHz 174- 216 MHz	0.08	NA	NA
UHF TV	407- 806 MHz	0.08	NA	NA
Trunking 800 MHz Mobile	806-869 MHz 824-894MHz	0.08	2	4
Telephony 800 MHz Mobile	890-960 MHz	0.08	2	4
Telephony 900 MHz		0.08	2	4
PCS 1800	1710- 1880 MHz	0.08	2	4
PCS 1900	1850- 1900 MHz	0.08	2	4

NA: Not applicable

### **Reference levels for telecommunication services**

ICNIRP reference levels for the main telecommunication services are given in Table 2 and illustrated in Fig. 2

**Table 2 ICNIRP reference levels for general public exposure from the main telecommunication services**

Services	Frequency range (MHz)	E- field strength ( $Vm^{-1}$ )	H- field strength ( $Am^{-1}$ )	B- field ( $\mu T$ )	Equivalent plane wave power density $S_{eq}$ ( $Wm^{-2}$ )
FM broadcast	88- 108 MHz	28.0	0.073	0.092	2.0
VHF TV	54- 88 MHz 174- 216 MHz	28.0	0.073	0.092	2.0

UHF TV	407- 806 MHz	29.8	0.08	0.099	2.0
Trunking 800 MHz	806-869 MHz	40.0	0.10	0.13	4.3
Mobile Telephony 800 MHz	824-894MHz	40.6	0.11	0.14	4.4
Mobile Telephony 900 MHz	890-960 MHz	41.0	0.11	0.14	4.5
PCS 1800	1710- 1880 MHz	56.9	0.15	0.19	8.6
PCS 1900	1850- 1900 MHz	60.5	0.16	0.20	9.7

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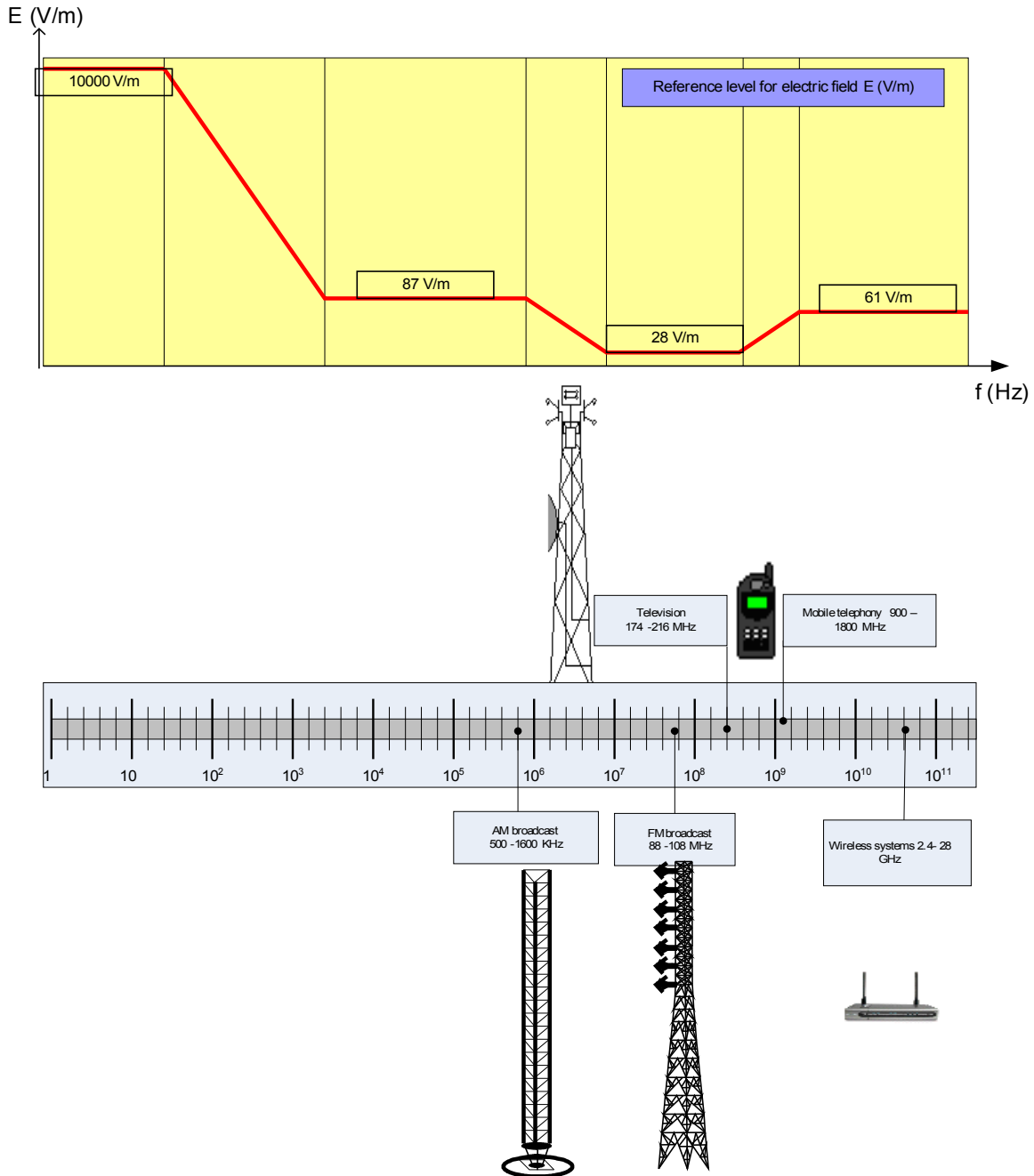


Figure 2 Electric field reference levels for the main telecommunication services

## IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

The IEEE Standard for Safety Levels with Respect to Human Exposure to Radio



Frequency Electromagnetic Fields, 3 kHz to 300 GHz (IEEE, 2006) is aimed to protect people against established adverse health effects in human beings exposed to electric, magnetic and electromagnetic fields in the frequency range of 3 kHz to 300 GHz. The IEEE Standard C95.1-2005 is the revision of IEEE Standard C95.1-1991.

These recommendations are expressed in terms of basic restrictions (BRs) and maximum permissible exposure (MPE) values.

The basic restrictions are exposure restrictions to electromagnetic fields based on established health effects. The maximum permissible exposure values (MPEs) are derived from the BRs and are limits on external fields and induced and contact current. These recommendations are not intended to prevent interference with medical and other devices that may be susceptible to radiofrequency (RF) fields.

Generally speaking the IEEE Standard is less strict than the ICNIRP Guidelines although it is based on the same science

Details on how to purchase the IEEE Standard C95.1-2005 can be found on the web site of IEEE; [www.ieee.org](http://www.ieee.org)

### **Basic restrictions for telecommunication services**

For the frequencies of important telecommunication systems the applicable IEEE basic restriction are given in Table 3.

**Table 3 Basic restrictions for the main telecommunication services and systems**

Services/systems	Frequency range (MHz)	Whole- body average SAR (Wkg <sup>-1</sup> )	Localized SAR (head and trunk ) (Wkg <sup>-1</sup> )	Localized SAR (limbs) (Wkg <sup>-1</sup> )
FM broadcast	88- 108 MHz	0.08	NA	NA
VHF TV	54- 88 MHz	0.08	NA	NA
	174- 216 MHz			
UHF TV	407- 806 MHz	0.08	NA	NA
Trunking 800 MHz	806-869 MHz	0.08	2	4
Mobile Telephony 800 MHz	824-894MHz	0.08	2	4
Mobile Telephony 900 MHz	890-960 MHz	0.08	2	4
PCS 1800	1710- 1880 MHz	0.08	2	4
PCS 1900	1850- 1900 MHz	0.08	2	4

NA: Not applicable

### Reference levels for telecommunication services

Reference levels for the main telecommunication services and systems are given in the Table 4.

**Table 4. Reference levels for the main telecommunication services and systems**

Service	Frequency range (MHz)	$E_{rms}$ (V/m)	$H_{rms}$ (A/m)	$S_{rms}$ E field, H-field		Averaging time $[E]^2$ , $[H]^2$ o S (min)	
VHF TV	54-88	27.50	0.13	2.00	6.27	30	6
FM broadcast	88-108	27.50	0.08	2.00	2.14	30	6
VHF TV	174-216	27.50	0.07	2.00	2.00	30	6
Trunking 800 MHz	806-869	-	-	4.19		30	
Mobile Telephony 800 MHz	824- 894	-	-	4.30		30	
Mobile Telephony 900 MHz	890-960	-	-	4.63		30	
PCS 1800 MHz	1710-1880	-	-	8.98		30	
PCS 1900 MHz	1850-1900	-	-	9.38		30	

### **ITU-T Recommendation K.52 “Guidance on complying with limits for human exposure to electromagnetic fields”.**

The International Telecommunications Union (ITU) is the United Nations body with responsibility for telecommunication services and has issued recommendations on compliance with safety limits for EMF used in telecommunication systems. ITU-T Recommendation K.52 (ITU, 2004) helps determine compliance with safety limits for human exposure to EMF from telecommunication installations and mobile handsets or other RF emitting devices used against head. It presents general guidance, a calculation method, and an installation assessment procedure. The assessment procedure for telecommunication installations is based on safety limits provided by ICNIRP and helps users determine the likelihood of installation compliance based on accessibility criteria, antenna properties and emitter power. Recommendation K.52 proposes the IEC Standard for compliance measurement of mobile handsets [IEC, 2004]. ITU-T Recommendation K.52 is available from their web site: [www.itu.int](http://www.itu.int)

## **Compliance of mobile handsets**

ITU-T Recommendation K.52 states that compliance with the ICNIRP safety limits for mobile handsets or other RF devices operating in the frequency range of 300 MHz to 3 GHz used against the head, can be achieved by applying the measurement procedures for SAR in IEC 62209 (2004).

## **Compliance of radio stations**

Telecommunications equipment is broadly defined as an intentional or unintentional RF emitter. For unintentional emitters it is assumed the fields produced are orders of magnitude below the safety limits, so it is not necessary to perform EMF assessment to assure compliance with safety limits. For an intentional emitter, it is recommended to determine an appropriate procedure for exposure assessment as a function of the operating power, antenna gain, frequency, orientation and directivity of the transmitting antenna and the operating environment of the installation.

According to Recommendation K.5 the steps to conduct the exposure assessment are:

- a) To classify potential exposure to EMF as belonging to a compliance zone, occupational zone or an exceedance zone.
- b) To perform the *exposure level assessment procedure* that considers as general criteria: the worst-case emission conditions and the simultaneous presence of several EMF sources, even at different frequencies.
- c) To classify the installation as a function of a set of reference antennas and a set of accessibility conditions as inherently compliant, normally compliant or provisionally compliant and
- d) Where necessary define mitigation techniques

## **USA FCC guidelines**

The USA Federal Communications Commission guidelines (FCC, 1997) are used as guidance for some Latin American countries e.g. Bolivia and Peru.

### **General considerations**

The revised OET Bulletin 65 issued by the Federal Communications Commission of the United States (FCC) in August 1997 includes the Maximum Permissible Exposure limits. These guidelines provide assistance in determining whether a transmitting facility or device complies with the limits adopted for FCC.

The limits adopted by FCC are generally based on "IEEE Standard for Safety

Levels with Respect to Human Exposure to Radio Frequency Fields, 3 kHz to 300 GHz” ANSI/IEEE C95.1-1992. Tables 6 and 7 give the limits of exposure for the General Population and Workers

**Table 6 Limits for General Population/ Uncontrolled Exposure**

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm <sup>2</sup> )	Averaging Time  E <sup>2</sup>  ,  H <sup>2</sup>   or S (minutes)
0.3 – 3.0	614	1.63	(100)*	30
3.0 – 30	824 / f	2.19 / f	(180 / f <sup>2</sup> )*	30
30 – 300	27.5	0.073	0.2	30
300 – 1 500	N/A	N/A	f / 1500	30
1500 – 100 000	N/A	N/A	1.0	30

**Table 7 Limits for Occupational/ Controlled Exposure**

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm <sup>2</sup> )	Averaging Time  E <sup>2</sup>  ,  H <sup>2</sup>   or S (minutes)
0.3 – 3.0	614	1.63	(100)*	6
3.0 – 30	1842 / f	4.89 / f	(900 / f <sup>2</sup> )*	6
30 – 300	61.4	0.163	1.0	6
300 – 1 500	N/A	N/A	f / 300	6
1500 – 100 000	N/A	N/A	5.0	6

f= frequency in MHz

\* Plane –wave equivalent power density

**NOTE 1:** Occupational/controlled limits apply to situations in which persons are exposed as consequence of their employment, provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Limits for occupational /controlled exposure also apply in situations when an individual is in transit through a location where occupational/controlled limits apply provided he or she is made aware of the potential for exposure.

**NOTE 2:** General population/ uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure.

It’s important to point out that the FCC’s OET Bulletin 65 includes guidelines on how to comply with RF safety standards so it is used for some Latin American telecommunication administrations as a basis for compliance with their regulation.

## Regulation and Standards in Latin America

Currently in Latin America there are 10 countries that have implemented non-ionizing radiation standards for telecommunication systems: Argentina, Bolivia, Brazil, Colombia, Chile, Ecuador, Panama, Paraguay, Perú and Venezuela. Most of these standards are based on ICNIRP guidelines as can be seen in Table 8. Others are being developed, such as Costa Rica, Dominican Republic and Uruguay.

**Table 8 Summary of main aspects on Latin American non-ionizing radiation regulations**

COUNTRY	REFERENCE	FREQUENCY RANGE/SERVICES	SENSITIVE AREAS	MINIMUM DISTANCES
ARGENTINA	Before ICNIRP guidelines 1998 were issued, but are nearly the same levels	100 kHz- 300 GHz	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation, but in some cities like Rosario there is a limit of 800 m between towers. For tower height less than 5 m of the same service provider the limit is 100 m.
BOLIVIA	FCC	300 kHz- 100 GHz	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation.
BRAZIL	ICNIRP	9 kHz- 300 GHz	There is to sensitive areas in the national regulation. In some towns there are stricter limits for sensitive areas	It was established, 50 m as the limit for sensitive areas There is no reference to minimum distances in the national regulation.
CHILE	ICNIRP	Mobile telephony and PCS	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation.



<b>COUNTRY</b>	<b>REFERENCE</b>	<b>FREQUENCY RANGE/SERVICES</b>	<b>SENSITIVE AREAS</b>	<b>MINIMUM DISTANCES</b>
COLOMBIA	ICNIRP	9 kHz- 300 GHz	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation.
ECUADOR	ICNIRP	9 kHz- 300 GHz	There is no reference to sensitive areas	
PANAMA	IEEE	300 kHz – 100 GHz	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation.
PARAGUAY	ICNIRP	0 kHz- 300 GHz	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation
PERÚ	ICNIRP	9 kHz- 300 GHz	It is considered that places nearby schools and hospital must need an additional protection. In these areas are used half of the ICNIRP reference levels for public exposure	There is no reference to minimum distances in the national regulation
VENEZUELA	ICNIRP	3 kHz- 300 GHz	There is no reference to sensitive areas	There is no reference to minimum distances in the national regulation

## ARGENTINA

Argentina has the oldest regulation on NIR in the Latin American Region (Ministry of Public Health and Social Action of Argentina, 1995; Communications Secretariat of Argentina, 2000). When Maximum Exposure Levels (MEP) were established in Argentina the ICNIRP (1998) guidelines had not been published but the limits were known and so the Argentinean exposure limits are the same. The Argentinean regulation on MEP for NIR were based on earlier guidelines published by the ICNIRP predecessor committee INIRC/IRPA and research carried out by the Argentinean Ministry of Health in cooperation with State Secretariat for Science and Technology. The fifteen years of research was summarize in the “Handbook of safety standards for radiofrequencies and microwaves between 100 kHz and 300 GHz” and “Radiofrequency radiations: biophysics, biomedical considerations and criteria for establishing exposure standards”.

In 1995 the Ministry of Public Health and Social Action, through Resolution N° 202 MSyAS/95 established the MEP values for NIR. In 2000 by means of Resolution N° 530 SC/2000 of the Communications Secretariat, the MPE limits from the Ministry of Health were adopted for telecommunication systems.

The National Communications Commission in Resolution CNC 3690/2004 established that radio and broadcast station licensees must demonstrate that radiations generated by their radio-base-station antennae do not have adverse effects on nearby populations through compliance with the MEPs. This document also gives the measurement protocol for NIR.

According to Resolution N° 269 CNC/2002, an exposure evaluation must be carried out to meet parameters recommended in Resolution N° 202/95 before installing antennae for telecommunications. Table 9 gives the Maximum Permissible Limits for Argentina

**Table 9 Maximum Permissible Limits for general public exposure to non-ionizing - radiation power density, electric and magnetic fields**

Frequency range f (MHz)	Equivalent plane wave power density S (W/m <sup>2</sup> )	Electric Field E (V/m)	Magnetic Field H (A/m)
0.3-1	20	275	0,73
1-10	20/f <sup>2</sup>	275/f	0.73/f
10-400	0,2	27,5	0,073
400-2000	f/2000	1.375f <sup>1/2</sup>	-
2000-100000	1	61,4	-



## BOLIVIA

On April 12, 2002, the Technical Committee of the Telecommunications Superintendent, in accordance with the Report COMTEC /2002/001, adopted the guidelines issued by the Federal Communications Commission of the United States (FCC).

The Telecommunications Superintendent through Nota Interna ST/NI/INT/33/2002 of April 19, 2002, based on the Technical Report COMTEC/2002/001 of April 12, 2002, recommended approval of the Technical standard "Human Exposure Limits for Radiofrequency Electromagnetic Fields". This standard establishes the maximum permissible limits for the human exposure to radiofrequency electromagnetic fields in the frequency range of 300 kHz to 100 GHz.,

This Standard uses as reference the following documents:

- U.S. Federal Communications Commission 96-326: Guidelines for Evaluating the Environmental Effects of Radiofrequency Radiation.
- OET Bulletin 65 - "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields".
- Supplement A to OET Bulletin 65 – "Additional Information for Radio and Television Broadcast Stations".
- Supplement B to OET Bulletin 65 – "Additional Information for Amateur Radio Stations".
- Supplement C to OET Bulletin 65 – "Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radiofrequency Emissions"
- "A Local Government Official's Guide to Transmitting Antenna RF Emission Safety: Rules, Procedures, and Practical Guidance". FCC Junio de 2000.

The Bolivian limits for general population and occupational exposure are presented in Tables 10 and 11

**Table 10 Limits for General Population/ Uncontrolled Exposure**

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm <sup>2</sup> )
0.3 – 1.34	614	1.63	100

1.34 – 30	824 / f	2.19 / f	180 / f <sup>2</sup>
30 – 300	27.5	0.073	0.2
300 – 1500	N/A	N/A	f / 1500
1500 – 100000	N/A	N/A	1.0

**Table 11 Limits for Occupational/ Controlled Exposure**

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm <sup>2</sup> )
0.3 – 3.0	614	1.63	100
3.0 – 30	1842 / f	4.89 / f	900 / f <sup>2</sup>
30 – 300	61.4	0.163	1.0
300 – 1500	N/A	N/A	f / 300
1500 – 100000	N/A	N/A	5

## BRASIL

In July 1999, the regulatory body for telecommunications, the National Agency for Telecommunications (ANATEL: Agência Nacional de Telecomunicações), decided to adopt the ICNIRP reference levels as a guide for the evaluation of human exposure to radiofrequency electromagnetic fields from telecommunication-services transmitter stations. The Brazilian limits for occupational and general public exposure are shown in tables 12 and 13.

In July 2002 Brasil started the development of regulations for non-ionizing radiations through Resolución N° 303 that approved the report “The Exposure Limits to Electric, Magnetic and Electromagnetic Fields in the frequency range of 9 kHz to 300 GHz” (ANATEL, 2002a, 2002b)

**Table 12. Limits for occupational exposure to RF EMF in the radiofrequency band from 9 kHz to 300 GHz**  
(unperturbed rms values)

Frequency range	Electric field strength E (V/m)	Magnetic field Strength H (A/m)	Equivalent plane wave power density S <sub>eq</sub> (W/m <sup>2</sup> )
9 kHz – 65 kHz	610	24.4	–
0.065 MHz – 1 MHz	610	1.6 / f	–
1 MHz – 10 MHz	610 / f	1.6 / f	–
10 MHz – 400 MHz	61	0.16	10
400 MHz – 2000 MHz	3 f <sup>0.5</sup>	0.008 f <sup>0.5</sup>	f / 40
2 GHz – 300 GHz	137	0.36	50

**Table 13 Limits for general public exposure to RF EMF in the radiofrequency band from 9 kHz to 300 GHz**  
(unperturbed rms values)

Frequency range	Electric field strength E (V/m)	Magnetic field Strength H (A/m)	Equivalent plane wave power density $S_{eq}$ (W/m <sup>2</sup> )
9 kHz – 150 kHz	87	5	–
0.15 MHz – 1 MHz	87	$0.73/f$	–
1 MHz – 10 MHz	$87/f^{0.5}$	$0.73/f$	–
10 MHz – 400 MHz	28	0.073	2
400 MHz – 2000 MHz	$1.375f^{0.5}$	$0.0037f^{0.5}$	$f/200$
2 GHz – 300 GHz	61	0.16	10

On May 5th, 2009 the President of Brazil issued the Law N° 11.934 “ Dispõe sobre limites a exposição humana a campos elétricos, magnéticos e eletromagnéticos: altera a Lei N° 4.771, de 15 de setembro de 1965; e dá outras providências”. This law, among others, enacts the following:

- Enforces ICNIRP guideline limits as Brazilian limits in the frequency range up to 300GHz, including SAR limits for occupational and general public exposures.
- The scope of this law includes electric energy service providers, telecommunication service providers that use radiocommunication transmitter stations and mobile phone manufacturers.
- It defines as critical areas those that located within 50 m from hospitals, clinics, schools and nurseries.
- It provides mechanisms for financing research on EMF and possible health effects from electric energy networks and telecommunication networks.
- It establishes monitoring of EMF for electric energy networks, telecommunications networks and mobile phone manufacturers. For telecommunications providers the monitoring data must be online.
- It also establishes that compliance results must be published on the web.

## CHILE

On May 8, 2000, the regulatory body for telecommunications the

Telecommunication Subsecretariat (SUBTEL, 2000) of the Ministry of Transports and Telecommunications, issued Resolución N° 505/2000 “Norm on Safety Requirements for Telecommunication Installations”. Despite its title, this regulation only establishes requirements for mobile telephony systems. It requires that emissions from antennae for the Mobile Telephony Public Service are to be less than  $435 \mu\text{W}/\text{cm}^2$  ( $4.35 \text{ W}/\text{m}^2$ ) in places accessible to the general public. The Mobile Telephony Public Service includes Mobile Cellular Telephony Public Service in the 800 MHz frequency band and the Digital Mobile Telephony Public Service in the 1900 MHz frequency band.

The limit values issued by SUBTEL are based on the ICNIRP reference levels for the 800 MHz frequency band so the reference levels for 1900 MHz frequency band are much stricter than ICNIRP. The frequency bands for Mobile Cellular and Digital Mobile Telephony Public Services are 820-920 MHz and 1850-1990 MHz respectively.

In December 2002 Resolución N° 505/2000 (SUBTEL, 2002) was modified by adding the specific absorption rate (SAR) to the requirements to be met by mobile phones.

Table 14 gives a comparison of Chilean limits and the ICNIRP Guidelines

**Table 14 Comparison between Chilean limits and ICNIRP reference levels for general public exposure**

Frequency range	General public ICNIRP reference levels, S [ $\text{W}/\text{m}^2$ ]	Chilean limits [ $\text{W}/\text{m}^2$ ]
	for the center frequency	
Cell Band	4,35	4.35
PCS Band	9,60	4.35

## COLOMBIA

On January 31, 2005 the President of the Republic of Colombia issued the Decreto N° 195 “Limits for Human Exposure to Electromagnetic Fields”, with the approval of the Ministry of Social Protection, Ministry of Telecommunications and the Ministry of Environment, Housing and Territorial Development..

This regulation is based on the ITU Recommendation K-52 “Guidance on complying with limits for human exposure to electromagnetic fields”, which in turn endorses ICNIRP reference levels. It is for telecommunication systems in the

frequency range of 9 kHz to 300 GHz and includes the exposure limits, the requirements for persons or entities in charge of measuring EMF and the requirements for installation of radio electric stations for telecommunications. The Colombian limits are presented in the table 15

**Table 15 Limits for Human Exposure to Electromagnetic Fields**

Exposure Type	Frequency range	Electric field strength, E (V/m)	Magnetic field strength, H (A/m)	Equivalent plane wave power density, S (W/m <sup>2</sup> )
Occupational Exposure	9 kHz – 65 kHz	610	24.4	–
	0.065 MHz – 1 MHz	610	1.6 / f	–
	1 MHz – 10 MHz	610 / f	1.6 / f	–
	10 MHz – 400 MHz	61	0.16	10
	400 MHz – 2000 MHz	3 f <sup>0.5</sup>	0.008 f <sup>0.5</sup>	f / 40
General Public Exposure	2 GHz – 300 GHz	137	0.36	50
	9 kHz – 150 kHz	87	5	–
	0.15 MHz – 1 MHz	87	0.73 / f	–
	1 MHz – 10 MHz	87 / f <sup>0.5</sup>	0.73 / f	–
	10 MHz – 400 MHz	28	0.073	2
	400 MHz – 2000 MHz	1.375 f <sup>0.5</sup>	0.0037 f <sup>0.5</sup>	f / 200
	2 GHz – 300 GHz	61	0.16	10

## ECUADOR

On January 11, 2005 the National Telecommunications Council (CONATEL), the administrator and regulatory body for telecommunications, issued Resolution 01-01-CONATEL-2005 “Regulation on Protection Against Non- ionizing Radiation Generated by using Radio Electric Spectrum” (CONATEL, 2005).

This regulation is based on ITU Recommendation K-52 “Guidance on complying with limits for human exposure to electromagnetic fields”, which in turn endorses ICNIRP reference levels. It is for telecommunication systems operating in the frequency range of 9 kHz to 300 GHz and includes the exposure limits, the requirements for persons or entities in charge of measuring electromagnetic fields and requirements for the installation of radio electric stations for telecommunications.

The Ecuadorian limits are presented in table 16

**Table 16 Maximum exposure limits per fixed radio electric station**

Exposure Type	Frequency range	Electric field strength, E (V/m)	Magnetic field strength, H (A/m)	Equivalent plane wave power density, S (W/m <sup>2</sup> )
Occupational Exposure	3 – 65 kHz	610	24.4	–
	0.065 – 1 MHz	610	1.6 / f	–
	1 – 10 MHz	610 / f	1.6 / f	–
	10 – 400 MHz	61	0.16	10
	400 – 2000 MHz	3 f <sup>0.5</sup>	0.008 f <sup>0.5</sup>	f / 40
General Public Exposure	2 – 300 GHz	137	0.36	50
	3 – 150 kHz	87	5	–
	0.15 – 1 MHz	87	0.73 / f	–
	1 – 10 MHz	87 / f <sup>0.5</sup>	0.73 / f	–
	10 – 400 MHz	28	0.073	2
	400 – 2000 MHz	1.375 f <sup>0.5</sup>	0.0037 f <sup>0.5</sup>	f / 200
	2 – 300 GHz	61	0.16	10

## PANAMA

On November 29, 2007 the Ministry of Health, through Resolution N° 1056 established the regulation for location, installation and operation of antenna towers for mobile telephony, trunking and similar systems as well as antenna towers for radiofrequency repeaters. This document included the limits for power density in the frequency range of 0.3 MHz - 100 GHz that is based on the Action Levels of the IEEE Standard C95.1™-2005 Maximum Permissible Exposure limits but it is not the same. Resolution N° 1056 was revoked on October 21, 2008 when the National Authority for Public Services (ASEP) assumed responsibility for the regulation and technical norms, installation systems and telecommunications antennas, and public services for telecommunications, radio and television.

On October 28, 2008 the National Authority for Public Services (ASEP) issued the Resolution AN N° 2161 endorsing the standard which was given in the Resolution N° 1056 (ASEP, 2008)

The Panamanian limits are presented in Table 17

**Table 17 Power Density Limits**

Power density mW/cm <sup>2</sup>	Frequency (MHz)
100	0.3 a 3
180 / f <sup>2</sup> ,	3 – 30
0.2	30 – 300
f / 1500	300- 1500

1	1500 – 100 000
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NOTE:  $f$  is the frequency in MHz.

## PARAGUAY

On March 2, 2007 the Ministry of Health and Social Welfare, by means of Decreto N° 10071, established the regulation for Maximum Permissible Limits for exposure of persons to NIR produced by activities that generate EMF in the frequency range of 0 Hz - 300 GHz. It endorses ICNIRP reference levels as their national NIR standard.

It states that licensees from the different services (including telecommunications) must adopt measures (including monitoring of EMF to ensure the compliance of the Maximum Permissible Limits (LMP) by stations or installations that emit radiations.

The authority in charge of the application is the Secretariat of the Environment and states that procedures and analytical methods to be used for telecommunications are those established in the International Union for Telecommunications (ITU) Recommendation K.52.

Table 18 gives the Paraguayan limits.

**Table 18 ICNIRP reference levels  
(0 Hz – 300 GHz unperturbed rms values)**

Exposure Type	Frequency range	E- field strength (Vm <sup>-1</sup> )	H- field strength (Am <sup>-1</sup> )	B- field (μT)	Equivalent plane wave power density S <sub>eq</sub> (Wm <sup>-2</sup> )
Occupational Exposure	up to 1 Hz	–	1.63 x 10 <sup>5</sup>	2 x 10 <sup>5</sup>	–
	1 – 8 Hz	20 000	1.63 x 10 <sup>5</sup> / $f^2$	2 x 10 <sup>5</sup> / $f^2$	–
	8 – 25 Hz	20 000	2 x 10 <sup>4</sup> / $f$	2.5 x 10 <sup>4</sup> / $f$	–
	0.025 – 0.82 kHz	500 / $f$	20 / $f$	25 / $f$	–
	0.82 – 65 kHz	610	24.4	30.7	–
	0.065 – 1 MHz	610	1.6 / $f$	2 / $f$	–
	1 – 10 MHz	610 / $f$	1.6 / $f$	2 / $f$	–
	10 – 400 MHz	61	0.16	0.2	10
	400 – 2000 MHz	3 $f^{0.5}$	0.008 $f^{0.5}$	0.01 $f^{0.5}$	$f / 40$
	2 – 300 GHz	137	0.36	0.45	50
General Public Exposure	up to 1 Hz	–	3.2 x 10 <sup>4</sup>	4 x 10 <sup>4</sup>	–
	1 – 8 Hz	10 000	3.2 x 10 <sup>4</sup> / $f^2$	4 x 10 <sup>4</sup> / $f^2$	–
	8 – 25 Hz	10 000	4000/ $f$	5000/ $f$	–
	0.025 – 0.8 kHz	250 / $f$	4/ $f$	5/ $f$	–
	0.8 – 3 kHz	250 / $f$	5	6.25	–
	3 – 150 kHz	87	5	6.25	–
	0.15– 1 MHz	87	0.73/ $f$	0.92 / $f$	–
1 – 10 MHz	87/ $f^{0.5}$	0.73/ $f$	0.92/ $f$	–	

10 – 400 MHz	28	0.073	0.092	2
400 – 2000 MHz	$1.375f^{0.5}$	$0.0037f^{0.5}$	$0.0046f^{0.5}$	$f/200$
2 – 300 GHz	61	0.16	0.20	10

## PERU

Peru has since 2005 an environmental regulation “The Environmental Quality Standard for Non Ionizing Radiations” that establishes limits for the frequency range of 0-300 GHz, including all possible applications of electricity, medical devices, domestic appliances (microwave ovens) and of course telecommunications, but only for general public exposure (CONAM, 2005). Based on this environmental standard, limits for the different frequency ranges have been established. However, the regulation for telecommunications was established before the environmental standard.

The Environmental Quality Standard for Non Ionizing Radiations was issued by the National Council for the Environment in 2005 by means of the Supreme Decree N° 010-2005-PCM. It is based on ICNIRP reference levels for general public exposure in the frequency range of 0 Hz to 300 GHz

The Peruvian standards are presented in Tables 19- 21

**Table 19 Environmental Quality Standard for Non Ionizing Radiations**

Frequency range	E- field strength ( $Vm^{-1}$ )	H- field strength ( $Am^{-1}$ )	B- field ( $\mu T$ )	Equivalent plane wave power density $S_{eq}$ ( $Wm^{-2}$ )	Main application (not restrictive)
Up to 1 Hz	–	$3.2 \times 10^4$	$4 \times 10^4$	–	Power lines for electric trains, magnetic resonance
1 – 8 Hz	10 000	$3.2 \times 10^4 / f^2$	$4 \times 10^4 / f^2$	–	
8 – 25 Hz	10 000	$4000 / f$	$5000 / f$	–	Power lines for electric trains Electricity networks, power
0.025 – 0. 8 kHz	$250 / f$	$4 / f$	$5 / f$	–	lines for electric trains, VDU
0.8 – 3 kHz	$250 / f$	5	6.25	–	VDU
3 – 150 kHz	87	5	6.25	–	VDU
0.15– 1 MHz	87	$0.73 / f$	$0.92 / f$	–	AM broadcast
1 – 10 MHz	$87 / f^{0.5}$	$0.73 / f$	$0.92 / f$	–	AM broadcast, diathermy FM broadcast, VHF- TV, aeronautical radio navigation and radio mobile systems, wireless telephones, magnetic resonance, diathermy
10 – 400 MHz	28	0.073	0.092	2	UHF – TV, mobile telephony system, trunking, mobile satellite services, wireless telephones, personal communication services
400 – 2000 MHz	$1.375f^{0.5}$	$0.0037f^{0.5}$	$0.0046f^{0.5}$	$f/200$	



2 – 300 GHz	61	0.16	0.20	10	Wireless telephony networks, microwave and satellite communications, radars, microwaves ovens
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1.  $f$  as indicated in the frequency range column.
2. For frequencies between 100 kHz and 10 GHz,  $S_{eq}$ ,  $E^2$ ,  $H^2$  y  $B^2$  are to be averaged over any 6- min period.
3. For frequencies between 100 kHz and 10 GHz,  $S_{eq}$ ,  $E^2$ ,  $H^2$  y  $B^2$  are to be averaged over any  $68/f^{1.05}$ -min period ( $f$  in GHz).

On July 6, 2003 the Ministry of Transports and Communications issued “The Maximum Permissible Limits (LMP) for Non-ionizing Radiations from Telecommunications” by means of Supreme Decree N° 038-2003-MTC. This is based on ICNIRP reference levels for general public and occupational exposure in the frequency range from 9 kHz to 300 GHz.

This Maximum Permissible Limits Supreme Decree N° 038-2003-MTC was modified in December 2006 by Supreme Decree N° 038-2006-MTC. The Peruvian Regulation for NIR from telecommunications has supplementary technical regulations to ensure compliance with the LMP.

- Ministerial Resolution N° 610-2004-MTC/03 issued on August 17, 2004 that approves the management over supervision and control procedures for the maximum permissible limits of non-ionizing radiations for telecommunications.
- Ministerial Resolution N° 612-2004-MTC/03 issued on August 18, 2004 that approves technical guidelines for the development of theoretical studies on non-ionizing radiations.
- Ministerial Resolution N° 613-2004-MTC/03 issued on August 19, 2004 that approves the technical guidelines on measurement protocols for non-ionizing radiations.
- Ministerial Resolution N° 120-2005-MTC/03 issued on February 28, 2005 that approves the technical guidelines on restrictions in areas of public use.
- Ministerial Resolution N° 965-2005-MTC/03 issued on December 29, 2005 that approves the procedures to certificate non-ionizing radiation equipment.

**Table 20. Maximum Permissible Limits for occupational exposure to 9 kHz to 300 GHz**  
(unperturbed rms values)

Frequency range	Electric field strength E (V/m)	Magnetic field Strength H (A/m)	Equivalent plane wave power density $S_{eq}$ (W/m <sup>2</sup> )
9 kHz – 65 kHz	610	24.4	–
0.065 MHz – 1 MHz	610	$1.6 / f$	–
1 MHz – 10 MHz	$610 / f$	$1.6 / f$	–
10 MHz – 400 MHz	61	0.16	10

400 MHz – 2000 MHz	$3 f^{0.5}$	$0.008 f^{0.5}$	$f / 40$
2 GHz – 300 GHz	137	0.36	50

**Table 21 Maximum Permissible Limits for general public occupational exposure to 9 kHz to 300 GHz**  
(unperturbed rms values)

Frequency range	Electric field strength E (V/m)	Magnetic field Strength H (A/m)	Equivalent plane wave power density, $S_{eq}$ (W/m <sup>2</sup> )
9 kHz – 150 kHz	87	5	–
0.15 MHz – 1 MHz	87	$0.73 / f$	–
1 MHz – 10 MHz	$87 / f^{0.5}$	$0.73 / f$	–
10 MHz – 400 MHz	28	0.073	2
400 MHz – 2000 MHz	$1.375 f^{0.5}$	$0.0037 f^{0.5}$	$f / 200$
2 GHz – 300 GHz	61	0.16	10

## VENEZUELA

In April 2005 the National Telecommunications Commission (CONATEL), the administrator and regulatory body for telecommunications issued the Administrative Provision (Decree) "Safety Conditions against Radiofrequency Emissions from Fixed Radioelectric Stations in the Range of 3 kHz to 300 GHz" (CONATEL, 2005).

This regulation is based on ITU Recommendation K-52 "Guidance on complying with limits for human exposure to electromagnetic fields", which in turn endorses ICNIRP reference levels. It is for telecommunication systems operating in the frequency range of 9 kHz to 300 GHz and includes the exposure limits, the requirements for persons or entities in charge of measuring electromagnetic fields and the requirements for the installation of radio stations for telecommunications.

Table 22 gives the Venezuelan limits.

Exposure category	Frequency Range	E – field strength (V/m)	H - field strength (A/m)	Equivalent planewave power density S (W/m <sup>2</sup> )
Occupational	3 - 65 kHz	610	24,4	–
	0,065 -1 MHz	610	1,6 /f	–
	1 - 10 MHz	610 /f	1,6 /f	–
	10- 400 MHz	61	0,16	10
	400 - 2000 MHz	3f <sup>½</sup>	0,008f <sup>1/2</sup>	f /40
	2 - 300 GHz	137	0,36	50
General public	3 - 150 kHz	87	5	–
	0,15 - 1 MHz	87	0,73 /f	–
	1 - 10 MHz	87/f <sup>½</sup>	0,73 /f	–
	10 - 400 MHz	28	0,073	2
	400 - 2000 MHz	1,375f <sup>½</sup>	0,0037f <sup>1/2</sup>	f /200
	2 - 300 GHz	61	0,16	10

## Conclusions

In general Latin American standards on NIR from telecommunications have endorsed the ICNIRP Guidelines with the exception of Bolivia that adopted the FCC standards and Panama that implemented standards based on the IEEE Standard C95.1-2005. The reasons for this situation is the lack of promotion of ICNIRP standards and the importance of the harmonization process

**Table 23 Latin American Countries that have Adopted ICNIRP Standards**

## References Standards

<b>COUNTRY</b>	<b>FREQUENCY RANGE/SERVICES</b>	<b>DATE OF ADOPTION</b>
BRAZIL	9 kHz- 300 GHz 0 Hz-300 GHz	2002 2009
CHILE	Mobile telephony and PCS	2000
COLOMBIA	9 kHz- 300 GHz	2005
ECUADOR	9 kHz- 300 GHz	2005
PARAGUAY	0 kHz- 300 GHz	2007
PERÚ	9 kHz- 300 GHz 0 Hz-300 GHz	2003 2005
VENEZUELA	3 kHz- 300 GHz	2005

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## ANNEX I - Basic Concepts in Clinical Epidemiology

There are four main kinds of analytical epidemiological studies: case-control, cohort, case-cohort and cross-sectional. They can be **prospective** or **retrospective**, i.e. they can either analyze and compare subjects that were already exposed to the environmental agent (also called the *historical* approach), or collect longitudinal data as the study progresses (also called the *current* approach).

**Cohort studies** start with the exposure variable, and collect data from a selected, initially healthy, group within the population (the *cohort*) over a given period of time, who are known to be exposed to an agent. It aims to compare incidences of endpoints or outcomes, in subjects who were exposed (*index* subjects), with outcomes in subjects who were not exposed. The measure of disease in cohort studies is the **incidence rate**, which is the proportion of subjects who develop the disease under study within a specified time period (the number of diseased subjects divided by the number of person-years of observation). Separate incidence rates are calculated for the exposed and non-exposed subjects and compared statistically. The measure of association between exposure and disease in cohort studies is the relative risk (RR). The **relative risk** is the ratio of the incidence rate of exposed to unexposed. A RR of 1.0 means that the incidence rate is the same among exposed and non-exposed subjects and indicates a lack of association between exposure and disease. If it is less than 1, it means that the incidence rate of disease among the exposed is lower than non-exposed, whereas a RR above 1.0 indicates that exposed people are at higher risk of disease than non-exposed persons. The magnitude of the RR shows the strength of association between exposure and disease And the confidence interval shows a precision of the estimate.

**Case-control studies** have subjects with the target disease and compare two controls sampled from a population from which case arose. The purpose of the control group is to provide an estimate of the frequency and amount of exposure in subjects in the population without the disease being studied. So a case-control study is concerned with the frequency and amount of exposure in subjects with a specific disease (*cases*) and people without the disease (*controls*). No measure of disease incidence rate or risk ratios can be estimated, so measures of association, such as the **odds ratio**, are used instead. The odds ratio (OR) is generally a good estimate of the relative risk for rare diseases, and is obtained by the probability (*odds*) of exposure in disease subjects, divided by the probability of exposure in non-diseased subjects. *Matching* between the groups is done according to several criteria, such as gender, age,

Both approaches have their own methodological problems in terms of confounding variables, sources of bias, quantification of exposure, identification of effects, etc., which we will briefly discuss at the end of this section, so as to qualify the scientific relevance and power of evidence of such epidemiological studies.

Since these are essentially observational research methods, they are potentially subject to the effect of extraneous factors which may distort the findings. **Confounding variable** or factor refers then to an extraneous element that simultaneously is a risk factor for the disease being studied, and is associated with the exposure being studied but is not one of its consequences (Meirik, 2007). There are several ways of controlling, or adjusting for, confounding factors, **stratification** (i.e., the subdivision of groups according to presence/absence of these factors) and **multivariate analysis** (which takes into account these variables in the statistical model). **Matching** strategies (in order to make subjects of both groups be the most similar possible for all known variables, except the study variables) is usually not recommended except for basic variables such as age and gender.

**Bias**, on the other hand, is any systematic error in the design, conduction, or analysis of a study that results in a mistaken estimate of an exposure's effect on the risk of disease. There are several sources of bias in epidemiological studies, such as selection bias, recall bias, reporting bias, proxy bias, etc.

Biases and confounding variables must be identified and understood as soon as possible in the observational design, and compensated for or post-adjusted, in order to avoid the distortion of statistical inferences that will inevitably arise and that can possibly invalidate, partially or totally, the findings of the study.

The decision whether to use cohort or case-control studies depend on many factors and is a complex one (Meirik, 2007). For putative RF-exposure induced or promoted disease, which is the main focus of epidemiological studies, cohort studies are to be preferred over case-control studies (Leitgeb, 2006), but they present many problems, such as the need for a large number of cases in rare diseases, unsuitability when there is a very long latency between exposure and disease manifestation, when there is change of exposure patterns along the collection of data, and the high rate of loss of follow-up. All this also make long term cohort studies very expensive.

Case-control studies are easier, faster and cheaper, can study rare diseases with long latencies, but also have their score of drawbacks for RF exposure studies: they have a high recall and proxy biases, validation of past exposure is many times difficult or impossible, and selection bias is common.

Finally, the induction of causal relationships from epidemiological statistical studies implies a number of requirements (Hill, 1969). They are nine: strength of



association, intra- and inter-studies consistency, specificity of the association, time sequence (precession of cause in relation to effect), existence of a dose-response relationship, biological, physical and chemical plausibility, consistent support from experiments, and analogy to other similar, discovered cause-effect relationships. Hill noted that "*none of my nine viewpoints can bring indisputable evidence for or against the cause-and-effect hypothesis and none can be required as a sine qua non*".

## Basic Concepts in the Design of Experimental Studies

The most frequent experimental designs used in such studies are:

**Self-control designs:** in these experiments, a baseline of the dependent variable(s) is recorded for some time under normal conditions, with all subjects in the same standard situation. Exposure to RF is then applied, also for some time, and the dependent variables are collected again during and/or after the exposure, and compared with the baseline. Thus, subjects are their own controls, facilitating the statistical, pair-wise comparison or pre- and post-irradiation comparisons. This kind of design provides low-strength evidence, because other confounding or intervening variables may be acting simultaneously with irradiation, experimenter and subject biases, or a pos-hoc influence may be operating and are hard to detect and to avoid.

**Controlled designs:** in these studies, a better strength of evidence is achieved by adding a control group, as similar as possible to the experimental group, with the exception that it is subjected to a sham, or fictitious RF irradiation. The statistical power and strength of evidence of such studies are much better than self-control, but problems may arise if involuntary differences between real and sham groups exist (for example, a clicking or whirring noise when real irradiation starts).

**Crossover designs:** in order to avoid the effect of different confounding variables present in the experimental and control groups, and to maintain the convenience and statistical power of pair-wise comparison, the crossover designs switches alternatively the subjects between the groups, allowing sufficient time to the effect to wear out, if any. This design may present a problem if the effects have a long duration or if this parameter is of interest of the study;

**Randomized and blinded experiments:** the final improvement to experimental studies is to avoid experimenter and selection biases, by randomization and single or double blinding (avoiding totally that the experimenters, the subjects or both detect to what group they were assigned to).

