Statement of the
International Evaluation Committee to Investigate the Health Risks of Exposure to Electric, Magnetic and Electromagnetic Fields

Executive summary

Recent years have seen an unprecedented increase in the number and diversity of sources of electric and magnetic fields or electromagnetic fields (EMF) used for individual, medical, industrial and commercial purposes. Such sources include television, radio, computers, mobile cellular phones, microwave ovens, radars and equipment used in industry, medicine and commerce.

All these technologies have made our life richer and easier. Modern society would be inconceivable without electricity for computers, telecommunications, television and radio. Mobile phones have greatly enhanced the ability of individuals to communicate with each other and have facilitated the dispatch of emergency medical and police aid to persons in both urban and rural environments. Radar surveillance makes air travelling much safer.

At the same time, these technologies have brought with them concerns about possible health risks associated with the electromagnetic fields that they emit. Such concerns have been raised particularly about the safety of cellular mobile telephones and their base stations, and electric power lines.

This statement by the International Evaluation Committee to Investigate the Health Risks of Exposure to Electric, Magnetic and Electromagnetic Fields, established by the Italian Ministers of Environment, Health and Telecommunication, addresses these concerns in the light of the most recent scientific information, and particularly with respect to the Framework Law (No. 36, dated February 22nd, 2001) that addresses exposure to EMF fields in Italy.

The mandate of the Committee was:

- To review the state of scientific evidence related to health risks deriving from EMF exposure;
- To evaluate the current Italian Law No. 36, dated February 22nd, 2001, also in relation to the state of the art of research and legislation at the international level;
- To provide recommendations on possible revisions of such Law.

Members of the Committee were:
Prof. Francesco Cognetti (Coordinator), Regina Elena National Institute for Cancer Research, Rome, Italy
Prof. Sir Richard Doll, University of Oxford, Oxford, UK
Prof. Gabriele Falciasecca, University of Bologna, Bologna, Italy
Prof. Tullio Regge, University of Torino, Torino, Italy
Dott. Michael Repacholi, World Health Organization, Geneva, Switzerland

The Committee reviewed the most recent scientific evidence related to possible health consequences from exposure to electric, magnetic and electromagnetic fields (EMF) in the frequency range >0 to 300 GHz. The conclusions of this review were then compared with the:

- Framework Law No. 36 on "Protection from exposure to electric, magnetic and electromagnetic fields" issued 22 February 2001,
- Presidential Decree number 381 on "Regulations setting standards for determining radiofrequency ceilings compatible with human health", issued 3 November 1998,
- Presidential Decree on "Limits of exposure to electric and magnetic fields generated at the nominal power frequency (50 Hz) in residential areas and the external environment" issued 23 April 1992, and
- Draft decree on 50 Hz fields presented at a press conference in 2001.

Reviews of current scientific information have all indicated that, while there are gaps in knowledge requiring further research before better health risk assessments can be made, there have not been any adverse health consequences confirmed from EMF exposures below the ICNIRP (1998) guideline limits.

The Committee concurs with the opinions of the General Assembly of the Higher Health Council of the Italian Ministry of Health (2001) issued at its meeting on 18 September 2001, and the Scientific Committee on Toxicology, Ecotoxicity and the Environment (CSTEE) of the European Commission (DG Health and Consumer Protection) issued 30 October 2001 (EC, 2001), as well as the conclusions of the World Health Organization and Health Council of the Netherlands, to support the use of international guidelines on EMF exposure limits.

Based on these conclusions, the Committee recommends:

1. In order to avoid confusion about the applicable level of EMF exposure, it is appropriate to revise the Framework Law No. 36 to retain only the "exposure limits" defined in the Law. The limit values should be aligned fully with the "basic restrictions" in the guidelines on exposure limits of the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998).
   The "reference values" in the ICNIRP guidelines should be used for monitoring compliance with the basic restrictions, as described in (ICNIRP, 1998).

2. Responsibility for determining compliance with the exposure limits should be clearly assigned and the results of all EMF measurements in areas of public interest should be made easily accessible to the general population.

3. To ensure that EMF levels are kept low, but commensurate with good quality operation of EMF technology, voluntary cost effective precautionary measures should be encouraged that are in accordance with the recommendations of the World Health Organization fact sheets (See references: WHO, 2000, 2001 and WHO Backgrounder, 2000).

4. Given uncertainties in the science, the Government should provide significant funds for high quality EMF research that particularly addresses the agenda of studies already identified as being needed by the WHO International EMF Project.

5. The Italian Government should initiate an effective campaign of public education about possible effects of EMF exposure, as well as the meaning and use of precautionary measures, using information provided for this purpose by the European Commission and WHO.

6. Italian government authorities should work closely with WHO's International EMF Project to address EMF issues of concern to the general population and workers, so that actions to protect people from exposure to EMF are harmonized world wide.

7. The Italian Government should identify or establish a single authoritative scientific body responsible for providing advice on current knowledge about possible health risks of electromagnetic fields. Such a body could be similar in scope and function to bodies already established in some other European Union countries.

Introduction

Over recent years the possibility that adverse effects on health could result from exposure to EMFs has become one of considerable scientific, political and economic importance. There is a high level of concern and sensitivity about this issue among the Italian population.

On 21 February 2001, Italy passed Framework Law No. 36 on protection from electric, magnetic and electromagnetic fields (EMF) covering the frequency range 0-300 GHz. This law provides a detailed framework of administrative controls for limiting human exposure to EMF through the provision of three levels of EMF exposure (exposure limits, attention levels and quality goals), and measures to protect the environment and landscape.

The Framework Law was issued despite the recommendations of Council of the European Union of 12 July, 1999 for member states to use the international guidelines for EMF exposure limitation provided by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998). All countries of the European Union, except Italy, accepted the Council's advice (EC, 1999).

A decree of the President of the Council of Ministers on "Limits of exposure to electric and magnetic fields generated by the nominal power frequency (50 Hz) in residential areas and in the external environment" was passed in April 1992. This decree had limits of exposure that were essentially in agreement with the international guidelines.

In 2001, a draft decree was issued on "Exposure limits, attention levels and quality goals for health protection of the general public against electromagnetic fields up to 100 kHz". The draft decree introduced the two new levels required by the Framework Law, called "attention levels" and "quality goals". As can be seen from the values in Table 1, the exposure limit are basically those recommended by the EC and 1992 decree, but the attention levels and quality goals are 200 and 500 times below these limits.

In the Table 1, limits in the 1992 Presidential Decree and draft 50 Hz decree using the Framework Law No 36 are compared with those recommended by the European Commission.

Table 1: Limits in the 1992 Presidential Decree and draft 50 Hz decree (using the Framework Law No 36) are compared with limits recommended by the European Commission in 1999.

Area/Country	Reference law	Limit application	Magnetic field (µT)	Electrical field (V/m)
European Commission	Recommendation 1888/512/CE	Prolonged exposure	100	5.000
Italy	Decree 23/04/1992	Whole day Few hours	100 1.000	5.000 10.000
	Draft decree for 50 Hz using Framework Law	Exposure limits Attention levels Quality goals	100 0.5 0.2	5.000 1.000 500

On 3 November 1998 a Decree (No. 381) of the Minister of the Environment was published in the Official Gazette (No. 257): "Regulations setting standards for determining radiofrequency ceilings compatible with human health". These limits were for RF fields emitted in the frequency range 100 kHz to 300 GHz. The limits apply to RF exposure from fixed telecommunications and broadcast antennas, but not for mobile antennas, used in mobile phones. Table 2 gives the limit values in the decree.

Table 2: Limit values in the Regulations setting standards for determining radiofrequency ceilings compatible with human health, issued in 1998.

Frequency (MHz)	Electric field V/m	Magnetic field A/m	Power density W/m^2
0.1 - 3	60	0.2	-
>3 - 3000	20	0.05	1
>3000 - 300000	40	0.1	4
0.1 - 300000 (>4 hrs)	6	0.016	0.1 (for 3 - 300000)

This decree also states that for "living spaces where it is possible to remain for more than four hours" the limits are reduced to the values shown in the last row of the Table 2. In this case the power density limit of 0.1 W/m applies only for the frequency range 3 - 300000 MHz.

After its election in May 2001, the new Italian government wanted to determine if the Framework Law was appropriate and whether the limits on EMF exposure in the decrees were reasonable, given the current state of the science. To obtain independent scientific advice, the Italian Ministers of Environment and Territories, Health and Telecommunications established in December 2001 a Committee composed of the following members:

Prof. Francesco Cognetti (Coordinator), Regina Elena National Institute for Cancer Research, Rome, Italy
Prof. Sir Richard Doll, University of Oxford, Oxford, UK
Prof. Gabriele Falciasecca, University of Bologna, Bologna, Italy
Prof. Tullio Regge, University of Torino, Torino, Italy
Dott. Michael Repacholi, World Health Organization, Geneva, Switzerland

A short resume of each Committee member is given in Annex 1.

This statement has been prepared according to the mandate given to the Committee and represents the collective views of the members as individual experts. In addition to the review of the science and assessment of the Framework Law No 36 and the decrees at low and high frequency fields, the Committee felt it was appropriate to provide information on such topics as: The types of studies are important for assessing health risks; the differences between a biological effect and a health risk; how biological effects are established and become part of the science database from which health risks can be assessed; and how standards are developed from the science.

Mandate
The Committee was given the following mandate:

- To review the state of scientific evidence related to health risks deriving from EMF exposure;
- To evaluate the current Italian Law No. 36, dated February 22nd, 2001, also in relation to the state of the art of research and legislation at the international level;
- To provide recommendations on possible revisions of such Law.

Administration
The Committee was administered through the Agenzia Nazionale per la Protezione dell'Ambiente (ANPA: the National Agency for Environmental Protection). On behalf of the Italian Minister of the Environment and Territory, ANPA formally invited internationally recognized scientists to become Committee members and asked them to provide a statement in accordance with the mandate.

Electromagnetic fields
This statement covers the health effects of electric, magnetic and electromagnetic fields (EMF) in the frequency range from >0 to 300 GHz. For a description of EMF and the way they interact with the body, as well as the terms and units used to describe them, readers are referred to Annex 2.

Where can national authorities seek reliable scientific advice?

It is important for governments that they obtain the best advice possible on issues before formulating national policy. When there is a reliance on scientific and technical information to help formulate national policy, there is a hierarchy of levels in science for provision of reliable advice.

International or national peer review panels of independent scientists are recognized in the scientific community as providing the most reliable and scientifically supportable information. Such reviews are currently provided at the international level by the World Health Organization (WHO), International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the European Commission (EC), and at the national level by specialized governmental agencies and professional societies such as the National Radiological Protection Board (NRPB) in the United Kingdom, the National Institute of Environmental Health Sciences (NIEHS) and the National Academy of Sciences in the United States, the Royal Society of Canada, and the Health Council of the Netherlands.

Individual opinions, even when provided by scientists, are not as reliable as those provided by multi-disciplined panels of experts. This is especially true in the EMF area, which involves many branches of science and where some discordant opinions have been expressed.

World Health Organization

WHO was established by over 190 countries as the highest level and most reliable authority within the United Nations system to advise national authorities on health issues. To provide such advice, WHO has established criteria and methods for evaluating scientific studies to determine if there are health risks from physical, biological and chemical agents. These methods have evolved over the more than 50 years that WHO has existed.

To address the many issues related to possible health risks from EMF exposure, WHO established the International EMF Project in 1996. This project has 8 international organizations and over 45 national authorities participating and providing oversight to the Project. WHO staff provide administrative support and the secretariat for all meetings; they are not members of any of the Project committees.

A Project web site gives the results of all meetings as part of an open and transparent implementation of all activities.

The International EMF Project was set up as a logical progression of activities leading to a determination of any possible adverse health consequences from low-level long-term exposure to EMF over the frequency range 0 to 300 GHz. The progressive steps within the Project are:

- Assessment of the scientific literature to determine what health effects are confirmed and what further research is needed to make better health risk assessments
- Promotion of research to fill gaps in knowledge about possible consequences of low-level EMF exposure
- Formal assessment of the scientific results when key research is completed
- Publication of health risk assessments that can be used as a basis for policy development
- Development of a standards framework for use by national authorities to harmonize standards world wide
- Publication of scientific reports and fact sheets (written in lay language and multiple languages) to inform the public about the results of the Project and the current WHO conclusions and recommendations. These are available on the WHO web site at: www.who.int/emf.

The Committee has drawn on information from the WHO EMF Project and recent reviews by national and international scientific committees to provide the supporting evidence for its conclusions and recommendations.

Hierarchy of scientific data

Since risk assessment is ultimately aimed at human health, ideally the data should be derived from human studies. The relationship between exposure and certain short-term biological effects can sometimes be evaluated from human laboratory studies, whereas, data on long-term human effects can be derived only from epidemiological studies. However, in spite of their direct relevance, the results of epidemiological studies may be difficult to interpret when the suggested risks are small, as they may be due to bias or confounding, and it is seldom possible to conclude that they imply a causal relationship without supportive evidence from experimental studies and reason to believe that causality is biologically plausible.

Animal experiments are valuable in the analysis of the biological effects and mechanisms, as they involve a complete organism, including all relevant in vivo reactions, at least for the animal. Experimental studies can also be useful in clarifying whether a causal relationship exists. In vitro studies can provide detailed information on biophysical mechanisms at the level of molecular, cellular or intercellular interactions.

The results of animal and in vitro experiments need to be well understood in order for them to be extrapolated to possible effects in humans. In general, supportive human data are important for a full evaluation of the relevance to human health of the results from animal studies.

Clinical experience, although failing to fulfil the quality criteria given above for human health studies, may nevertheless provide complementary information. Reports of individual observations in themselves do not provide a basis for the assessment of risk, because of their inherently poor control and possible observational bias. They may, however, provide an indication of the need for further investigation.

Development of standards using science

For the development of standards that limit human exposure to EMF, there needs to be a comprehensive and critical assessment of the peer-reviewed scientific literature. The review should be undertaken by a panel of recognized experts that includes all appropriate scientific disciplines such as medical specialists, biologists, engineers, epidemiologists, physicists and toxicologists.

For studies to be useful to health risk assessments, they must be of high scientific quality with clearly-defined hypotheses, estimates should be given of the ability of the study to detect small effects, and protocols that are consistent with good scientific or laboratory practice should be used. Quality assurance procedures should be included in the protocol and monitored during the study.

Various schemes and "criteria" exist in order to make the evaluation of the studies transparent. Among these the Bradford Hill criteria (Hill, 1965) and the IARC scheme for assessment of carcinogenicity (IARC 1987) are well recognized. These have been elaborated for EMF by Repacholi and Cardis (1997).

Standards harmonization

Globalization of trade and the rapid expansion of use of electrical devices have focused attention on the large differences existing in standards limiting exposure to EMF. Protecting populations against potentially hazardous agents is part of the political process so there is no reason to expect that all jurisdictions will choose exactly the same levels of protection. However, the disparities in EMF standards around the world do not arise from this fact alone. They have arisen also from different interpretations of the scientific data that underlie all of the standards and from different philosophies for public health standards development.

Large disparities in national standards can increase public anxiety about EMF exposures from the introduction of new technologies.

In November 1998, WHO commenced a process of harmonization of EMF standards world wide. Since over 45 countries and 8 international organizations are involved in the International EMF Project, the Project provides a unique umbrella to bring countries together to develop a framework for harmonizing EMF standards and to agree on what type of scientific results should be used and how health risks should be assessed. Thus the Project can encourage the development of exposure limits and other control measures that provide the same high level of health protection to all people. Such an endeavour is in line with the World Trade Organization (WTO) requirement for countries who are a signatory to the General Agreement on Tariffs and Trade (GATT) to harmonize with international standards.

There are many benefits to having harmonized standards for EMF exposure. These are:

- Increased public confidence that governments and scientists agree on health risks
- Reduced debate and fears about EMF
- Health protection for everyone to the same high level
- Avoids confusion in the public mind and stress about health effects from EMF exposure when there are different EMF limits required by different authorities, particularly between authorities at the local, regional and national levels within the same country.

In addition to the health benefits that can be established from the scientific studies, use of international standards avoids the possibility of limitations on free trade between countries.

Thus there are strong arguments for the use of internationally acceptable standards.

International standard

The text of the international guidelines (ICNIRP, 1998) is available in English and Italian (See Annex 3). A statement from ICNIRP on the use of the guidelines is given on their web site at: www.icnirp.org/use

On July 12, 1999, the Council of the European Union issued a Recommendation to Member States for a common framework of protection of the general public to electromagnetic fields, based on the best available scientific data. For this purpose, the Council endorsed the ICNIRP guidelines. In addition, following a recent review of the scientific literature, an expert committee of the European Commission (EC, 2001) recently recommended that the EC continue to adopt the ICNIRP guidelines.

National standards

The ICNIRP guidelines are now used as the basis for limiting exposure to EMF in a large number of countries around the world. While stricter limits have been set for

particular sources (e.g. mobile telephone base stations) in a few countries (Switzerland, Belgium), there is a general tendency towards harmonization.
In the UK, the ICNIRP guidelines were recommended by an Independent Expert Group on Mobile Phones (IEGMP, 2001) and accepted by the Government.

Actions toward harmonization are in progress in Eastern Europe. The Czech Republic has withdrawn its former Soviet regulations and adopted the ICNIRP guidelines in 2001. Other Eastern Countries are working with WHO on standards harmonization.

A database of EMF standards world wide is being collected within the WHO International EMF Project and will soon be available on the web site at: www.who.int/emf.

Overview of health risks from EMF exposure

This brief review provides a summary of the health effects and conclusions found by national and international scientific panels established to fully investigate the scientific studies from the original publications. These panels are normally composed of scientists from all the appropriate disciplines needed to properly investigate each study.

The review is divided into the following frequency ranges: extremely low frequency (ELF) fields (>0 to 300 Hz), intermediate frequency (IF) fields (>300 Hz to 10 MHz), and radiofrequency (RF) fields (>10 MHz to 300 GHz). For purposes of this statement, static fields will not be dealt with any further. Thus the frequency range of interest will be >0 to 300 GHz.

In order to understand how international and national reviews arrive at their conclusions it is necessary to understand the criteria by which science determines when a biological effect can be considered to be established, and when a biological effect could have an adverse consequence on health.

Identification of health risks from biological effects

The existence of biological effects from EMF exposure may be established when research results are independently replicated or supported by related studies. This is further strengthened when:

- There is agreement with accepted principles or results lead to new scientific principles
- The underlying mechanism of action on the biological system is understood
- A dose-response relationship can be determined

One of the reasons that people become so concerned about possible health effects of exposure to EMF is that they read, usually in the media, results of studies conducted by scientists attempting to find effects in biological systems from EMF exposure. In some cases the studies are preliminary or exploratory, or do not come from a scientifically qualified source. Media reports are generally given without reference to other studies that may or may not have found the same results. Also the reports tend to extrapolate biological effects to possible human health consequences. This is not an easy step.

Explicit distinctions are made between biological effect and health hazard, consistent with the criteria used by international and national bodies when making health risk assessments (Repacholi and Cardis, 1997). Biological effects occur when fields interact with tissues to produce physiological responses that may or may not be perceived by people. Deciding whether biological or physiological changes have health consequences depends, in part, upon whether they are reversible, are within the range for which the body has effective compensation mechanisms, or are likely, taking into account the variability of response among individuals, to lead to unfavourable changes in health.

The World Health Organization (WHO) defines health as the state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity. Biological effects are any measurable change in a biological system, but not all of them will be hazardous. Some may be innocuously within the normal range of biological variation and physiological compensation, and others may be beneficial under certain conditions. The health implications of others may be simply indeterminate. In this case uncertainty adds to the lack of acceptability of scientific results. A health hazard generally results from a biological effect producing changes outside the body's normal range of physiological compensation and is adverse to a person's well-being.
These considerations are important when determining whether biological effects have health implications.

ELF fields

Recent reviews of the scientific literature on possible health effects from exposure to electric and magnetic fields in the frequency range >0 to 300 Hz have been completed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998), the National Institute of Environmental Health Sciences (NIEHS, 1998), WHO (Repacholi and Greenebaum, 1999), the National Radiological Protection Board (AGNIR, 2001), the Health Council of the Netherlands (2001) and the International Agency for Research on Cancer (IARC, 2001). All reviews concluded that there were no established adverse health consequences from exposure to ELF field levels below the limits in the ICNIRP (1998) guidelines. The AGNIR –Advisor Group of Non-Ionizing Radiation (2001a) also note that, while there was only very weak evidence that ELF fields could cause neurodegenerative diseases such as Parkinson's or Alzheimer's disease, there was stronger evidence for people in electrical occupations having an increased risk of developing amyotrophic lateral sclerosis. However, it was noted that this could be due to an increased risk of electric shocks.

However, these reviews indicated that there was some consistency in the epidemiological studies on childhood leukaemia which suggested that there might be an increasing risk of disease in children exposed to mean magnetic fields above about 0.3 - 0.4 μT. IARC, a specialized agency of WHO to investigate cancer risks, formally assessed this information and, on the basis of epidemiological studies on children, classified ELF magnetic fields as a "possible human carcinogen". The meaning and implications of this classification have been explained in a WHO fact sheet #263 (WHO, 2001).

"Possibly carcinogenic to humans" is a classification used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals. This classification is the weakest of three categories ("is carcinogenic to humans", "probably carcinogenic to humans" and "possibly carcinogenic to humans") used by IARC to classify potential carcinogens based on published scientific evidence. To give some indication of what this means in comparison with other common substances or physical agents, examples of agents classified by IARC are listed in Table 3. (See: http://monographs.iarc.fr).

Regulatory policies for agents classified as possible carcinogens vary by country and by particular agent. The carcinogenic evaluation and classification of an agent by IARC does not automatically trigger a national regulatory response. While gasoline exhaust, pickled vegetables and coffee have been classified as possible human carcinogens, there has only been a significant response by government to reduce gasoline engine exhausts. However, there has not been any effort to limit intake of coffee or pickled vegetables.

Table 3 gives examples of common physical and chemical agents classified for their carcinogenicity in humans by the International Agency for Research on Cancer (IARC). For more examples refer to the IARC web site (See: http://monographs.iarc.fr).

Classification	Examples of Agents
Carcinogenic to humans (usually based on strong evidence of carcinogenicity in humans)	Asbestos Alcoholic beverages Benzene Mustard gas Radon gas Solar radiation Tobacco (smoked and smokeless) X-rays and Gamma radiation
Probably carcinogenic to humans (usually based on strong evidence of carcinogenicity in animals)	Creosotes Diesel engine exhaust Formaldehyde Polychlorinated biphenyls (PCBs)
Possibly carcinogenic to humans (usually based on evidence in humans which is considered credible, but for which other explanations could not be ruled out)	Coffee ELF magnetic fields Gasoline engine exhaust Glass wool Pickled vegetables Styrene

In response to increasing public concern over health effects from EMF exposure, several countries have established their own scientific reviews prior to the IARC evaluation. A working group examining the issue for the US National Institute of Environmental Health Sciences (NIEHS, 1998) classified ELF magnetic fields as possibly carcinogenic to humans. The US government agency has since recommended "passive regulatory action", described as continued information and education of the public and encouraging power utilities to voluntarily reduce exposure to people where practicable.

In the United Kingdom, an Advisory Group on Non-Ionising Radiation recently reported to the NRPB on the topic of power frequency EMF and the risk of cancer (AGNIR, 2001). It concluded that while the evidence is currently not strong enough to justify a firm conclusion that EMF fields cause leukaemia in children, the possibility remains that intense and prolonged exposures to magnetic fields may increase this risk. The Health Council of the Netherlands (2001), a major scientific advisory body of the Netherlands government, reached similar conclusions.

Following the classification by IARC, the ICNIRP issued a statement indicating that the evidence for ELF magnetic fields causing leukaemia in children is insufficiently strong to recommend any change to their guidelines (ICNIRP, 2001). Also following the IARC classification, an EC committee recommended continuing use of the ICNIRP guidelines (EC, 2001).

In response to the IARC classification, WHO issued a fact sheet (WHO, 2001). It states that it remains possible that there are other explanations for the observed association between exposure to ELF magnetic fields and childhood leukaemia. In particular, issues of selection bias in the epidemiological studies and exposure to other field types deserve to be rigorously examined and will likely require new studies.

However, there is a need to consider the effect on childhood cancer incidence in Italy if the epidemiological studies are showing a real risk with 50 Hz magnetic field exposures above 0.3 - 0.4 μT. To respond to this, it is reasonable to use data from the AGNIR (2001) review where the effect on incidence rates were calculated for England and Wales, which combined have about the same size population as Italy. According to the AGNIR (2001) report: "The nature of an association with increasing exposure is unclear, notably whether there is any such increase, and if there is, whether there may be a linear or quadratic relationship. This lack of clarity is augmented by the effect of regression dilution [an underestimate of the strength of the relationship] resulting from the absence of accurate exposure measurement at the relevant time before diagnosis. About 430 cases of leukaemia (all types) are registered each year in England and Wales in those aged under 15 years (1999 UK Office of National Statistics).

The UK childhood cancer study (UKCCS) indicates that 0.4% of children are exposed to 0.4 μT or more and, assuming a doubling of risk at this level some two cases would occur anyway and a further two cases annually might be attributable to electromagnetic field exposure. If regression dilution were concealing a relative risk of 1.5 for those exposed to between 0.2-0.4 μT, then the annual number of attributable cases might be six or seven. These estimates assume that any excess risk is confined to a very small number of children exposed to high electromagnetic field levels. If there is a linear exposure-response effect, the attributable numbers could be somewhat larger."

Thus if the epidemiological studies are revealing a real risk, then the increased number of childhood leukaemias in each year is about 2. Further, it is notable that, in the experience of the UKCCS, less than half the children receiving exposures of 0.4 μ T or more did not live in proximity to power lines. These exposures were received from the electricity supply within the homes either from the way the power wiring was connected or from electric appliance use.

What action can be taken in response to the scientific uncertainty identified by the IARC classification that ELF fields are a "possible human carcinogen"?. WHO recommends the adoption of science based guidelines, such as ICNIRP (1998), to protect public health against known ELF exposure hazards. In addition, national authorities could consider the use of voluntary precautionary measures to lower ELF exposures until the science is able to provide more precise information on the possibility that exposure to these fields could be associated with an increase in childhood leukaemia.

Since publication of these recommendations by WHO there have been two studies published that have received much media attention (Lee et al, 2002¸ Li et al, 2002). While these studies do not alter the basic conclusions on health, they suggest that further research is needed to clarify whether exposure to ELF fields can influence miscarriage rates.

Intermediate frequency (IF) fields

The results of a recent WHO international seminar and review of the health implications of exposure to EMF in the IF range has been published (Litvak et al, 2002). Unfortunately the frequency range 300 Hz to 10 MHz has received little study since most researchers have concentrated their efforts on either the ELF or RF ranges. To be able to assess any heath risks from IF fields, an extrapolation of possible effects has been conducted based on known mechanisms of tissue interaction and compared with the few biological studies that have been undertaken.

Litvak and colleagues (2002) published a detailed review of the mechanisms of action of IF fields on biological systems that could lead to possible health outcomes. As mentioned above, the main mechanism was found to be the induction of currents by these fields up to a frequency of about 1 MHz; above this frequency heating became increasingly dominant.

The review concluded that further research is needed since few data exist to determine thresholds for hazards, particularly for fields with complex waveforms. However, there was no scientific evidence to show that exposures below the ICNIRP guidelines had any consequence for health.

RF fields

Detailed reviews of the health effects of exposure to RF fields, some related to exposures from mobile telephones and their base stations, have been published by WHO (Repacholi, 1998), the Royal Society of Canada (1999), an independent expert group on mobile phones (IEGMP, 2000) established by the UK Minister for Public Health and the NRPB (2001). WHO has summarised the results of most of these reviews in a fact sheet (WHO, 2000). The recently published review of the Health Council of the Netherlands (2002) has also reached the same conclusions as WHO.

All reviews have concluded that while RF energy can interact with body tissues at levels too low to cause any significant heating, no study has shown adverse health effects at exposure levels below international guideline limits. Most studies have examined the results of short-term, whole body exposure to RF fields at levels far higher than those normally associated with wireless communications. With the advent of such devices as walkie-talkies and mobile phones, it has become apparent that few studies address the consequences of localised exposures to RF fields to the head.

The scientific research related to mobile phone use, that is also applicable to general exposure to RF fields, is summarised below:

Cancer: RF fields are unlikely to induce or promote cancers. Several studies of animals exposed to RF fields similar to those emitted by mobile phones found no evidence that RF causes or promotes brain cancer. One study (Repacholi et al., 1997) found that RF fields increased the rate at which genetically engineered mice developed lymphoma. However, the health implications of this result are unclear. Several studies are underway in other countries, including in Italy, to confirm this finding and to determine the relevance of the results to cancer in human beings. Recent epidemiological studies found no convincing evidence of an increased cancer risk with use of mobile phones.

IARC is coordinating a large multinational study to determine whether use of mobile phones is associated with any increase in head and neck cancers. This study will take another 2 years to complete and analyse the results.

Other health risks: Scientists have reported other effects of using mobile phones including changes in brain activity, reaction times, and sleep patterns. These effects are small and have no apparent health significance. More studies are in progress to try to confirm these findings.

Driving: Research has clearly shown an increased risk of traffic accidents when mobile phones (either handheld or with a "hands-free" kit) are used while driving (IEGMP, 2000). Research is still needed to determine whether the increased accident risk is due to changes in peoples' reaction time from exposure to the RF fields or merely having a conversation on the phone is distracting and that this leads to the accident.

The current debate about possible effects of RF fields is centred on whether *long-term, low level* exposure (below levels that could cause noticeable heating) can cause adverse health effects or influence people's well-being. Ongoing research aims to determine whether any long-term effects might occur at very low exposure levels. Given the widespread use of technology, degree of scientific uncertainty, and levels of public apprehension, rigorous scientific studies are under way and more are needed. While none of the recent reviews have concluded that exposure to the RF fields causes any adverse health consequence, there are gaps in knowledge that require further research to better assess health risks. It will take about 3-4 years for the required RF research to be completed, evaluated and to publish the final results of any health risks.

Italian decrees limiting 50 Hz and radiofrequency fields

A decree of the President of the Council of Ministers on "Limits of exposure to electric and magnetic fields generated by the nominal power frequency (50 Hz) in residential areas and in the external environment" was passed in April 1992 and is still in effect. However, in November 1999 a draft decree on ELF fields, with frequencies >0 and up to 100 kHz, was presented at an ad hoc press conference. Exposure limits at 50 Hz were 10 kV/m for the electric field, and 100 μT for the magnetic flux density. However, attention levels and quality goals proposed for the magnetic fields were 0.5 μT and 0.2 μT, respectively. See table 1 above.

In 1998, a decree was issued on exposure of the general public to electromagnetic fields in the range 100 kHz - 300 GHz. While exposure limits are of the same order of magnitude of the ICNIRP guidelines (but with a step-function dependence of frequency different from any international guideline), attention levels as low as 6 V/m and 0.016 A/m for the electric and the magnetic field, respectively, have been set. The attention levels are independent of frequency. See table 2 above.

Italian framework legislation

The Italian "Framework law" (Law No. 36/2001) was issued on February 22, 2001 and became law 60 days later. This Law (see Annex 4) aims to protect the Italian population against exposure to electromagnetic fields. One of the main characteristics of this Law is that it establishes three limits of exposure, calling them "exposure limits", "attention levels" and "quality goals". These are defined in the Law:

- Exposure limits are the electric, magnetic and electromagnetic field value, aimed at protecting health from acute effects, and are not to be exceeded under any condition of exposure of the population and workers.
- Attention levels or caution values are the electric, magnetic and electromagnetic field values not to be exceeded in homes and school environments and in places used for extended stays. This is meant to be a cautionary measure to protect against possible long-term effects.
- Quality objectives are the electric, magnetic and electromagnetic field values defined by the State (through decrees) with the aim of progressive mitigation of exposure to those fields.

Comments on the Framework Law and Decrees

1. In the Framework Law the three different exposure levels lead to a number of difficulties:

- Having three different limits for exposure means that the lowest level (the "quality goal")will always be considered as the "effective" exposure limit, making the other levels redundant. This is because the quality goals will be perceived as limits to over ride the attention levels, and these will have already overridden the exposure limits. So many limits also leads to great confusion in the public's mind.
- The Law defines a "quality goal" as being a value of the electric, magnetic, or electromagnetic field to be set by future decrees in order to minimize exposure to EMFs. However, in the absence of a cost-benefit criterion, and explanation of social or political considerations, the minimization of exposure has no meaning, since further reductions are (almost) always possible, but will likely have no or questionable benefits for health.
- Having the aim of setting further reductions in the EMF limits can only lead to a race towards lower and lower limits. If there are compliance programmes for such limits, the ever increasing costs will be transferred to the consumer for no established health benefit.
- Quality goals, if applied to the mobile phone handsets could prevent free circulation of goods, in violation of EU treaties.
- The cost to achieve a reduction in exposure to the levels of the quality goals defined in the draft decree for 50 Hz fields has been estimated to be many billions of euros (not counting the huge increase in administrative costs); an expenditure for which no health benefits have been established.

2. In the decrees, the basic dosimetric quantities such as induced current density or specific absorption rate are not mentioned. Without limits in terms of such quantities determination of compliance becomes difficult in complex exposure situations. The protection system using basic restrictions and reference levels makes the ICNIRP guidelines flexible and applicable to virtually any exposure condition. The abandonment of these basic dosimetric concepts is likely to make the Law impracticable in complex situations, that include most of the occupational exposures, and some important exposures of the public, such as cellular phones and electric transport.

3. The decrees and Framework Law are in conflict with the EC recommendation to member states to use international standards (ICNIRP, 1998).

4. The precautionary principle is only mentioned in the Framework Law with reference to the Treaty of the European Union. There is no reference to the statement issued by the European Commission in February 2000 (EC, 2000) that gives guidance to member states on how the Precautionary Principle should be applied. Further, the Framework Law complies with none of the guiding principles from this EC document (scientific evaluation of risk, proportionality, cost-benefit analysis, transparency, time limitation etc).

5. Adoption of very restrictive and arbitrary EMF exposure limits by countries tends to increase public concern rather than reducing worries and controversies. Differences between regional and national limits tend to create confusion and mistrust of authorities. Choosing exposure limits that cannot be justified, either scientifically or logically, have already created some mistrust of the science, and in the authorities.

6. There is a great inconsistency in having RF exposure limits that only apply to fixed antennas, such as base stations, but not to mobile phone handsets, where compliance has to be evaluated using proper dosimetric terms (local specific absorption rate: SAR), since the head of the user is close to the RF source. Thus having limits for one source of exposure and not the same limits for another source cannot be based on any science that aims to protect health. How can one justify the situation that exceeding a limit is dangerous in one case (fixed antennas of base stations) and safe for a device that can emit higher levels than the fixed antennas, the mobile phones? In addition, if the quality goals or attention levels were applied to mobile phones, they could prevent free circulation of goods, in violation with EU treaties. Also, there was an arbitrary reduction in the limits of greater than a factor of 10 for RF exposures in places where it is possible to remain for more than four hours. Thus these extended term limits become the exposure limits that apply in virtually all cases.

7. There is no scientific justification provided with the decrees, so the basis on which the exposure limits were derived are purely arbitrary. Thus, the level of any health protection provided by these limits is completely unknown. If the level of health protection is unknown, the huge additional cost that implementation of this law would entail, could well be for no benefit to health.

Thus it can be seen that this law is internally inconsistent, is unsound scientifically, and cannot be readily implemented. From current scientific information, it does not provide any additional protection to the health of the Italian population.

Conclusions and Recommendations

Reviews of the current scientific studies, conducted by highly reputable organizations and professional societies, have all concluded that, while there are gaps in knowledge requiring further research before better health risk assessments can be made, there have not been any adverse health consequences confirmed from EMF exposures below the limits in the ICNIRP (1998) guidelines. The conclusions from the scientific reviews and assessment of the Framework Law and decrees leads to the following recommendations:

1. In order to avoid confusion about the applicable level of EMF exposure, it is appropriate to revise the Framework Law No. 36 to retain only the "exposure limits" defined in the Law. The limit values should be aligned fully with the "basic restrictions" in the guidelines on exposure limits of the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998). The "reference values" in the ICNIRP guidelines should be used for monitoring compliance with the basic restrictions, as described in (ICNIRP, 1998).
2. Responsibility for determining compliance with the exposure limits should be clearly assigned, and the results of all EMF measurements in areas of public interest should be made easily accessible to the general population.
3. To ensure that EMF levels are kept low, but commensurate with good quality operation of EMF technology, voluntary cost effective precautionary measures should be encouraged that are in accordance with the recommendations of the World Health Organization fact sheets (See references: WHO, 2000, 2001 and WHO Backgrounder, 2000). Further information on precautionary measures are given in Annex 5.
4. Given uncertainties in the science, the Government should provide significant funds for high quality EMF research that particularly addresses the agenda of studies already identified as being needed by the WHO International EMF Project.
5. The Italian Government should initiate an effective campaign of public education about possible effects of EMF exposure, as well as the meaning and use of precautionary measures, using information provided for this purpose by the European Commission and WHO.
6. Italian government authorities should work closely with WHO's International EMF Project to address EMF issues of concern to the general population and workers, so that actions to protect people from exposure to EMF are harmonized world wide.
7. The Italian Government should identify or establish a single authoritative scientific body responsible for providing advice on current knowledge about possible health risks of electromagnetic fields. Such a body could be similar in scope and function to bodies already established in some other European countries.

Further reading

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Annex 1: Resume of Committee members

PROF. FRANCESCO COGNETTI

Head of the Medical Oncology Division of the Regina Elena National Institute for Cancer Research, Rome, Italy (1/01/96 to date)

Scientific Director of the Regina Elena National Institute for Cancer Research (8/7/2001)

Member of the Head and Neck Cooperative Group of the EORTC (1982 to present)

Member of the American Society of Clinical Oncology (ASCO)(1985 to present)

Member of the Executive Board of the European Society for Medical Oncology (ESMO) (1991 to present)

Member of the Council of the Federation of the European Cancer Societies (FECS) (1995 - 1997)

Chairman of the Scientific Committee of the III National Congress of the Italian Association of Medical Oncology (AIOM), Naples 4-7 November 2001 (1999 to present)

National Representative for Italy of the European Society for Medical Oncology (ESMO) (2001 to present)

Member of the Steering Committee of the European Society for Medical Oncology (ESMO) (2001 to present)

Member of the Nominating Committee of the European Society for Medical Oncology (ESMO) (2001 to date)

Chairman of the Italian Association of Medical Oncology (2001 to present)

Coordinator of several cooperative studies on the treatment of solid tumors, at the national and international level (1982 to present)

Member of the National Commission for Oncology for the triennium 2000-2002 (2002 to present)

Vice-Chairman of the Regional Oncology Commission (2001 to present)

Peer Reviewer of the "Annals of Oncology": Official Journal of the European Society for Medical Oncology (2000 to present)

Associate Editor of "Tumori": Journal of Experimental and Clinical Oncology (2000 to present)

Lecturing Professor of Clinical Oncology at the II Postgraduate School of Oncology at the "La Sapienza" University in Rome (1990 to present)

Chairman of the Scientific Council of the Postgraduate School of Oncology (2001 to present)

Author of approximately 200 scientific publications on national and international journals

PROF. RICHARD DOLL

Sir Richard Doll qualified in medicine at St Thomas Hospital Medical School, University of London in 1937.

He served in the Royal Army Medical Corps for several years before turning into research.

From 1948 to 1969 he worked in the Medical Research Council's Statistical Research Unit, at first under Sir Austin Bradford Hill and then as the Director of the Unit.
In 1969 he became Regius Professor of Medicine in Oxford and in 1979 the first Warden of Green College, Oxford.

Since his retirement in 1983 he has continued work as an honorary member of the Clinical Trials Service Unit and the Epidemiological Studies Unit.

Over the past half century Sir Richard Doll has done more than any other epidemiologist to transform the general understanding of the avoidability of cancer and many other diseases linked to behaviour and environmental exposures.

In 1950, major case-control studies by Doll and Hill in UK and by Wynder and Graham in the US showed that smoking was a major cause of death from heart disease (and showed that many other disease could also be caused by tobacco).

The 40-year follow-up showed the absolute hazards of really prolonged smoking, demonstrating that about half of all persistent smokers would eventually be killed by their habit.

The findings of Sir Richard Doll thereby paved the way for prevention of coronary disease.

Sir Richard Doll was elected FRCP in 1957 and FRS in 1966. He was knighted in 1971 and made a Companion of Honour in 1996.

He received the United Nations Award for cancer research in 1962, the BMA's Gold medal in 1983, the Wilhelm Conrad Rontgen Prize from the Accademia dei Lincei (Rome) in 1984, the Royal Societies Royal Medal in 1986.

He has received honorary degrees from thirteen universities.

In 2000 he received the Gold Medal of European Society of Cardiology.

PROF. GABRIELE FALCIASECCA

Full Professor on “Microwaves” at the University of Bologna Engineering Faculty.

His research activity is concentrated in the sectors of communication (guided waves and optical fibres), of radio infrastructures for air and surface traffic guidance, of power applications of microwaves for mobile and personal communications.

In this last sector he worked within the framework of the agreements linking the Foundations U. Bordoni e G. Marconi with the National High Institute of Post and Telecommunications. He acted as a consultant for the Bordoni Foundation and was for an extended period of time the Director of its Centre for Millimetre Waves. He was Chairman of the Scientific Committee of the G. Marconi Foundation and, subsequently, Chairman of the Foundation itself.

He is a member of the Scientific Committee of CSELT since 1992, and outstanding member of the High Technical Council P.T.A. He participated in the works of the Commission which produced the technical terms of reference for the rapid start of the second GSM operator. Presently, he is again an expert member of such Council, following an interruption. He is a member of various National Commissions CCR, CEI and URSI. He is the Chairman of the CNR Specialized Group on Electromagnetism and was a member of the Programme Committee of the CNR Targeted Telecommunication Project.

He is the author of over one hundred and fifty scientific works, presented to congresses or published in highly qualified journals at the national and international levels. He was member of several technical and programme committees of international conferences in the aforementioned sectors, among which the European Conference on MTT. He is a referee of the IEEE Tr. on Vehicular Technology and is member of the editorial board of the journal “Wireless and Personal Communications”.

He also was involved in the popularisation of scientific work in the field of information and telecommunications. He was chairman of the Board of “Science or Magic?”, a production unit for interactive scientific exhibitions set up by the Municipality of Bologna together with the Marconi Foundation. Successively, he designed the Museum G. Marconi, located within Villa Griffone, where the most significant experience arising from such line of work has been gathered.

He encouraged the creation of the Consortium Elettra 2000 for the promotion of research on the environmental impact of radio and of its social usage. He is currently Chairman of the Consortium.

From November 1994 to November 2000 he was Director of the Electronic Information and Systems Department of the Bologna University. He is a member of the Academic Senate of the University of Bologna since November 1996.

Since September 1997 is the Chairman of the Marconi Foundation.
Since November 1998 he is Vice-Chairman of the Board of the Department Directors of the University of Bologna.

Since February 2001 he is Chairman of ASTER.

PROF. TULLIO REGGE

Prof. Tullio Regge was Born in Turin on July 7, 1931. There he attended high school and graduated in Physics at the University of Turin (Italy) in 1952.

He was awarded a Fullbright fellowship for the biennium 1954-56, to study Theoretical Physics at the University of Rochester (NY), where he obtained his Ph.D. He returned to Italy and obtained the University Chair in Theoretical Physics in 1961.
Currently he is teaching Quantum Theory of Matter at the Turin Polytechnic.

In 1958-59 he spent six months at the Max Planck Institute in Munich, Germany, where he interacted with W. Heisenberg.

Following the period in Munich, he went to Princeton University in the United States and to the Institute for Advanced Study of which he became a member in 1964. He left it to return to Italy in 1979.

Throughout his career, Prof. Tullio Regge was awarded several prizes:

the "Dannie Heineman" Prize of the American Physical Society and of the American Institute of Physics in 1964;
the Prize of the "City of Como" (Italy) of the Somaini Foundation in 1968;
the "Einstein Medal" of the Lewis Strauss Foundation in 1979;
the European Society of Physics "Cecil Powell Medal" for his work in the field of science popularisation in 1987;
the "Prize of Culture" of the Italian Council of Ministers in 1988;
the ITPC "Dirac Medal" in 1996;
the "Marcel Grossman" Prize in 1997.

He is a national member of the "Accademia dei Lincei" (Rome), of the Academy of Science of Turin (Italy), of the Academy of XL, of the American Philosophical Society, of the Chilean Academy of Science and of the Russia Academy of Science.
Currently, he is also the Chairman of the Turin Section of the Association for research and prevention of handicaps (AIRH).

DR. MICHAEL REPACHOLI

Coordinator, Radiation and Environmental Health, Department of Protection of the Human Environment, World Health Organization, Geneva, Switzerland, with responsibility for WHO's radiation health programmes.

B.Sc. (Physics) University of Western Australia
M.Sc. (Radiation Biology) London University, United Kingdom.
Ph.D (Biology) Ottawa University, Canada. (1980)

Past Chairman and Chairman Emeritus of the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Participant in 10 World Health Organization task groups on various NIR.

Member of the UK Expert Committee on Mobile Telephone Technology established by the UK Minister of Public Health and member of the Program Management Committee (PMC) of the UK Mobile Telecommunications Health Research Program

- Fellow and Past President of the Australian Radiation Protection Society.
- Fellow and Past President of Australian College of Physical Scientists and Engineers in Medicine.
- Fellow of the Australian Institute of Physics.
- Member of the Health Physics Society.
- Member of the Bioelectromagnetics Society.

Author or co-author of over 160 scientific publications

Annex 2: Electromagnetic Fields

What are electromagnetic fields?
Electromagnetic radiation and fields are everywhere and are needed for life on earth. Without sufficient electromagnetic energy, for example in the form of infrared radiation, life would not exist as we know it.

Natural and many human-made sources generate electromagnetic energy as electromagnetic waves. These waves consist of oscillating electric and magnetic fields.

Electromagnetic waves can be characterized by their wavelength, frequency, or energy. The three parameters are interrelated and influence how they interact with a biological system.

- The frequency of an electromagnetic wave is simply the number of oscillations passing a fixed point per unit time. It is measured in cycles per second, or hertz. One cycle per second equals one hertz (Hz). Large divisions used to describe radiofrequency (RF) fields include: kilohertz (kHz), or one thousand cycles per second; megahertz (MHz), one million cycles per second; and gigahertz (GHz), one billion cycles per second.
- The wavelength is the distance between two successive points on an electromagnetic wave. The shorter the wavelength, the higher the frequency of the wave.
- The higher the frequency, the larger the amount of energy there is in the wave to damage molecules.

According to their frequency and energy, electromagnetic waves can be classified as either "ionizing radiations" or "non-ionizing radiations" (NIR).

- Ionizing radiations are extremely high frequency electromagnetic waves (X-rays and gamma rays) that have enough energy in the wave to cause ionization (create positive and negative electrically charged atoms or parts of molecules) by breaking the atomic bonds that hold molecules in cells together.
- Non-ionizing radiations (NIR) are in that part of the electromagnetic spectrum that have wave energies too weak to break atomic bonds. They include: long-wavelength ultraviolet radiation (UV), visible light, infrared radiation (IR or heat), radiofrequency (RF) and microwave fields, extremely low frequency (ELF) fields, as well as static electric and magnetic fields. While NIR cannot cause ionization in a biological system they can produce other biological effects, for instance, by heating, altering chemical reactions or inducing electrical currents in tissues and cells.

Electromagnetic fields, within the NIR part of the electromagnetic spectrum that include ELF and RF fields, have frequencies from >0 to 300 GHz and are divided up according to their frequency range.

- Static fields (0 Hz): Magnetic levitation trains for public transportation, magnetic resonance imaging devices used in medicine, and electrolytic devices using direct electric currents for materials processing in industry.

- Extremely low frequency (ELF) fields (>0 to 300 Hz): Trains for public transport (16 2/3 to 50 or 60 Hz, plus harmonics), any device involved in the generation, distribution or use of electric power (normally 50 or 60 Hz).
- Intermediate frequency (IF) fields (>300 Hz to 10 MHz): Anti-theft and security devices, induction heaters and video display units.
- Radiofrequency (RF) fields (>10 MHz to 300 GHz): Mobile telephones or telecommunications transmitters, radars and medical diathermy units.

How EMF interacts with tissues and the terms and units used to measure them
EMF produces different effects on biological systems such as cells or human beings, depending on the frequency and intensity of the field. Most established effects of EMF exposure result from two main mechanisms: tissue heating and the induction of electric currents. Which mechanism is dominant and likely to be the cause of any adverse consequence, depends on the EMF frequency and intensity. Within the frequency range of interest (>0 to 300 GHz) EMF can be divided into the following ranges according to their key mchanisms of action on biological systems:

EMF fields above 10 to 300 GHz are absorbed at the skin surface, with very little of the energy penetrating into the underlying tissues. This produces surface heating mainly to the skin.
* The basic dosimetric quantity for RF fields above 10 GHz is the **intensity** of the field measured as **power density** in watts per square metre (**W/m^2**) or for weak fields in milliwatts per square metre (**mW/m^2**) or microwatts per square metre (**$\mu W/m^2$**).

EMF fields between 1 MHz and 10 GHz penetrate exposed tissues and produce heating due to energy absorption in these tissues. The depth of penetration of the RF field into the tissue depends on the frequency of the field and is greater for lower frequencies.
* Energy absorption from RF fields in tissues is measured as a specific absorption rate (SAR) within a given tissue mass. The unit of SAR is watts per kilogram (W/kg). SAR is the basic dosimetric quantity for RF fields between about 1 MHz and 10 GHz.
* Most adverse health effects that could occur from exposure to RF fields between 1 MHz and 10 GHz are consistent with responses to induced heating, resulting in rises in tissue or body temperatures higher than 1^0C.
* Induced heating in body tissues may provoke various physiological and thermoregulatory responses, including a decreased ability to perform mental or physical tasks as body temperature increases. Similar effects have been reported in people subject to heat stress: for example, those working in hot environments or suffering a prolonged fever.

EMF fields from >0 to 1 MHz do not produce any significant heating. Rather, they induce electric currents and fields in tissues, which are measured as a current density in amperes per square metre (A/m^2). Current density is the basic dosimetric quantity for fields with frequencies below about 1 MHz.
* The many physiological reactions involved in staying alive have associated normal "background" currents of about 10 mA/m^2.
* Induced current densities that exceed at least 100 mA/m^2 can interfere with normal functioning of the body and cause involuntary muscle contractions.

Thus it is important when evaluating effects from EMF exposure that the frequency of the fields is known. This is especially true when discussing the effects from exposure to fields from power lines (50 or 60 Hz) and mobile phones (>800 MHz).

Annex 3: International Guidelines

An English version of the international guidelines on limits of exposure to electromagnetic fields is available on: www.icnirp.org. A version of these guidelines translated into Italian is given below..

Annex 4: Italian "Framework law" (Law No. 36/2001)

The English versions of Law No. 36/2001 are given below

LAW 22 February 2001, n.36

Framework law on protection from exposure to electrical, magnetic and electromagnetic fields.

The Chamber of Deputies and the Senate of the Republic have approved;

THE PRESIDENT OF THE REPUBLIC

Promulgates the following law:

Art 1.
(Purpose of the law)

1. The aim of the present law is to establish basic principles directed towards:
a) ensuring protection of the health of workers and the population from the effects of exposure to determined levels of electrical, magnetic and electromagnetic fields for aims of and in compliance with article 32 of the Constitution;
b) promoting scientific research for the evaluation of the long-term effects and implementing protective measures to be adopted in application of the precautionary principle set forth in art. 174, paragraph 2, of the treaty establishing the European Union;
c) ensuring protection of the environment and landscape and promoting technological innovation and reclamation actions aimed at minimising the intensity and effects of electrical, magnetic and electromagnetic fields using the best available technologies.
2. The special-status regions and the autonomous provinces of Trento and Bolzano are taking measures for the aims of the present law as part of the competences assigned to them in accordance with their statutes and relevant implementing regulations and according to the provisions of their respective structures.

Art 2.
(Scope of application)

1. The present law refers to installations, systems and equipment for civil, military and police use that may involve the exposure of workers and the population to electrical, magnetic and electromagnetic fields at frequencies of between 0 Hz and

300 GHz.
In particular, the present law applies to transmission lines and radio-electrical installations, including mobile-telephone installations, radars and radio-broadcasting installations.
2. The present law's provisions do not apply in cases of intentional exposure for diagnostic or therapeutic aims. Only those provisions set forth at articles 10 and 12 of the present law apply to appliances and devices for domestic, individual and work use.
3. With regard to the armed forces and the police forces, the provisions of the present law are applied taking into account the special needs of the service performed, identified by the decree referred to at article 4, paragraph 2, letter a).
4. Jurisdiction in matters of worker safety and health attributed by current provisions to the health and technical services established for the armed forces and for the police forces remain unchanged; the aforesaid services also have jurisdiction for reserved or operational areas and for those having analogous needs identified by the decree referred to at paragraph 3.

Art 3.
(Definitions)
1. For aims of application of the present law, the following definitions are assumed:
a) exposure: this is the condition of a person subjected to electrical, magnetic and electromagnetic fields, or to contact currents, of artificial origin;
b) exposure limit: this is the electrical, magnetic and electromagnetic field value, considered as input value, defined for aims of protecting health from acute effects, which is not to be exceeded under any condition of exposure of the population and workers for the aims set forth at article 1, paragraph 1, letter a);
c) caution value: this is the electrical, magnetic and electromagnetic field value considered as input value, which is not to be exceeded in home and school environments and in places used for extended stays for the aims referred to at article 1, paragraph 1, letter b) and c). This is a cautionary measure for aims of protecting from possible long-term effects and must be reached in the times and manner prescribed by the law;
d) quality objectives are:
1) localising criteria, urban-planning standards, instructions and incentives for the use

of the best available technologies, indicated by regional laws according to the jurisdictions defined at article 8;
the electrical, magnetic and electromagnetic field values defined by the State according to the assessments set forth at article 4, paragraph 1, letter a) for aims of the progressive mitigation of exposure to those fields;
e) transmission line: refers to all power lines, substations and transformer rooms;
f) exposure of workers: this is any type of exposure of workers who, by virtue of their own specific work activity, are exposed to electrical, magnetic and electromagnetic fields;
g) exposure of the population: this is any type of exposure to electrical, magnetic and electromagnetic fields, with the exception of the exposure cited at letter f) and of intentional exposure for diagnostic or therapeutic aims;
h) radio-electrical stations and systems or installations: these are one or more transformers and receivers, or a group of transmitters and receivers, including accessory equipment, necessary at a given site to ensure radio broadcasting, radio communication or radio astronomy; i) mobile-telephone installation: this is the radio land station of the mobile telephony service, intended for radio linkage of mobile terminals with the mobile telephony service network;
l) fixed radio broadcasting installation: this is the land station for television or radio broadcasting service.

Art 4.
(The State's functions)
1. The State exercises functions relating to:
a) determining exposure limits, caution values and quality objectives, inasmuch as they are field values as defined by article 3, paragraph 1, letter d), number 2), in consideration of the nation's overriding interest in establishing unified criteria and consistent regulations in regard to the aims set forth at article 1;
b) promoting research activity and technical and scientific testing, as well as coordinating the gathering, processing and diffusion of data, annually informing the Parliament on this activity; in particular the Health Ministry promotes. through public and private not-for-profit institutions having proven experience in the scientific field, a multi-year programme of epidemiological research and experimental oncogenesis, in order to explore the risks associated with exposure to low- and high-frequency

electromagnetic fields;
c) establishing a naional registry of the fixed and mobile sources of electrical, magnetic and electromagnetic fields and of the geographical areas involved, in order to survey the field levels present in the environment;
d) determining criteria for drawing up recovery plans as set forth at article 9, paragraph 2, with special reference to intervention priorities, implementation times, and means of coordinating activities involving multiple regions, as well as to the best technologies available with regard to implications of an economic and infrastructure nature;
e) identifying techniques for measuring and surveying electromagnetic pollution;
f) achieving planning agreements with transmission-line or transmission-grid managers or their owners, or with those who in any case who have same available to them, as well as with operators of installations for radio and television broadcasting and mobile telephony, in order to promote technologies and installation construction techniques that make it possible to minimise environmental emissions and to protect the landscape;
g) defining routes for transmission lines greater than 150 kV;
h) determining parameters for setting transmission-line restricted zones for transmission lines; within these restricted zones, no building is allowed to be used for residential, school, health or any other use that would involve a stay of at least four hours;
2. The exposure limits, caution values and quality objectives, techniques for measuring and surveying electromagnetic pollution, and parameters for establishing the restricted zone for transmission lines as described at paragraph 1, letter a), e) and h) are established within sixty days from the date on which the present law takes effect:
a) for the population, by decree of the President of the Council of Ministers at the proposal of the Ministry of the Environment in concert with the Minister of Health, having consulted the opinion of the Committee described at article 6 and the competent parliamentary commissions, following agreement in the jopint conference described at article 8 of Legislative Decree 28 August 1997, n. 281, hereinafter the "Joint Conference;"
b) for workers, without prejudice to the provisions set forth in Legislative Decree 19

September 1994, n. 626, and subsequent modifications, by decree of the President of the Council of Ministers at the proposal of the Minister of Health, having consulted the opinion of the Ministers of the Environment and of Labour and Social Welfare, the Committee described at article 6, and the competent parliamentary commissions, upon agreement reached in the Joint Conference. This same decree also governs the system of medical monitoring of works exposed on the job.

3. If agreements are not reached by the Joint Conference by the deadline set at paragraph 2, the President of the Council of Ministers, within thirty days, adopts the decrees described at paragraph 2, letters a) and b).

4. Within one hundred twenty days from the date on which the present law takes effect, the criteria for preparation of the recovery plans, in accordance with paragraph 1, letter d), are determined by decree of the President of the Council of Ministers at the proposal of the Minister of the Environment, having consulted the Committee described at article 6 and the Joint Conference.

5. The regions adapt their own legislation to the exposure limits, caution values and, within the limits of the definition at article 3, paragraph 1 letter d), number 2), quality objectives set forth by the decrees described at paragraph 2 of the present article.

6. For aims of the present article, the expenditure of Lire 8,000 million is authorised for each of the years 2001, 2002 and 2003 for the activities described at paragraph 1, letter b); Lire 2,000 million annually is authorised starting with 2001 for the activities described at paragraph 1, letter c); and Lire 5,000 million is authorised for each of the years 2001, 2002 and 2003 for realisation of the planning agreements described at paragraph 1, letter f), as well as for the subsequent planning agreements described at articles 12 and 13.

Art 5.

(Measures to protect the environment and landscape) Procedure for authorisation of construction and operation of transmission lines

1. In order to protect the environment and the landscape, by special regulation adopted within one hundred twenty days from the date on which the present law takes effect, in accordance with article 17, paragraph 2, of the Law 23 August 1988, n. 400, and article 29, paragraph 2, letter g) of legislative decree 31 March 1998, n. 112, at the proposal of the Ministers of Public Works and of Cultural Properties and Activities, upon the opinion of the Committee mentioned at article 6 and having

consulted the competent parliamentary commissions, specific measures are adopted relating to the technical characteristics of installations and the location of routes for the design, construction, and modification of transmission lines and installations for mobile telephony and broadcasting. The same regulation indicates the particular measures likely to avoid damage to environmental and landscape values, and further specific measures may be adopted for the design, construction and modification of transmission lines in areas subject to constraints imposed by national and regional laws as well as by regional and urban planning instruments to protect historic, artistic, architectural, archaeological, landscape and environmental interests, without prejudice to the provisions of the consolidation act of legislative provisions regarding cultural and environmental properties, approved by legislative decree 29 October 1999, n. 490, and without prejudice to compliance with the aforesaid constraints and planning instruments.

2. By the same regulation described at paragraph 1, measures are adopted to contain the electrical risk of the installations described at the same paragraph 1, and in particular the risk of electrocution and avian collisions.

3. By the same regulation described at paragraph 1, a new regulation is defined for authorisation procedures for the construction and operation of power lines greater than 150 kV, so as to ensure compliance with the principles of the present law, without prejudice to current provisions regarding environmental impact assessment. This latter regulation also conforms to the following criteria and principles:

a) simplification of administrative procedures;

b) identification of the types of infrastructure having less impact on the environment, the landscape and on citizen health;

c) coordination with the affected regions and local entities in the administrative procedures for defining routes;

d) identification of responsibilities and of monitoring and control procedures, e) adjustment of procedures relating to transmission-line easements and the relevant compensation;

f) advance evaluation of pre-existing electromagnetic fields.

4. The standards, including those of law, that govern the procedures described at paragraph 3, identified by the regulation described at the same paragraph, are abrogated with effect on the date on which the regulation takes effect.

Art 6.

(Interministerial committee for the prevention and reduction of electromagnetic pollution)

1. The Interministerial Committee for the Prevention and Reduction of Electromagnetic Pollution, hereinafter the "Committee," is established.

2. The Committee is presided over by the Minister of the Environment or by the delegated Undersecretary for the environment, and is composed of the ministers, or by the delegated undersecretaries of Health, Universities and Scientific and Technological Research, Public Works, Industry, Commerce and Handicrafts, Cultural Properties and Activities, Transport and Navigation, Communications, Defence, and the Interior.

3. The Committee carries out the activities described at articles 4, paragraph 1, letters b) and f), and 12, paragraph 2, and 13.

4. The Committee expresses the opinions described at articles 4, paragraph 2, letters a) and b), 4, paragraph 4, 5, paragraph 1, and 12, paragraph 1.

5. The Committee monitors the procedures prescribed by the present law and prepares an annual report to the Parliament on its activity.

6. The Committee avails itself of the freely rendered contributions of entities, agencies, institutions and organisations of a public nature having specific competences in the various areas of interest under the present law.

7. For the creation and operation of the Committee a maximum expenditure of Lire 1,000 million annually is authorised, beginning in 2001.

Art 7.

(National land registry)

1. The national land registry described at article 4, paragraph 1, letter c) is established within one hundred twenty days from the date on which the present law takes effect by the Minister of the Environment, having consulted the Minister of Health and the Minister of Industry, Trade and Handicrafts, as part of the informational and monitoring system described at article 8 of the Decree of the President of the Republic 4 June 1997, n. 335. The national land registry operates in coordination with the regional registries described at article 8, paragraph 1, letter d). The means of data input are defined by the Minister of the Environment, in concert with the Minister of Communications with regard to the input of data relating to fixed sources associated

with radio-electric installations, systems and equipment for civil telecommunication uses, with the Minister of Public Works and with the Minister of Industry, Commerce and Handicrafts with regard to the input of data relating to transmission lines, with the Minister of Transport and Navigation with regard to the input of data relating to transport facilities, and with the Ministers of Defence and the Interior with regard to the input of data relating to fixed sources associated with installations, systems and equipment for military and police uses.

Art 8.

(Competences of the regions, provinces and municipalities)

1. The following, in compliance with exposure limits, caution values and quality objectives as well as the criteria and methods established by the State, without prejudice to the competences of the State and of independent authorities, are competences of the regions:

a) exercise of functions relating to the identification of transmission sites and installations for mobile telephony, of radio-electric installations and broadcasting installations, in accordance with Law 31 July 1997, n. 249, and in compliance with the decree described at article 4, paragraph 2, letter a), and with the principles established by the regulation described at article 5);

b) definition of the routes of transmission lines not exceeding 150 kV, with establishment of restricted zones according to the parameters set in accordance with article 4 and with the obligation to indicate them;

c) procedures for the issue of authorisations for the installation of the facilities described in the present article, in accordance with criteria of administrative simplification, taking into account pre-existing electrical, magnetic and electromagnetic fields;

d) the creation and management, in coordination with the national land registry described at article 4, paragraph 1, letter c), of a registry of fixed sources of electrical, magnetic and electromagnetic fields, in order to survey the levels of those fields regionally, with reference to population exposure conditions;

e) identification of instruments and actions to achieve the quality objectives described at article 3, paragraph 1, letter d), number 1);

f) contributing to increased scientific understanding of the effects on health, especially long-term, deriving from exposure to electrical, magnetic and electromagnetic fields.

2. In exercising the functions described at paragraph 1, letters a) and c), the regions following principles relating to the protection of the public health, environmental compatibility and the need to protect the environment and landscape.

3. In the event of noncompliance by the regions, article 5 of Legislative Decree 31 March 1998, n. 112, is applied.

4. In the areas described at paragraph 1, the regions define the competences of the provinces and municipalities, in compliance with the provisions of the Law 31 July 1997, n. 249.

5. The activities described at paragraph 1 regarding areas affected by military installations or those belonging to other State bodies having functions affecting public order and safety are defined through specific agreements by the joint equal committees described at article 3 of the Law 24 December 1976, n. 898, and subsequent modifications.

6. Municipalities may adopt a regulation to ensure proper urban and regional siting of installations and to minimise the population's exposure to electromagnetic fields.

Art 9.

(Recovery plans)

1. Within twelve months of the date on which the decree described at article 4, paragraph 2, letter a) takes effect, the region, at the proposal of operators and having consulted the interested parties, adopts a recovery plan in order to upgrade gradually, and in any case within twenty-four months, those radio-electrical installations already existing to the exposure limits, caution values and quality objectives established according to the present law. Twelve months after the date on which the decree described at article 4, paragraph 2, letter a) takes effect, in the event of inaction or noncompliance by operators, the recovery plan is adopted by the regions, having consulted the municipalities and interested parties, within the following three months. The plan, implementation of which is monitored by the regions, may also call for the relocation of broadcasting installations to sites complying with planning in this area, and of other types of installations to suitable sites. The recovery is carried out with costs borne by the owners of the installations.

2. Within twelve months from the date on which the decree described at article 4, paragraph 4, takes effect, transmission-line operators present a proposed recovery plan in order to ensure protection of health and the environment. Owners of portions of the national grid, or those who in any case have access to it, are required to promptly provide to the national grid operator, within six months of the date on which the decree described at article 4, paragraph 2, letter a) takes effect, proposed measures for reorganising the lines under their jurisdiction, as well as all information necessary for aims of presentation of the proposed recovery plan. The plan must cover those projects which it is intended to carry out in order to comply with the exposure limits and caution values, and to achieve the quality objectives established by the decree described at article 4, paragraph 2, letter a). It must indicate a chronological implementation schedule, adapted to the priorities set forth in the aforementioned decree, considering in any case as priority situations those subject to the highest levels of electromagnetic pollution, in proximity to residential, school, and health-care buildings or in any case buildings used for stays of no less than four hours, with particular reference to protection of infant health.
Twelve months after the date on which the decree described at article 4, paragraph 2, letter a) takes effect, in the event of inaction or noncompliance by operators, the recovery plan described at the first point of paragraph 3 is proposed by the region within the following three months.
3. For transmission lines greater than 150 kV, the proposed recovery plan is presented to the Ministry of the Environment. The plan is approved, with any modifications, supplements and instructions, within sixty days, by the Minister of the Environment, in concert with the Ministers of Industry, Trade and Handicrafts and of Public Works, having consulted the Minister of Health and the regions and municipalities affected. For transmission lines less than 150 kV, the proposed recovery plan is presented to the region, which approves the plan, with any modifications, supplements and instructions, within sixty days, having consulted the municipalities affected. Twelve months after the date on which the decree described at article 4, paragraph 2, letter a) takes effect, in the event of inaction or noncompliance by operators, the recovery plan for transmission lines greater than 150 kV is adopted by the region, within the period described at the third point of the present paragraph.
4. Recovery of the transmission lines must be completed within ten years from the

date on which the present law takes effect.
Recovery of those transmission lines not complying with the limits described at article 4 and with the conditions described at article 5 of the decree of the president of the Council of Ministers 23 April 1992, published in the Official Gazette n. 104 of 6 May 1992, must be completed by 31 December 2004 and by 31 December 2008, respectively, in order to meet the exposure limits, caution values and quality objectives established according to article 4, paragraph 2, letter a) of the present law. Recovery is carried out with costs borne by the owners of the transmission lines, as defined according to Legislative Decree 16 March 1999, n. 79. The Electrical Energy and Gas Authority, in accordance with article 2, paragraph 12, of the Law 14 November 1995, n. 481, within sixty days of approval of the recovery plan, evaluates the costs directly associated with carrying out the reorganisaiton measures, as well as the criteria, terms and conditions for their eventual recovery.
5. For aims of granting subsidies to the regions for preparation of the recovery plans, creation of the regional land registries and monitoring and control activities, a maximum expenditure of Lire 2,000 million annually is authorised beginning in 2001. Sums deriving from application of the sanctions called for by article 15, paid into the State budget, are entirely reassigned by decree of the Minister of the Treasury, Budget and Economic Planing to special basic forecast units of the estimate of the Ministry of the Environment; based on the criteria set by the Joint Conference, these sums are assigned to subsidies granted to the regions to supplement the resources assigned to them according to the first point of the present paragraph, for aims of preparing the recovery plans, establishing the regional land registries, and carrying out monitoring and control activities.
6. Failure to reorganise the transmission lines, radio-electric stations and systems, mobile-telephony installations and broadcasting installations according to the plan's instructions, owing to inaction or noncompliance by the owners of the transmission lines or those who in any case have access to them, carries with it, without prejudice to the provisions of article 15, non-recognition by the national grid operator of the use fee for the unreorganised line and deactivation of the aforesaid installations for a period of up to six months, ensuring however the rights of users to the public-utility service. Deactivation is imposed:
a) by disposition of the Minister of the Environment in concert with the Minister of

Industry, Commerce and Handicrafts, having consulted the Minister of Health and of Labour and Social Welfare, as well as the regions affected, for transmission lines greater than 150 kV;

b) by disposition of the chairman of the regional council for transmission lines less than 150 kV and radio-electrical systems, with the exclusion of mobile-telephony and broadcasting installations and fixed-telephony installations as well as radio-electrical stations for data transmission, deactivation of which is effected by disposition of the Minister of Communications, who ensures uniform application of the regulations throughout the country.

7. Within one hundred eighty days from the date on which the present law takes effect, an easily visible informational label must be affixed to each structure described at letters e), h) and l) of paragraph 1 of article 3, showing the voltage produced, the exposure limits and caution values prescribed by national and regional laws, and the restriction distances.

Art 10.

(Environmental education)

1. The Minister of the Environment, in concert with the Ministers of Health, of Universities and Scientific and Technological Research, and of Public Education, promotes environmental information and education campaigns according to the Law 8 July 1986, n. 349. To this end, expenditure of Lire 2,000 million annually is authorised beginning with 2001.

Art 11.

(Participation in the administrative procedure)

1. The provisions of Chapter III of the Law 7 August 1990, n. 241, and subsequent modifications regarding participation in the administrative procedure are applied to procedures for defining transmission-line routes as described at articles 4 and 8, as well as to procedures for adoption and approval of recovery plans as described at article 9, paragraph 2.

Art 12.

(Appliances for household, individual and work use)

1. By decree of the Minister of the Environment in concert with the Minister of Health, upon receiving the opinion of the Committee and having consulted the competent parliamentary commissions, within one hundred twenty days of the date on which the present law takes effect, and taking into account the European Union's

guidelines and acts regarding electromagnetic pollution, consumer protection and instructions for product use, the information which the manufacturers of appliances and devices, particularly of those for household, individual or work use, generating electrical, magnetic and electromagnetic fields, are required to provide to users and workers through special labels or informational materials, are established. This information must cover, in particular, the exposure levels produced by the appliance or device, the recommended distance for use to reduce exposure to the electrical, magnetic and electromagnetic field, and the main safety instructions. This same decree identifies the types of appliances and devices for which there is no electrical, magnetic and electromagnetic field emission, or for which such emissions are to be considered so low as not to require any precaution.

2. The Committee promotes the concluding of accords and planning agreements with firms producing appliances for household, individual or work use that produce electrical, magnetic and electromagnetic fields, in order to promote and develop technologies that make it possible to minimise emissions.

Art 13.

(Planning agreements for public-transport services)

2. The Minister of the Environment, at the proposal of the Committee, promotes the conclusion of accords and planning agreements with operators of public-transport services that produce electrical, magnetic and electromagnetic fields, in order to promote and develop technologies that make it possible to minimise emissions.

Art 14.

(Controls)

1. In order to exercise health and environmental control and oversight functions for implementation of the present law, provincial and municipal governments utilise the offices of the regional environmental protection agencies, as described by the Decree-Law 4 December 1993, n. 496, converted with modifications by the Law 21 January 1994, n. 61. This is without prejudice to the oversight competences in work places attributed by current legislation.

2. In regions where regional environmental protection agencies are not yet operating, for the aims of paragraph 1 provincial and municipal governments make use of the technical support of the National Environmental Protection Agency, the PMP (multi-zone prevention facilities), the ISPESL (Higher Institute for Job Safety and Prevention), and the regional inspectors of the Communications Ministry, in

compliance with the specific competences attributed by current legislation.
3. Monitoring inside the fixed or mobile installations used for the institutional activities of the armed forces, police and fire departments is governed by specific sectoral regulations. In particular, the provisions for the armed forces and police at articles 1, paragraph 2, and 23, paragraph 4, of the Legislative Decree 19 September 1994, n. 626, and subsequent modifications, remain in force.
4. Personnel responsible for said monitoring, in exercising their functions of oversight and control, may have access to installations that are sources of electromagnetic emissions and, in accordance with the provisions of the Law 7 August 1990, n. 241 and subsequent modifications, may request the data, information and documents necessary to perform their functions. These personnel bear an identifying document from the agency to which they belong.

Art 15.

(Sanctions)

1. Unless the act constitutes a crime, anyone who, in operating or using a source or installation that generates electrical, magnetic and electromagnetic fields, exceeds the exposure limits and caution values set forth in the decrees of the President of the Council of Ministers described at article 4, paragraph 2, and in the decrees described at article 16, is punished by administrative sanction to pay the sum of from Lire 2 million to Lire 600 million. The aforesaid sanction is applied as well to anyone who, during implementation of recovery plans, does not comply with the prescribed limits and deadlines.
2. Unless the act constitutes a crime, violation of the protective measures described at article 5, paragraph 1, is punished by administrative sanction to pay the sum of from Lire 2 million to Lire 200 million. In the event of recidivism, the penalty is doubled.
3. Unless the act constitutes a crime, the penalties described at paragraphs 1 and 2 are meted out by the competent authorities based on the investigations conducted by the authorities authorised to conduct the monitoring described at article 14. The authorities competent to inflict the penalties described at paragraphs 1 and 2 are identified by the decrees described at article 4, paragraph 2.
4. In the event of noncompliance with the prescriptions established, for aims of protecting the environment and health, by the authorisation, concession or licensing for the installation and operation of the installations regulated by the present law, a

penalty of suspension of the aforesaid authorised acts is applied, of from two to four months. In the event of a second infraction, the authorising act is revoked.
5. The penalty described at paragraph 4 is applied by the authority competent on the basis of current legislation to issue the authorising act, based on inspections conducted by the authorities authorised to monitor.
6. Noncompliance with the decree described at article 12, paragraph 1, is punished by administrative sanction to payment of a sum of from Lire 2 million to Lire 600 million.
7. In reference to the penalties provided under the present article, the reduced payment described at article 16 of the Law 24 November 1981, n 698, and subsequent modifications, is not allowed.

Art 16.

(Interim regimen)

1. Until the date on which the decree of the President of the Council of Ministers described at article 4, paragraph 2) letter a) takes effect, the provisions of the decree of the President of the Council of Ministers 23 April 1992, published in the Official Gazette n. 104 of 6 May 1992, and subsequent modifications, the provisions of the decree of the president of the Council of Ministers 28 September 1995, published in the Official Gazette n. 232 of 4 October 1995, and the provisions of the decree of the Minister of the Environment 10 September 1998, n. 381, are applied insofar as they are compatible with the present law.

Art 17.

(Financial coverage)

The cost deriving from implementation of the present law, equal to Lire 20,000 million for each of the years 2001, 2002 and 2003, is provided for:

a) with regard to Lire 7,000 million beginning in 2001, by use of projections for those years of the appropriation entered for aims of the 2001-2003 three-year budget as part of the basic anticipatory unit, Special Fund current account, of the estimate of the Ministry of the Treasury, Budget and Economic Planning for the year 2001, partially utilising for this aim the allocation for the Environment Ministry;

b) with regard to Lire 13,000 million for each of the years 2001, 2002 and 2003, by use of projections for those years of the appropriation entered for aims of the 2001-2003 three-year budget as part of the basic anticipatory unit, Special Fund capital account, of the estimate of the Ministry of the Treasury, Budget and Economic

Planning for the year 2001, partially utilising for this aim the allocation for the Environment Ministry.

2. The Minister of the Treasury, Budget and Economic Planning is authorised to make by his decree the necessary budget changes.

The present law, bearing the State seal, shall be inserted into the Official Record of regulatory acts of the Republic of Italy. Compliance and enforcement of compliance with it as a law of the State is mandatory for all.

Given in Rome, 22 February 2001

CIAMPI

Amato, President of the Council of Ministers

Bordon, Minister of the Environment

Approval by the Keeper of the Seals: Fassino

PREPARATORY WORKS

Chamber of Deputies (act n. 4816):

Presented by the Minister of the Environment (Ronchi) on 24 April 1998.

Assigned to the VIII commission (Environment), in reporting session, on 11 May 1998, with opinions from commissions I, II, IV, V, VII, IX, X, XI, and XII.

Examined by the VIII commission, in reporting session, on 11 and 18 February; 26 May: 9 July; 17 November;

9 December 1998; 27 January: 3, 17 and 24 February; 3 and 17 March; 21 and 28 April; and 26 May 1999.

Again assigned to the VIII commission (Environment), in drafting session, on 30 June 1999.

Examined by the VIII commission in drafting session on 30 June, 7, 14 and 21 July 1999; 22 and 28 September and 6 October, 1999.

Presentation of the text of the articles announced on 7 October 1999 (act. n. 4816-342-452-2095-4036-4464-4467-4487-4561-5212-5982-A/RED), Sen. Vigni reporting.

Examined on the floor and approved on 14 October 1999.

Senate of the Republic (act. n. 4273):

Assigned to the 13th commission (Territory), in deliberating session, on 27 October 1999, with opinions from commissions 1a, 2a, 4a, 5a, 7a, 8a, 10a, 11a, 12a, Board for European Community affairs and parliamentary commission for regional matters.

Examined by the 13th commission, in deliberating session, on 16 December 1999.

Again assigned to the 13th commission, in reporting session, on 16 December 1999.

Examined by the 13th commission in reporting session on 16 December 1999; 2, 9, 14, 15, 16 March; 5 April; 9, 10, 11, 23, 24, 30, 31 May; 1, 6, 7, 8, 14, 22, 27, 28 June; 5 and 6 July 2000.

Examined on the floor on 6 December 2000; 17, 18 and 23 January 2001, and approved with modifications on 24 January 2001.

Chamber of Deputies (act n. 4816-B):

Assigned to the VIII commission (Environment), in reporting session, on 29 January 2001, with opinions from commissions I, II, IV, V, VII, IX, X, XI, XII, XIV and parliamentary commission for regional matters.

Examined by the VIII commission on 30 January; 1, 6 and 7 February 2001.

Examined on the floor on 9 February 2001 and approved on 14 February 2001.

N O T ES:

Notice:

The text of the notes published here was prepared by the competent office, in accordance with art. 10, paragraph 3, of the consolidation act of provisions on the promulgation of laws and decrees of the President of the Republic and on official publications of the Republic of Italy, approved by Pr. D. 28 December 1985, n. 1092, for the sole aim of facilitating the reading of the provisions of law to which reference was made. The value and effectiveness of the legislative acts here transcribed remain unchanged.

Notes to art. 1:

- Art. 32 of the Constitution is as follows:

Art. 32 – The Republic protects health as a fundamental right of the individual and interest of society, and ensures free care for the indigent.

No one may be obligated to undergo a given health treatment except by provision of law. The law may in no case violate the limits imposed by respect for the human person."

- Paragraph 2 of art. 174 of the treaty establishing the European Union is as follows:

"2. The Community's policy in environmental matters aims at a high degree of protection, taking into account the diversity of situations in the various regions of the Community. The policy is founded on principles of precaution and preventive action, on the principal of priority correction at the source of damage caused to the environment, and on the principle of 'the polluter pays.'

In this context, harmonising measures meeting the needs of environmental protection include, in due cases, a safeguarding clause that authorises member states to take provisional measures, for environmental reasons of a non-economic nature, subject to a Community monitoring procedure."

Notes to art. 4:

- Art. 8 of the Legislative Decree 28 August 1997, n. 281, is as follows:

Art. 8 (State-city and local autonomy conference and Joint Conference). - 1. The State-City and local autonomy Conference is combined for matters and tasks of joint interest to the regions, provinces, municipalities and mountain communities, with the State-Region Conference.

The State-City and local autonomy Conference is presided over by the President of the Council of Ministers or, by his delegation, by the Minister of the Interior or by the Minister for Regional Affairs; the Minister of the Treasury, Budget and Economic Planning, the Minister of Finance, the Minister of Public Works, the Minister of Health, the president of the National Association of Italian Municipalities – ANCI, the president of the Italian Provinces Union – UPI, and the president of the National Union of Municipalities and Mountain Communities and Entities – UNCEM are also part of it. In addition, fourteen mayors designated by ANCI and six provincial presidents designated by UPI also belong to it.

Notes to art. 5:

- Art. 17, paragraph 2, of the Law 23 August 1998, n. 400, is as follows:

"2. By decree of the President of the Republic, after deliberation by the Council of Ministers, having consulted the State Council, regulations are issued to govern matters not covered by absolute reservation of law as provided by the Constitution, for which the laws of the Republic, authorising exercise of the government's regulatory powers, set general regulatory standards and provide for the abrogation of current legislation, taking effect when the regulatory standards take effect."

- Art. 29, paragraph 2, letter g) of the Legislative Decree 31 March 1998, n. 112, is as follows:

"2. Reserved for the State are, in addition, administrative functions concerning:

a)-f) (omission);

g) the construction and operation of installations for the production of electrical energy greater than 300 MW, except those producing energy from renewable sources and from waste in accordance with Legislative Decree 5 February 1997, n. 22, and transmission grids greater than 150 kV, the issue of technical standards relating to the construction of transmission lines, the issue of concessions for electrical operations of State competence, and other oil and gas pipeline networks of national interest."

- Legislative Decree 29 October 1999, n. 490, establishes:

"Consolidation act for legislative provisions in the area of cultural and environmental properties, in accordance with art. 1 1 of the Law 8 October 1997, n. 352".

Of the fourteen mayors designated by ANCI, five represent the cities identified by art. 17 of the Law 8 June 1990, n. 142. Other members of the government may be invited to the meetings, as well as representatives of State and local government offices and public entities.

3. The State-City and local autonomy Conference is convened every three months, and in any case whenever the president deems it necessary or should the president of ANCI, UPI or UNCEM so request.

4. The Joint Conference described at paragraph 1 is convened by the President of the Council of Ministers.

Meetings are chaired by the President of the Council of Ministers or, at his delegation, by the Minister for Regional Affairs or, if that office is not filled, by the Minister of the Interior.

- Legislative Decree 19 September 1994, n. 626, implementing the directives 89/391/CEE, 89/654/CEE, 89/655/CEE, 89/656/CEE, 90/269/CEE, 90/270/CEE, 90/394/CEE, 90/679/CEE, 93/88/CEE, 97/42/CE and 1999/38/CE regarding improvement of worker safety and health on the job, is published in the ordinary supplement to the Official Gazette n. 265 of 12 November 1994.

Note to art. 7:

- Art. 8 of the decree of the President of the Republic 4 June 1997, n. 335, is as follows:

"Art. 8 (Environmental information and monitoring system). - 1. The measures adopted in implementation of art. 18, par. 1, letter e) of the Law 11 March 1988, n. 67. relating to the environmental monitoring and information system (SINA) and the relevant technical endowments are transferred to ANPA in accordance with art. 1b, paragraph 4, of the Decree-Law 4 December 1993, n. 496, converted with modifications by the Law 21 January 1994, n. 61.

2. For recognition of the measures implemented or being implemented as part of the system described at paragraph 1, and of the relevant technical endowments to be transferred to ANPA, the Ministry of the Environment, within sixty days from the date on which the present regulation takes effect, adopts a decree that identifies:

a) the measures already taken by the Ministry of the Environment, with the relevant technical endowments;

b) the measures, with their relevant technical endowments, in any case aimed at the completion, strengthening or implementation of the environmental monitoring and information system still being realised or carried out by virtue of contracts, conventions, agreements and measures stipulated or adopted by the Ministry of the Environment;

c) the financial resources aimed at realising, strengthening, implementing or managing the SINA to be made available to ANPA;

d) the measures of the autonomous regions and provinces for completion and strengthening of the environmental monitoring and information system funded by the Ministry of the Environment, which funds are kept in the spending estimate of the Ministry pending their transfer to the parties responsible for the measures in accordance with the decision of the Interministerial Committee for Economic Planning 21 December 1993, and subsequent modifications and supplements.

3. The decree described at paragraph 2 also defines, after a functional check with ANPA, the technical and administrative methods for transfer and logistical relocation at ANPA of the measures and technical endowments described at paragraph 2, letters a) and b), and of the funding described at letter c), in order to ensure prompt

resumption of the operational capabilities of the system transferred, which takes into account the informational situation at the Agency and the functional needs of the Ministry of the Environment, as well as methods for managing the transition period. In addition, the same decree defines the methods for coordinating the measures described at paragraph 2, letter d) necessary to ensure functional liaison with the SINA nationwide, in order to allow consistent maintenance of data flows between the principals of the measures and ANPA.

4. This decree is submitted to the Permanent Conference for relations between the State and the regions and autonomous provinces for aspects relating to the environmental monitoring and information systems of the regions and autonomous provinces, promoted and coordinated within the SINA and to the relevant funding.

5. The State's agencies, including those that are autonomous, as well as public, regional and local entities and joint-stock companies operating under an exclusive concession that in any case gather data in the environmental sector transmit the data to ANPA according to the specifications provided by ANPA in relation to the type of information, as well as the methods and frequencies to be used for effecting those exchanges.

6. The specifications may in particular involve the structure of the data, transmission frequency, and the transmission medium, normally via online network.

7. Integration with environmental data regarding the enterprise system is achieved according to the methods established in the planning agreement with Unioncamere described at art. 1, paragraph 6 of the Decree-Law 4 December 1993, n. 496, converted with modifications into the Law 21 January 1994, n. 61.

8. These activities are carried out in collaboration with the regional agencies and those of the autonomous provinces, including through those instruments prescribed at art. 10, paragraph 4.

The diagrams for the technical specifications, including the levels of data aggregation and processing, are approved by the Minister of the Environment, having consulted the Permanent Conference for relations between the State and the regions and autonomous provinces.

9. Based on the decree described at paragraphs 2 and 3, ANPA draws up a schedule of activities that takes into account the measures adopted nationally and locally relating to information systems of environmental interest for the coordinated development and

evolution of the environmental information system. This schedule is forwarded to the Ministry of the Environment to be submitted for examination by the Permanent Conference for relations between the State and the regions and autonomous provinces for the relevant agreement."

Notes to art. 8:

- Law 31 July 1997, n. 249, authorising:

"Establishment of the Telecommunications Authority and standards on telecommunications and radio and television systems" is published in the Official Gazette n. 177 of 31 July 1997.

- Following is the text of art. 5 of the Legislative Decree 31 March 1998, n. 112:

"Art. 5 (Substitutive powers) – 1. With respect to the functions and tasks falling to the regions and local entities, in the event of proven inactivity that results in noncompliance with the obligations deriving from membership in the European Union or serious harm to national interests, the President of the Council of Ministers, at the proposal of the minister competent for that area, assigns an appropriate deadline to the noncompliant entity to perform.

2. If the deadline passes without effect, the Council of Ministers, after having consulted the noncompliant party, appoints a commissioner to act in its stead.

3. In cases of absolute urgency, the procedures described at paragraph 1 are not applied, and the Council of Ministers may adopt the measure described at paragraph 2, at the proposal of the President of the Council of Ministers and in concert with the competent minister. The measure thus adopted is immediately executed and immediately communicated to the Permanent Conference for relations between the State and the regions and autonomous provinces of Trento and Bolzano, hereinafter the "State-region Conference," and to the State-City and local autonomy Conference expanded to include the representatives of the mountain communities, who may seek reexamination, under the terms and for the aims envisioned by art. 8, paragraph 3, of the Law 15 March 1997, n. 59.

4. Provisions in the matter of substitutive powers provided by current legislation remain unchanged."

- Art. 3 of the Law 24 December 1976, n. 898, is as follows:

"Art. 3 – In each region, a mixed joint consultation committee is established to examine, including with alternative proposals from the region and the military authorities, problems associated with harmonisation among territorial and economic and social-development plans of the regions and sub-regions, and the programmes of military installations and consequent limitations.

In the Trentino-Alto Adige the regional committee is replaced by two provincial committees, one each for Trento and Bolzano.

Consequently any indication of the region, regional council and president of the regional board is intended to refer, for Trentino-Alto Adige, to the province, the provincial council and the president of the provincial board.

Should military-secrecy requirements make an in-depth examination impossible, the president of the regional board may ask the competent authority to authorise communication of the necessary information.

The committee is consulted every six months on all corps or unit firing exercise schedules in order to define the locations, regional air and sea spaces, time and means of the exercises, as well as use of firing ranges in the region. Should a majority of the members designated by the region be opposed, the Minister of Defence makes the final decision on training schedules.

Each committee, having consulted the local entities and interested bodies, defines the zones suitable for a concentration of firing exercises in the region for the creation of firing ranges, giving priority where possible to the use of State-owned land.

Once these military areas are established, firing exercises must be held for the most part within these areas. For training, land, sea and air areas both temporary and permanent, regulations for use are stipulated between the military authority and the region affected. In the absence of agreement, the regulatory project is referred to the Minister of Defence who decides, having consulted the competent president of the regional board and the president of the mixed joint committee.

The committee is formed of five representatives from the Ministry of Defence, one representative from the Treasury Ministry, one representative from the Finance Ministry, designated by their respective ministries, and of seven representatives of the region appointed by the president of the regional board, at the designation, with limited vote, of the regional council.

For each member, an alternate is named.

The committee meets at the request of the regional military commander or the commander-in-chief of the navy department or the regional air force commander or

the president of the region; the highest or most senior general or admiral presides; the lowest or least senior officer serves as secretary.
Minutes of committee meetings will be kept, which will keep track of proposals from members dissenting on the entire matter at hand or on specific points within it.
Final decisions on plans for military installations and related limitations as described at the first paragraph are reserved for the Minister of Defence. The affected region may, within fifteen days of publication or communication of the minister's decision, ask the President of the Council of Ministers that the matter be submitted for reexamination by the Council of Ministers.
In particular cases, the President of the Council of Ministers may provide that ownership-limiting measures be suspended pending the decision of the Council of Ministers. The Council of Ministers issues its decision on the request for reexamination within ninety days.
The president of the regional board involved is invited to the meeting of the Council of Ministers."
Notes to art. 9:
- Art. 4 of the decree of the President of the Council of Ministers 23 April 1992 published in the Official Gazette n. 104 of 6 May 1992 is as follows:
"Art. 4 (Exposure limits and application criteria) - The following limits are set:
5 kV/m and 0.1 mT, respectively, for the intensity of the electrical field and the magnetic induction, in areas and environments where it may be reasonably expected that individuals will spend a significant part of the day;
10 kV/m and 1 mT, respectively, for the intensity of the electrical field and the magnetic induction, when the exposure is reasonably limited to a few hours a day.
The electrical-field values are referred to the undisturbed electrical field, this being understood as the electrical field measurable at a point in the absence of people, animals and things not fixed."
- Legislative Decree 16 March 1999, n. 79, setting:
"Implementation of the directive 96/1992/CE setting standards for the domestic electrical energy market" is published in the Official Gazette n. 75 of 31 March 1999.
- Art. 2, paragraph 12, of the Law 14 November 1995, n. 481, is as follows:
"12. In pursuing the goals set at art. 1, each authority performs the following functions:

a) formulates comments and proposals to be sent to the government and the parliament regarding services to be subjected to concession or authorisation and on the relevant market forms, within the limits of existing laws, proposing to the government the necessary legislative and regulatory modifications in relation to the technological dynamics, market conditions and evolution of Community law;
b) proposes to the competent ministers outlines for change and for possible variations in individual concession or authorisation acts and planning agreements and contracts;
c) checks that the conditions and means of access for operators providing the services, however established, are implemented in compliance with the principles of competition and transparency, including in reference to individual cost items, in order to establish the requirement that the service be provided under conditions of equality, so that all reasonable user needs are met, including those of the elderly and the disabled, ensuring respect for: the environment, installation safety, and worker health;
d) proposes modification of concession clauses and agreements, including those relating to exclusive operation, authorisations, current planning contracts and service conditions, where this is required by the market or by reasonable user demands, setting technical-economic conditions for access and interconnection to the grids, where called for by current legislation;
e) establishes and updates according to market trends the basic rate, parameters and other reference factors to determine the rates described at paragraphs 17, 18 and 19, and the means for recovering any costs incurred in the general interest so as to ensure the quality and efficiency of the service and adequate diffusion of same throughout the country, as well as the achievement of general objectives of a social nature, for environmental protection and efficient use of resources as described at paragraph 1 of art. 1, keeping separate from the rate any improper tax or charge; checks compliance with the criteria described at the present letter for proposals for updating rates presented annually and issues an opinion, having consulted any service providers, within ninety days from receiving the proposal; should the opinion not be issued within that time, the rates are understood to have been approved;
f) issues directives for accounting and administrative separation and checks the costs of individual services to ensure among other things that they are correctly broken down and attributed by function performed, by geographical area and by user category, separately showing costs resulting from universal supply of the service

defined by the agreement, then comparing them with analogous costs in other countries and seeing to the publication of the data;
g) checks how the services are provided, with powers of inspection, access, acquisition of documentation and useful information, determining cases of automatic payment of compensation by service providers to users when the provider does not comply with contractual clauses or provides the service with qualitative levels lower than those established in the service rules as described at paragraph 37, in the planning contract or in accordance with letter h);
h) issues directives concerning the production and delivery of services by the service providers, in particular setting the general quality levels for the complex of services provided and specific quality levels referring to the individual service to be guaranteed to the user, having consulted the service providers and user and consumer representatives, possibly differentiating them by sector and type of service; these determinations produce the effects described at paragraph 37;
i) ensures the broadest possible communication of the service conditions; studies the evolution of the sector and of individual services, in order to modify technical, legal and economic conditions relating to delivery of the services; promotes measures aimed at improving means for delivery of the services; annually presents to the Parliament and to the President of the Council of Ministers a report on the state of the services and on the activity carried out;
l) publicises and disseminates awareness of the conditions for delivering services in order to ensure the maximum transparency, competition and chances for better choices by intermediate and final users;
m) evaluates claims, petitions and reports presented by users or consumers, individual or in groups, regarding compliance with quality and rate levels by service operators, with whom he intervenes to impose, where appropriate, modifications in the way they provide the service or revising the service regulations described at paragraph 37;
n) checks the consistency of the measures adopted by service operators in order to ensure equal treatment of users, ensure the continuity of the services, periodically check the quality and efficiency of the service, seeking for this aim user evaluations, ensure all information regarding delivery of the services and their quality levels, allow users and consumers the easiest possible access to offices open to the public, reduce the number of bureaucratic steps required of users by simplifying procedures

for delivery of the service, and assure timely response to claims, petitions and reports regarding quality levels and rates;

o) proposes to the competent minister suspension or termination of the concession for those cases in which such measures are allowed by regulations;

p) checks that each service operator, based on the directive on principles for the delivery of public services of the President of the Council of Ministers of 27 January 1994, published in the Official Gazette n. 43 of 22 February 1994, adopts a public service charter, indicating the standards for individual services, and ensures that they are met."

Note to art. 10:

- Law 8 July 1986, n. 349, setting: "Establishment of the Ministry of the Environment and standards for environmental damage" is published in the ordinary supplement to the Official Gazette n. 162 of 15 July 1986.

Note to art. 11:

- Chapter III of the Law 7 August 1990, n. 241, sets:

"Participation in the administrative proceeding."

Notes to art. 14:

- Law 21 January 1994, n. 61, setting:

"Urgent provisions on recovery of environmental controls and establishment of the national environmental protection agency" is published in the Official Gazette n. 21 of 27 January 1994.

- Art. 1, paragraph 2, of the Legislative Decree 19 September 1994, n. 626, is as follows:

"2. In regard to the armed forces and the police and civil protection services, as well as within judicial and penitentiary structures and those intended for institutional aims to the activities of bodies responsible for public order and safety, universities, institutions of university education, educational institutions of every type and level, archives, libraries, museums and archaeological areas of the State, diplomatic and consular offices and air and sea transport means, the standards of the present decree are applied taking into account the special needs associated with the service provided, identified by decree of the competent minister in concert with the Ministers of Labour and Social Welfare, Health, and Public Office."

- Art. 23, paragraph 4, of the Legislative Decree 19 September 1994, n. 626, is as

follows:
“4. Competences in matters of worker safety and health attributed by current provisions to air and sea health officers and maritime, port and airport authorities, and to health and technical services established for the armed forces and the police remain unchanged; the aforesaid services are also competent for reserved or operational areas and for those having similar needs, to be identified with regard to means of implementation by a decree of the competent minister in concert with the Ministers of Labour and Social Welfare and Health.
The administration of justice may avail itself of the services established for the armed forces and police, including through agreements with the respective ministries, and of services established with reference to penitentiary structures.”
- Law 7 August 1990, n. 241, sets: “New standards regarding administrative proceedings and rights of access to administrative documents.”
Note to art. 15:
- Following is the text of art. 16 of the Law 24 November 1981, n. 689 (Modifications to the penal system):
“Art. 16 (Reduced payment). - The payment of a reduced sum is acceptable, equal to one-third the maximum penalty set for the violation committed, or, if more favourable or if the minimum statutory penalty is established, equal to twice the relevant amount, plus costs of the proceeding, within thirty days of the immediate protest or, if no protest was made, from notification of the particulars of the violation.
In cases of violation of municipal and provincial regulations, art. 107 of the consolidation act for municipal and provincial laws approved by royal decree 3 March 1934, n. 383, continues to be applied.
Reduced payment is accepted even in cases in which the standards predating the effective date of the present law did not allow such payment.”
Notes to art. 16:
- The decree of the President of the Council of Ministers 28 September 1995, setting “Technical and procedural standards for implementation of the decree of the President of the Council of Ministers 23 April 1992, relating to transmission lines” is published in the Official Gazette n. 232 of 4 October 1995.
- The decree of the Minister of the Environment 10 September 1998, n. 381, setting: “Regulations setting standards for determining radio frequency ceilings compatible

with human health” is published in the Official Gazette n. 257 of 3 November 1998.

Annex 5: Precautionary measures

If regulatory authorities have adopted international science-based guidelines but, because of public concerns, would like to introduce additional precautionary measures to reduce exposure to EMF fields, they should not undermine the science base of the guidelines by incorporating arbitrary additional safety factors into the exposure limits. Limit values in the ICNIRP guidelines already incorporate large safety factors to take account of imprecision in the dosimetry and other scientific factors and variation in human sensitivity (see ICNIRP, 1998). These factors of safety below the lowest levels at which the first possible health effects have been established, are at least 10 for workers and 50 for the general public.

Precautionary measures should be introduced as a separate policy that encourages, through voluntary means, the reduction of EMF fields by equipment manufacturers and the public. Details of such measures are given in a separate WHO Background document (2000).

Research: As part of the precautionary measures that could be taken in the case of remaining scientific uncertainty, WHO recommends a follow-up, focused research programme to provide more definitive information.

Government and Industry: These entities should maintain a knowledge of the latest scientific developments and should provide the public with balanced, clear and comprehensive information on potential EMF risks, as well as suggestions for safe and low cost ways to reduce exposures. They should also promote research that will lead to better information from which assessments of health risk can be made.

An effective system of health information and communication among scientists, governments, industry and the public is needed to help raise general awareness of programmes to deal with exposure to EMF fields and reduce any mistrust and fears.

Measures for reducing ELF exposure

Individuals: Members of the general public might choose to reduce their ELF exposure by minimizing the use of certain electrical appliances, checking the efficiency of the wiring in their homes or by increasing the distance from sources that can produce relatively high fields.

Consultation with local authorities, industry and the public when siting new power lines: Obviously power lines must be sited to provide power to consumers. Siting decisions are often required to take into account aesthetics and public sensibilities. However, siting decisions should also consider ways to reduce peoples' exposure.

Measures for reducing RF exposure

Examples of measures that can be used for reducing RF exposures are given below for mobile phones and their base stations, but the same principle applies to other RF sources.

Individuals: Present scientific information does not indicate the need for any special precautions for the use of mobile phones. If individuals are concerned, they might choose to limit their own or their children's' RF exposure by limiting the length of calls, or using "hands-free" devices to keep mobile phones away from the head and body. (Note: the Health Council of the Netherlands (2002) studied the case of children and made the following statement: "….., the Committee feels that there is no reason to recommend that children should restrict the use of mobile telephones ….")

Obey local restrictions on mobile phone use to avoid EMF interference: Mobile phones may interfere with certain electromedical devices, such as cardiac pacemakers and hearing aids. In hospital intensive care departments mobile phone use can be a danger to patients and should not be used in these areas. Similarly mobile phones should not be used in aircraft as they may interfere with its navigation systems.

Consultations with the community in siting base stations: Base station sites must offer good signal coverage and be accessible for maintenance. While RF field levels around base stations are not considered a health risk, siting decisions should take into account aesthetics and public sensibilities. Siting base stations near kindergartens, schools and playgrounds may need special consideration. Open communication and discussion between the mobile phone operator, local council and the public during the planning stages for a new antenna can help create public understanding and greater acceptance of a new facility.

Annex 1: Resume of Committee members

PROF. FRANCESCO COGNETTI

Head of the Medical Oncology Division of the Regina Elena National Institute for Cancer Research, Rome, Italy (1/01/96 to date)

Scientific Director of the Regina Elena National Institute for Cancer Research (8/7/2001)

Member of the Head and Neck Cooperative Group of the EORTC (1982 to present)

Member of the American Society of Clinical Oncology (ASCO)(1985 to present)

Member of the Executive Board of the European Society for Medical Oncology (ESMO) (1991 to present)

Member of the Council of the Federation of the European Cancer Societies (FECS) (1995 - 1997)

Chairman of the Scientific Committee of the III National Congress of the Italian Association of Medical Oncology (AIOM), Naples 4-7 November 2001 (1999 to present)

National Representative for Italy of the European Society for Medical Oncology (ESMO) (2001 to present)

Member of the Steering Committee of the European Society for Medical Oncology (ESMO) (2001 to present)

Member of the Nominating Committee of the European Society for Medical Oncology (ESMO) (2001 to date)

Chairman of the Italian Association of Medical Oncology (2001 to present)

Coordinator of several cooperative studies on the treatment of solid tumors, at the national and international level (1982 to present)

Member of the National Commission for Oncology for the triennium 2000-2002 (2002 to present)

Vice-Chairman of the Regional Oncology Commission (2001 to present)

Peer Reviewer of the “Annals of Oncology”: Official Journal of the European Society for Medical Oncology (2000 to present)

Associate Editor of “Tumori”: Journal of Experimental and Clinical Oncology (2000 to present)

Lecturing Professor of Clinical Oncology at the II Postgraduate School of Oncology at the “La Sapienza” University in Rome (1990 to present)

Chairman of the Scientific Council of the Postgraduate School of Oncology (2001 to present)

Author of approximately 200 scientific publications on national and international journals

PROF. RICHARD DOLL

Sir Richard Doll qualified in medicine at St Thomas Hospital Medical School, University of London in 1937.

He served in the Royal Army Medical Corps for several years before turning into research.

From 1948 to 1969 he worked in the Medical Research Council's Statistical Research Unit, at first under Sir Austin Bradford Hill and then as the Director of the Unit.
In 1969 he became Regius Professor of Medicine in Oxford and in 1979 the first Warden of Green College, Oxford.

Since his retirement in 1983 he has continued work as an honorary member of the Clinical Trials Service Unit and the Epidemiological Studies Unit.

Over the past half century Sir Richard Doll has done more than any other epidemiologist to transform the general understanding of the avoidability of cancer and many other diseases linked to behaviour and environmental exposures.

In 1950, major case-control studies by Doll and Hill in UK and by Wynder and Graham in the US showed that smoking was a major cause of death from heart disease (and showed that many other disease could also be caused by tobacco).

The 40-year follow-up showed the absolute hazards of really prolonged smoking, demonstrating that about half of all persistent smokers would eventually be killed by their habit.

The findings of Sir Richard Doll thereby paved the way for prevention of coronary disease.

Sir Richard Doll was elected FRCP in 1957 and FRS in 1966. He was knighted in 1971 and made a Companion of Honour in 1996.

He received the United Nations Award for cancer research in 1962, the BMA's Gold medal in 1983, the Wilhelm Conrad Rontgen Prize from the Accademia dei Lincei (Rome) in 1984, the Royal Societies Royal Medal in 1986.

He has received honorary degrees from thirteen universities.

In 2000 he received the Gold Medal of European Society of Cardiology.

PROF. GABRIELE FALCIASECCA

Full Professor on "Microwaves" at the University of Bologna Engineering Faculty.

His research activity is concentrated in the sectors of communication (guided waves and optical fibres), of radio infrastructures for air and surface traffic guidance, of power applications of microwaves for mobile and personal communications.

In this last sector he worked within the framework of the agreements linking the Foundations U. Bordoni e G. Marconi with the National High Institute of Post and Telecommunications. He acted as a consultant for the Bordoni Foundation and was for an extended period of time the Director of its Centre for Millimetre Waves. He was Chairman of the Scientific Committee of the G. Marconi Foundation and, subsequently, Chairman of the Foundation itself.

He is a member of the Scientific Committee of CSELT since 1992, and outstanding member of the High Technical Council P.T.A. He participated in the works of the Commission which produced the technical terms of reference for the rapid start of the second GSM operator. Presently, he is again an expert member of such Council, following an interruption. He is a member of various National Commissions CCR, CEI and URSI. He is the Chairman of the CNR Specialized Group on Electromagnetism and was a member of the Programme Committee of the CNR Targeted Telecommunication Project.

He is the author of over one hundred and fifty scientific works, presented to congresses or published in highly qualified journals at the national and international levels. He was member of several technical and programme committees of international conferences in the aforementioned sectors, among which the European Conference on MTT. He is a referee of the IEEE Tr. on Vehicular Technology and is member of the editorial board of the journal "Wireless and Personal Communications".

He also was involved in the popularisation of scientific work in the field of information and telecommunications. He was chairman of the Board of "Science or Magic?", a production unit for interactive scientific exhibitions set up by the Municipality of Bologna together with the Marconi Foundation. Successively, he designed the Museum G. Marconi, located within Villa Griffone, where the most significant experience arising from such line of work has been gathered.

He encouraged the creation of the Consortium Elettra 2000 for the promotion of research on the environmental impact of radio and of its social usage. He is currently Chairman of the Consortium.

From November 1994 to November 2000 he was Director of the Electronic Information and Systems Department of the Bologna University. He is a member of the Academic Senate of the University of Bologna since November 1996.

Since September 1997 is the Chairman of the Marconi Foundation.
Since November 1998 he is Vice-Chairman of the Board of the Department Directors of the University of Bologna.

Since February 2001 he is Chairman of ASTER.

PROF. TULLIO REGGE

Prof. Tullio Regge was Born in Turin on July 7, 1931. There he attended high school and graduated in Physics at the University of Turin (Italy) in 1952.

He was awarded a Fullbright fellowship for the biennium 1954-56, to study Theoretical Physics at the University of Rochester (NY), where he obtained his Ph.D.
He returned to Italy and obtained the University Chair in Theoretical Physics in 1961. Currently he is teaching Quantum Theory of Matter at the Turin Polytechnic.

In 1958-59 he spent six months at the Max Planck Institute in Munich, Germany, where he interacted with W. Heisenberg.

Following the period in Munich, he went to Princeton University in the United States and to the Institute for Advanced Study of which he became a member in 1964. He left it to return to Italy in 1979.

Throughout his career, Prof. Tullio Regge was awarded several prizes:

the "Dannie Heineman" Prize of the American Physical Society and of the American Institute of Physics in 1964;
the Prize of the "City of Como" (Italy) of the Somaini Foundation in 1968;
the "Einstein Medal" of the Lewis Strauss Foundation in 1979;
the European Society of Physics "Cecil Powell Medal" for his work in the field of science popularisation in 1987;
the "Prize of Culture" of the Italian Council of Ministers in 1988;
the ITPC "Dirac Medal" in 1996;
the "Marcel Grossman" Prize in 1997.

He is a national member of the "Accademia dei Lincei" (Rome), of the Academy of Science of Turin (Italy), of the Academy of XL, of the American Philosophical Society, of the Chilean Academy of Science and of the Russia Academy of Science.
Currently, he is also the Chairman of the Turin Section of the Association for research and prevention of handicaps (AIRH).

DR. MICHAEL REPACHOLI

Coordinator, Radiation and Environmental Health, Department of Protection of the Human Environment, World Health Organization, Geneva, Switzerland, with responsibility for WHO's radiation health programmes.

B.Sc. (Physics) University of Western Australia
M.Sc. (Radiation Biology) London University, United Kingdom.
Ph.D (Biology) Ottawa University, Canada. (1980)

Past Chairman and Chairman Emeritus of the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Participant in 10 World Health Organization task groups on various NIR.

Member of the UK Expert Committee on Mobile Telephone Technology established by the UK Minister of Public Health and member of the Program Management Committee (PMC) of the UK Mobile Telecommunications Health Research Program

- Fellow and Past President of the Australian Radiation Protection Society.
- Fellow and Past President of Australian College of Physical Scientists and Engineers in Medicine.
- Fellow of the Australian Institute of Physics.
- Member of the Health Physics Society.
- Member of the Bioelectromagnetics Society.

Author or co-author of over 160 scientific publications

Annex 2: Electromagnetic Fields

What are electromagnetic fields?

Electromagnetic radiation and fields are everywhere and are needed for life on earth. Without sufficient electromagnetic energy, for example in the form of infrared radiation, life would not exist as we know it.

Natural and many human-made sources generate electromagnetic energy as electromagnetic waves. These waves consist of oscillating electric and magnetic fields.

Electromagnetic waves can be characterized by their wavelength, frequency, or energy. The three parameters are interrelated and influence how they interact with a biological system.

- The frequency of an electromagnetic wave is simply the number of oscillations passing a fixed point per unit time. It is measured in cycles per second, or hertz. One cycle per second equals one hertz (Hz). Large divisions used to describe radiofrequency (RF) fields include: kilohertz (kHz), or one thousand cycles per second; megahertz (MHz), one million cycles per second; and gigahertz (GHz), one billion cycles per second.
- The wavelength is the distance between two successive points on an electromagnetic wave. The shorter the wavelength, the higher the frequency of the wave.
- The higher the frequency, the larger the amount of energy there is in the wave to damage molecules.

According to their frequency and energy, electromagnetic waves can be classified as either "ionizing radiations" or "non-ionizing radiations" (NIR).

- Ionizing radiations are extremely high frequency electromagnetic waves (X-rays and gamma rays) that have enough energy in the wave to cause ionization (create positive and negative electrically charged atoms or parts of molecules) by breaking the atomic bonds that hold molecules in cells together.
- Non-ionizing radiations (NIR) are in that part of the electromagnetic spectrum that have wave energies too weak to break atomic bonds. They include: long-wavelength ultraviolet radiation (UV), visible light, infrared radiation (IR or heat), radiofrequency (RF) and microwave fields, extremely low frequency (ELF) fields, as well as static electric and magnetic fields. While NIR cannot cause ionization in a biological system they can produce other biological effects, for instance, by heating, altering chemical reactions or inducing electrical currents in tissues and cells.

Electromagnetic fields, within the NIR part of the electromagnetic spectrum that include ELF and RF fields, have frequencies from >0 to 300 GHz and are divided up according to their frequency range.

- Static fields (0 Hz): Magnetic levitation trains for public transportation, magnetic resonance imaging devices used in medicine, and electrolytic devices using direct electric currents for materials processing in industry.

- Extremely low frequency (ELF) fields (>0 to 300 Hz): Trains for public transport (16 2/3 to 50 or 60 Hz, plus harmonics), any device involved in the generation, distribution or use of electric power (normally 50 or 60 Hz).
- Intermediate frequency (IF) fields (>300 Hz to 10 MHz): Anti-theft and security devices, induction heaters and video display units.
- Radiofrequency (RF) fields (>10 MHz to 300 GHz): Mobile telephones or telecommunications transmitters, radars and medical diathermy units.

How EMF interacts with tissues and the terms and units used to measure them

EMF produces different effects on biological systems such as cells or human beings, depending on the frequency and intensity of the field. Most established effects of EMF exposure result from two main mechanisms: tissue heating and the induction of electric currents. Which mechanism is dominant and likely to be the cause of any adverse consequence, depends on the EMF frequency and intensity. Within the frequency range of interest (>0 to 300 GHz) EMF can be divided into the following ranges according to their key mchanisms of action on biological systems:

EMF fields above 10 to 300 GHz are absorbed at the skin surface, with very little of the energy penetrating into the underlying tissues. This produces surface heating mainly to the skin.

* The basic dosimetric quantity for RF fields above 10 GHz is the **intensity** of the field measured as **power density** in watts per square metre (**W/m^2**) or for weak fields in milliwatts per square metre (**mW/m^2**) or microwatts per square metre (**$\mu W/m^2$**).

EMF fields between 1 MHz and 10 GHz penetrate exposed tissues and produce heating due to energy absorption in these tissues. The depth of penetration of the RF field into the tissue depends on the frequency of the field and is greater for lower frequencies.

* Energy absorption from RF fields in tissues is measured as a specific absorption rate (SAR) within a given tissue mass. The unit of SAR is watts per kilogram (W/kg). SAR is the basic dosimetric quantity for RF fields between about 1 MHz and 10 GHz.

* Most adverse health effects that could occur from exposure to RF fields between 1 MHz and 10 GHz are consistent with responses to induced heating, resulting in rises in tissue or body temperatures higher than 1^0C.

* Induced heating in body tissues may provoke various physiological and thermoregulatory responses, including a decreased ability to perform mental or physical tasks as body temperature increases. Similar effects have been reported in people subject to heat stress: for example, those working in hot environments or suffering a prolonged fever.

EMF fields from >0 to 1 MHz do not produce any significant heating. Rather, they induce electric currents and fields in tissues, which are measured as a current density in amperes per square metre (A/m^2). Current density is the basic dosimetric quantity for fields with frequencies below about 1 MHz.

* The many physiological reactions involved in staying alive have associated normal "background" currents of about 10 mA/m^2.

* Induced current densities that exceed at least 100 mA/m^2 can interfere with normal functioning of the body and cause involuntary muscle contractions.

Thus it is important when evaluating effects from EMF exposure that the frequency of the fields is known. This is especially true when discussing the effects from exposure to fields from power lines (50 or 60 Hz) and mobile phones (>800 MHz).

GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC, AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz)

International Commission on Non-Ionizing Radiation Protection[1]

INTRODUCTION

In 1974, the International Radiation Protection Association (IRPA) formed a working group on non-ionizing radiation (NIR), which examined the problems arising in the field of protection against the various types of NIR. At the IRPA Congress in Paris in 1977, this working group became the International Non-Ionizing Radiation Committee (INIRC).

In cooperation with the Environmental Health Division of the World Health Organization (WHO), the IRPA/INIRC developed a number of health criteria documents on NIR as part of WHO's Environmental Health Criteria Programme, sponsored by the United Nations Environment Programme (UNEP). Each document includes an overview of the physical characteris-tics, measurement and instrumentation, sources, and applications of NIR, a thorough review of the literature on biological effects, and an evaluation of the health risks of exposure to NIR. These health criteria have provided the scientific database for the subsequent development of exposure limits and codes of practice relating to NIR.

At the Eighth International Congress of the IRPA (Montreal, 18-22 May 1992), a new, independent scientific organization-the International Commission on Non-Ionizing Radiation Protection (ICNIRP)-was established as a successor to the IRPA/INIRC. The functions of the Commission are to investigate the hazards that may be associated with the different forms of NIR,develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection.
Biological effects reported as resulting from exposure to static and extremely-low-frequency (ELF) electric and magnetic fields have been reviewed by UNEP/ WHO/IRPA (1984, 1987). Those publications and a number of others, including UNEP/WHO/IRPA (1993) and Allen et al. (199 1), provided the scientific rationale for these guidelines.

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During the preparation of these guidelines, the composition of the Commission was as follows: A. Ahlbom (Sweden); U. Bergqvist (Sweden); J. H. Bernhard& Chairman since May 1996 (Germany); J. P. C&arini (France); L. A. Court, until May 1996 (France); M. Grandolfo, Vice-Chairman until April 1996 (Italy); M. Hietanen, since May 1996 (Finland); A. F. McKinlay, Vice-Chairman since May 1996 (UK); M. H. Repacholi, Chairman until April 1996, Chairman emeritus since May 1996 (Australia); D. H. Sliney (USA); J. A. J. Stolwijk (USA); M. L. Swicord, until May 1996 (USA); L. D, Szabo (Hungary); M. Taki (Japan); T. S. Tenforde (USA); H. P. Jammet (Emeritus Member, deceased) (France); R. Matthes, Scientific Secretary (Germany).
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A glossary of terms appears in the Appendix.

PURPOSE AND SCOPE

The main objective of this publication is to establish guidelines for limiting EMF exposure that will provide protection against known adverse health effects. An adverse health effect causes detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

Studies on both direct and indirect effects of EMF are described; direct effects result from direct interaction of fields with the body, indirect effects involve interactions with an object at a different electric potential from the body. Results of laboratory and epidemiological studies, basic exposure criteria, and reference levels for practical hazard assessment are discussed, and the guidelines presented apply to occupational and public exposure.

Guidelines on high-frequency and 50/60 Hz electromagnetic fields were issued by IRPA/INIRC in 1988 and 1990, respectively, but are superseded by the present guidelines which cover the entire frequency range of time-varying EMF (up to 300 GHz). Static magnetic fields are covered in the ICNIRP guidelines issued in 1994 (ICNIRP 1994).

In establishing exposure limits, the Commission recognizes the need to reconcile a number of differing expert opinions. The validity of scientific reports has to be considered, and extrapolations from animal experiments to effects on humans have to be made. The restrictions in these guidelines were based on scientific . data alone; currently available knowledge, however, indicates that these restrictions provide an adequate level of protection from exposure to time-varying EMF. Two classes of guidance are presented:

- *Basic restrictions*: Restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects are termed “basic restrictions.” Depending upon the frequency of the field, the physical quantities used to specify these restrictions are current density **(J),** specific energy absorption rate (SAR), and power density (S). Only power density in air, outside the body, can be readily measured in exposed individuals.
- *Reference levels*: These levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Some reference levels are derived from relevant basic restrictions using measurement and/or computational techniques, and some address perception and adverse indirect effects of exposure to EMF. The derived quantities are electric field strength **(E),** magnetic field strength **(H),** magnetic flux density **(B),** power density (S), and currents flowing through the limbs (IL). Quantities that address perception and other indirect effects are contact current (I,-) and, for pulsed fields, specific energy absorption (SA). In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does

not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary.

These guidelines do not directly address product performance standards, which are intended to limit EMF emissions under specified test conditions, nor does the document deal with the techniques used to measure any of the physical quantities that characterize electric, magnetic, and electromagnetic fields, Comprehensive descriptions of instrumentation and measurement techniques for accurately determining such physical quantities may be found elsewhere (NCRP 1981; IEEE 1992; NCRP 1993; DIN VDE 1995).

Compliance with the present guidelines may not necessarily preclude interference with, or effects on, medical devices such as metallic prostheses, cardiac pacemakers and defibrillators, and cochlear implants. Interference with pacemakers may occur at levels below the recommended reference levels. Advice on avoiding these problems is beyond the scope of the present document but is available elsewhere (UNEP/WHO/IRPA 1993).

These guidelines will be periodically revised and updated as advances are made in identifying the adverse health effects of time-varying electric, magnetic, and electromagnetic fields.

QUANTITIES AND UNITS

Whereas electric fields are associated only with the presence of electric charge, magnetic fields are the result of the physical movement of electric charge (electric current). An electric field, **E, exerts** forces on an electric charge and is expressed in volt per meter ($V\ m^{-1}$). Similarly, magnetic fields can exert physical forces on electric charges, but only when such charges are in motion. Electric and magnetic fields have both magnitude and direction (i.e., they are vectors). A magnetic field can be specified in two ways-as magnetic flux density, **B,** expressed in tesla (T), or as magnetic field strength, **H,** expressed in ampere per meter ($A\ m^{-1}$). The two quantities are related by the expression:

$$\mathbf{B} = \mu \mathbf{H}, \qquad (1)$$

where μ is the constant of proportionality (the magnetic permeability); in a vacuum and in air, as well as in non-magnetic (including biological) materials, μ has the value $4\pi \times 10^{-7}$ when expressed in henry per meter ($H\ m^{-1}$). Thus, in describing a magnetic field for protection purposes, only one of the quantities **B** or **H** needs to be specified.

In the far-field region, the plane-wave model is a good approximation of the electromagnetic field propagation. The characteristics of a plane wave are:
- The wave fronts have a planar geometry;
- The **E** and **H** vectors and the direction of propagation are mutually perpendicular;

- The phase of the **E** and **H** fields is the same, and the quotient of the amplitude of E/H is constant throughout space. In free space, the ratio of their amplitudes E/H = 377 ohm, which is the characteristic impedance of free space;
- Power density, S, i.e., the power per unit area normal to the direction of propagation, is related to the electric and magnetic fields by the expression:

$$\boldsymbol{S} = \boldsymbol{E} \cdot \boldsymbol{H} = E^2/377 = 377 \cdot H^2 \quad (2)$$

The situation in the near-field region is rather more complicated because the maxima and minima of E and H fields do not occur at the same points along the direction of propagation as they do in the far field. In the near field, the electromagnetic field structure may be highly inhomogeneous, and there may be substantial variations from the plane-wave impedance of 377 ohms; that is, there may be almost pure E fields in some regions and almost pure H fields in others. Exposures in the near field are

Table 1. Electric, magnetic, electromagnetic, and dosimetric quantities and corresponding SI units.

Quantity	Symbol	Unit
Conductivity	σ	siemens per meter (S rn^{-1})
Current	I	ampere (A)
Current density	**J**	ampere per square meter (A rn^{-2})
Frequency	*f*	hertz (Hz)
Electric field strength	**E**	volt per meter (V m^{-1})
Magnetic field strength	**H**	ampere per meter (A rn^{-1})
Magnetic flux density	**B**	tesla (T)
Magnetic permeability	μ	henry per meter (H rn^{-1})
		farad per meter (F rn^{-1})
Permittivity		
Power density	S	watt per square meter (W m^{-2})
Specific energy absorption	SA	joule per kilogram (J kg^{-1})
Specific energy absorption rate	SAR	watt per kilogram (W kg^{-1})

more difficult to specify, because both E and H fields must be measured and because the field patterns are morecomplicated; in this situation, power density is no longer an appropriate quantity to use in expressing exposure restrictions (as in the far field).
Exposure to time-varying EMF results in internal body currents and energy absorption in tissues that depend on the coupling mechanisms and the frequency involved. The internal electric field and current density are related by Ohm's Law:
J = oE,
where o is the electrical conductivity of the medium. The dosimetric quantities used in these guidelines, taking into account different frequency ranges and waveforms, are as follows:
l Current density, **J,** in the frequency range up to 10 MHz;
l Current, ***I,*** in the frequency range up to 110 MHz;
l Specific energy absorption rate, SAR, in the frequency range 100 kHz-10 GHz;
l Specific energy absorption, SA, for pulsed fields in the frequency range 300 MHz-10 GHz; and
l Power density, S, in the frequency range lo-300 GHz.
A general summary of EMF and dosimetric quanti-ties and units used in these guidelines is provided in Table 1.

BASIS FOR LIMXTING EXPOSURE

These guidelines for limiting exposure have been developed following a thorough review of all published scientific literature. The criteria applied in the course of the review were designed to evaluate the credibility of the various reported findings (Repacholi and Stolwijk 1991; Repacholi and Cardis 1997); only established effects were used as the basis for the proposed exposure restrictions. Induction of cancer from long-term EMF exposure was not considered to be established, and so these guidelines are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and elevated tissue temperatures resulting from absorption of energy during exposure to EMF. In the case of potential long-term effects of exposure, such as an increased risk of cancer, ICNIRP concluded that available data are insufficient to provide a basis for setting exposure restrictions, although epidemi-ological research has provided suggestive, but uncon-vincing, evidence of an association between possible carcinogenic effects and exposure at levels of 50/60 Hz magnetic flux densities substantially lower than those recommended in these guidelines.

In-vitro effects of short-term exposure to ELF or ELF amplitude-modulated EMF are summarized. Tran-sient cellular and tissue responses to EMF exposure have been observed, but with no clear exposure-response relationship. These studies are of limited value in the assessment of health effects because many of the re-sponses have not been demonstrated *irz vivo.* Thus, *in-vitro* studies alone were not deemed to provide data that could serve as a primary basis for assessing possible health effects of EMF.

COUPLING MECHANISMS BETWEEN FIELDS AND THE BODY

There are three established basic coupling mecha-nisms through which time-varying electric and magnetic fields interact directly with living matter (UNEP/WHO/IRPA 1993):

l coupling to low-frequency electric fields;
l coupling to low-frequency magnetic fields; and
l absorption of energy from electromagnetic fields.

Coupling to low-frequency electric fields

The interaction of time-varying electric fields with the human body results in the flow of electric charges (electric current), the polarization of bound charge (for-mation of electric dipoles), and the reorientation of electric dipoles already present in tissue. The relative magnitudes of these different effects depend on the electrical properties of the body-that is, electrical con-ductivity (governing the flow of electric current) and permittivity (governing the magnitude of polarization effects). Electrical conductivity and permittivity vary with the type of body tissue and also depend on the frequency of the applied field. Electric fields external to the body induce a surface charge on the body; this results in induced currents in the body, the distribution of which depends on exposure conditions, on the size and shape of the body, and on the body's position in the field.

Coupling to low-frequency magnetic fields

The physical interaction of time-varying magnetic fields with the human body results in induced electric fields and circulating electric currents. The magnitudes

of the induced field and the current density are propor- Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields 0 ICNIRP **GUIDELINES**
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tional to the radius of the loop, the electrical conductivity of the tissue, and the rate of change and magnitude of the . magnetic flux density. For a given magnitude and fre-quency of magnetic field, the strongest electric fields are induced where the loop dimensions are greatest. The exact path and magnitude of the resulting current induced in any part of the body will depend on the electrical conductivity of the tissue.

The body is not electrically homogeneous; however, induced current densities can be calculated using ana-tomically and electrically realistic models of the body and computational methods, which have a high degree of anatomical resolution.

Absorption of energy from electromagnetic fields

Exposure to low-frequency electric and magnetic fields normally results in negligible energy absorption and no measurable temperature rise in the body. How-ever, exposure to electromagnetic fields at frequencies above about 100 kHz can lead to significant absorption of energy and temperature increases. In general, expo-sure to a uniform (plane-wave) electromagnetic field results in a highly non-uniform deposition and distribu-tion of energy within the body, which must be assessed by dosimetric measurement and calculation.

As regards absorption of energy by the human body, electromagnetic fields can be divided into four ranges (Durney et al. 1985):

frequencies from about 100 kHz to less than about 20 MHz, at which absorption in the trunk de-creases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs;

frequencies in the range from about 20 MHz to 300 MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g., head) resonances are considered;

frequencies in the range from about 300 MHz to several GHz, at which significant local, non-uniform absorption occurs; and

frequencies above about 10 GHz, at which energy absorption occurs primarily at the body surface.

In tissue, SAR is proportional to the square of the internal electric field strength, Average SAR and SAR distribution can be computed or estimated from labora-tory measurements. Values of SAR depend on the fol-lowing factors:

the incident field parameters, i.e., the frequency, intensity, polarization, and source- object config-uration (near- or far-field);

the characteristics of the exposed body, i.e., its size and internal and external geometry, and the dielectric properties of the various tissues; and

ground effects and reflector effects of other ob-jects in the field near the exposed body.

When the long axis of the human body is parallel to the electric field vector, and under plane-wave exposure conditions (i.e., far-field exposure), whole-body SAR reaches maximal values. The amount of energy absorbed depends on a number of factors, including the size of the exposed body. "Standard Reference Man" (ICRP 1994), if not grounded, has a resonant absorption frequency close to 70 MHz. For taller individuals the resonant absorption frequency is somewhat lower, and for shorter adults, children, babies, and seated individuals it may exceed 100 MHz. The values of electric field reference levels are based on the frequency-dependence of human absorption; in grounded individuals, resonant frequencies are lower by a factor of about 2 (UNEP/WHO/IRPA 1993).

For some devices that operate at frequencies above 10 MHz (e.g., dielectric heaters, mobile telephones), human exposure can occur under near-field conditions. The frequency-dependence of energy absorption under these conditions is very different from that described for far-field conditions. Magnetic fields may dominate for certain devices, such as mobile telephones, under certain exposure conditions.

The usefulness of numerical modeling calculations, as well as measurements of induced body current and tissue field strength, for assessment of near-field expo-sures has been demonstrated for mobile telephones, walkie-talkies, broadcast towers, shipboard communica-tion sources, and dielectric heaters (Kuster and Balzano 1992; Dimbylow and Mann 1994; Jokela et al. 1994; Gandhi 1995; Tofani et al, 1995). The importance of these studies lies in their having shown that near-field exposure can result in high local SAR (e.g., in the head, wrists, ankles) and that whole-body and local SAR are strongly dependent on the separation distance between the high-frequency source and the body. Finally, SAR data obtained by measurement are consistent with data obtained from numerical modeling calculations. Whole-body average SAR and local SAR are convenient quan-tities for comparing effects observed under various ex-posure conditions. A detailed discussion of SAR can be found elsewhere (UNEPiWHO/IRPA 1993).

At frequencies greater than about 10 GHz, the depth of penetration of the field into tissues is small, and SAR is not a good measure for assessing absorbed energy; the incident power density of the field (in W mm2) is a more appropriate dosimetric quantity.

INDIRECT COUPLING MECHANISMS

There are two indirect coupling mechanisms:
contact currents that result when the human body comes into contact with an object at a different electric potential (i.e., when either the body or the object is charged by an EMF); and
coupling of EMF to medical devices worn by, or implanted in, an individual (not considered in this document). 498 Health Physics

The charging of a conducting object by EMF causes electric currents to pass through the human body in. contact with that object (Tenforde and Kaune 1987; UNEP/WHO/IRPA 1993). The magnitude and spatial distribution of such currents depend on frequency, the size of the object, the size of the person, and the area of contact; transient discharges-sparks-can occur when an individual and a conducting object exposed to a strong field come into close proximity.

BIOLOGICAL BASIS FOR LIMITING EXPOSURE (UP TO 100 KHZ)

The following paragraphs provide a general review of relevant literature on the biological and health effects of electric and magnetic fields with frequency ranges up to 100 kHz, in which the major mechanism of interaction is induction of currents in tissues. For the frequency range >O to 1 Hz, the biological basis for the basic restrictions and reference levels are provided in ICNIRP (1994). More detailed reviews are available elsewhere (NRPB 1991, 1993; UNEP/WHO/IRPA 1993; Blank 1995; NAS 1996; Polk and Postow 1996; Ueno 1996).

Direct effects of electric and magnetic fields

Epidemiological studies. There have been many reviews of epidemiological studies of cancer risk in relation to exposure to power-frequency fields (NRPB 1992, 1993, 1994b; ORAU 1992; Savitz 1993; Heath 1996; Stevens and Davis 1996; Tenforde 1996; NAS 1996). Similar reviews have been published on the risk of adverse reproductive outcomes associated with exposure to EMF (Chernoff et al. 1992; Brent et al. 1993; Shaw and Croen 1993; NAS 1996; Tenforde 1996).

Reproductive outcome. Epidemiological studies on pregnancy outcomes have provided no consistent evi-dence of adverse reproductive effects in women working with visual display units (VDUs) (Bergqvist 1993; Shaw and Croen 1993; NRPB 1994a; Tenforde 1996). For example, meta-analysis revealed no excess risk of spon-taneous abortion or malformation in combined studies comparing pregnant women using VDUs with women not using VDUs (Shaw and Croen 1993). Two other studies concentrated on actual measurements of the electric and magnetic fields emitted by VDUs; one reported a suggestion of an association between ELF magnetic fields and miscarriage (Lindbohm et al. 1992), while the other found no such association (Schnorr et al. 1991). A prospective study that included large numbers of cases, had high participation rates, and detailed expo-sure assessment (Bracken et al. 1995) reported that neither birth weight nor intra-uterine growth rate was related to any ELF field exposure. Adverse outcomes were not associated with higher levels of exposure. Exposure measurements included current-carrying ca-pacity of power lines outside homes, 7-d personal expo-sure measurements, 24-h measurements in the home, and self-reported use of electric blankets, heated water beds,

and VDUs. Most currently available information fails to support an association between occupational exposure to VDUs and harmful reproductive effects (NRPB 1994a; Tenforde 1996).

Residential cancer studies. Considerable contro-versy surrounds the possibility of a link between expo-sure to ELF magnetic fields and an elevated risk of cancer. Several reports on this topic have appeared since Wertheimer and Leeper reported (1979) an association between childhood cancer mortality and proximity of homes to power distribution lines with what the research-ers classified as *high current configuration.* The basic hypothesis that emerged from the original study was that the contribution to the ambient residential 50/60 Hz magnetic fields from external sources such as power lines could be linked to an increased risk of cancer in childhood.

To date there have been more than a dozen studies on childhood cancer and exposure to power-frequency magnetic fields in the home produced by nearby power lines. These studies estimated the magnetic field expo-sure from short term measurements or on the basis of distance between the home and power line and, in most cases, the configuration of the line; some studies also took the load of the line into account. The findings relating to leukemia are the most consistent. Out of 13 studies (Wertheimer and Leeper 1979; Fulton et al. 1980; Myers et al. 1985; Tomenius 1986; Savitz et al. 1988; Coleman et al. 1989; London et al. 1991; Feychting and Ahlbom 1993; Olsen et al. 1993; Verkasalo et al. 1993; Michaelis et al. 1997; Linet et al. 1997; Tynes and Haldorsen 1997), all but five reported relative risk estimates of between 1.5 and 3.0.

Both direct magnetic field measurements and esti-mates based on neighboring power lines are crude proxy measures for the exposure that took place at various times before cases of leukemia were diagnosed, and it is not clear which of the two methods provides the more valid estimate. Although results suggest that indeed the magnetic field may play a role in the association with leukemia risk, there is uncertainty because of small sample numbers and because of a correlation between the magnetic field and proximity to power lines (Feychting et al. 1996).

Little is known about the etiology of most types of childhood cancer, but several attempts to control for potential confounders such as socioeconomic status and air pollution from motor vehicle exhaust fumes have had little effect on results. Studies that have examined the use of electrical appliances (primarily electric blankets) in relation to cancer and other health problems have re-ported generally negative results (Preston-Martin et al. 1988; Verreault et al. 1990; Vena et al. 1991, 1994; Li et al. 1995). Only two case-control studies have evaluated use of appliances in relation to the risk of childhood leukemia. One was conducted in Denver (Savitz et al. 1990) and suggested a link with prenatal use of electric blankets; the other, carried out in Los Angeles (London

et al. 1991), found an association between leukemia and children using hair dryers and watching monochrome . television.

The fact that results for leukemia based on proxim-ity of homes to power lines are relatively consistent led the U.S. National Academy of Sciences Committee to conclude that children living near power lines appear to be at increased risk of leukemia (NAS 1996). Because of small numbers, confidence intervals in the individual studies are wide; when taken together, however, the results are consistent, with a pooled relative risk of 1.5 (NAS 1996). In contrast, short-term measurements of -magnetic field in some of the studies provided no evidence of an association between exposure to 50160 Hz fields and the risk of leukemia or any other form of cancer in children. The Committee was not convinced that this increase in risk was explained by exposure to magnetic fields, since there was no apparent association when exposure was estimated from magnetic field meter readings in the homes of both leukemia cases and controls. It was suggested that confounding by some unknown risk factor for childhood leukemia, associated with residence in the vicinity of power lines, might be the explanation, but no likely candidates were postulated.

After the NAS committee completed its review, the results of a study performed in Norway were reported (Tynes and Haldorsen 1997). This study included 500 cases of all types of childhood cancer. Each individual's exposure was estimated by calculation of the magnetic field level produced in the residence by nearby transmis-sion lines, estimated by averaging over an entire year. No association between leukemia risk and magnetic fields for the residence at time of diagnosis was observed. Distance from the power line, exposure during the first year of life, mothers' exposure at time of conception, and exposure higher than the median level of the controls showed no association with leukemia, brain cancer, or lymphoma. However, the number of exposed cases was small.

Also, a study performed in Germany has been reported after the completion of the NAS review (Michaelis et al. 1997). This was a case-control study on childhood leukemia based on 129 cases and 328 controls. Exposure assessment comprised measurements of the magnetic field over 24 h in the child's bedroom at the residence where the child had been living for the longest period before the date of diagnosis. An elevated relative risk of 3.2 was observed for BO.2 PT.

A large U.S. case-control study (638 cases and 620 controls) to test whether childhood acute lymphoblastic leukemia is associated with exposure to 60-Hz magnetic fields was published by Linet et al. (1997). Magnetic field exposures were determined using 24-h time-weighted average measurements in the bedroom and 30-s measurements in various other rooms. Measurements were taken in homes in which the child had lived for 70% of the 5 y prior to the year of diagnosis, or the corresponding period for the controls. Wire-codes were assessed for residentially stable case-control pairs in which both had not changed their residence during the years prior to diagnosis. The number of such pairs for which assessment could be made was 416. There was no indication of an association between wire-code category and leukemia. As for magnetic field measurements, the results are more intriguing. For the cut off point of 0.2 PT the unmatched and matched analyses gave relative risks of 1.2 and 1.5, respectively. For a cut off point of 0.3 pT, the unmatched relative risk estimate is 1.7 based on 45 exposed cases. Thus, the measurement results are suggestive of a positive association between magnetic fields and leukemia risk. This study is a major contribu-tion in terms of its size, the number of subjects in high exposure categories, timing of measurements relative to the occurrence of the leukemia (usually within 24 mo after diagnosis), other measures used to obtain exposure data, and quality of analysis allowing for multiple poten-tial confounders. Potential weaknesses include the pro-cedure for control selection, the participation rates, and the methods used for statistical analysis of the data. The instruments used for measurements took no account of transient fields or higher order harmonics. The size of this study is such that its results, combined with those of other studies, would significantly weaken (though not necessarily invalidate) the previously observed association with wire code results.

Over the years there also has been substantial interest in whether there is an association between magnetic field exposure and childhood brain cancer, the second most frequent type of cancer found in children. Three recent studies completed after the NAS Commit-tee's review fail to provide support for an association between brain cancer and children's exposure to mag-netic fields, whether the source was power lines or electric blankets, or whether magnetic fields were esti-mated by calculations or by wire codes (Guenel et al. 1996; Preston-Martin et al. 1996a, b; Tynes and Hal-dorsen 1997)

Data on cancer in adults and residential magnetic field exposure are sparse (NAS 1996). The few studies published to date (Wertheimer and Leeper 1979; Mc-Dowall 1985; Seversen et al. 1988; Coleman et al. 1989; Schreiber et al. 1993; Feychting and Ahlbom 1994; Li et al. 1996; Verkasalo 1996; Verkasalo et al. 1996) all suffer to some extent from small numbers of exposed cases, and no conclusions can be drawn.

It is the view of the ICNIRP that the results from the epidemiological research on EMF field exposure and cancer, including childhood leukemia, are not strong enough in the absence of support from experimental re-search to form a scientific basis for setting exposure guidelines. This assessment is also in agreement with recent reviews (NBPB 1992, 1994b; NAS 1996; CRP 1997).

Occupational studies. A large number of epidemi-ological studies have been carried out to assess possible links between exposure to ELF fields and cancer risk among workers in electrical occupations. The first study of this type (Milham 1982) took advantage of a death certificate database that included both job titles and

information on cancer mortality. As a crude method of assessing exposure, Milham classified job titles accord: ing to presumed magnetic field exposure and found an excess risk for leukemia among electrical workers. Sub-sequent studies (Savitz and Ahlbom 1994) made use of similar databases; the types of cancer for which elevated rates were noted varied across studies, particularly when cancer subtypes were characterized. Increased risks of various types of leukemia and nervous tissue tumors, and, in a few instances, of both male and female breast cancer, were reported (Demers et al. 199 1; Matanoski et al. 1991; Tynes et al. 1992; Loomis et al. 1994). As well-as producing somewhat inconsistent results, these studies suffered from very crude exposure assessment and from failure to control for confounding factors such as expo-sure to benzene solvent in the workplace.

Three recent studies have attempted to overcome some of the deficiencies in earlier work by measuring ELF field exposure at the workplace and by taking duration of work into consideration (Floderus et al. 1993; Theriault et al. 1994; Savitz and Loomis 1995). An elevated cancer risk among exposed individuals was observed, but the type of cancer of which this was true varied from study to study. Floderus et al. (1993) found a significant association with leukemia; an association was also noted by Theriault et al. (1994), but one that was weak and not significant, and no link was observed by Savitz and Loomis (1995). For subtypes of leukemia there was even greater inconsistency, but numbers in the analyses were small. For tumors of nervous tissue, Floderus et al. (1993) found an excess for glioblastoma (astrocytoma III-IV), while both Theriault et al. (1994) and Savitz and Loomis (1995) found only suggestive evidence for an increase in glioma (astrocytoma I-II). If there is truly a link between occupational exposure to magnetic fields and cancer, greater consistency and stronger associations would be expected of these recent studies based on more sophisticated exposure data.

Researchers have also investigated the possibility that ELF electric fields could be linked to cancer. The three utilities that participated in the Theriault et al. (1994) study of magnetic fields analyzed electric field data as well. Workers with leukemia at one of the utilities were reported to be more likely to have been exposed to electric fields than were control workers. In addition, the association was stronger in a group that had been exposed to high electric and magnetic fields combined (Miller et al. 1996). At the second utility, investigators reported no association between leukemia and higher cumulative exposure to workplace electric fields, but some of the analyses showed an association with brain cancer (Guenel et al. 1996). An association with colon cancer was also reported, yet in other studies of large populations of electric utility workers this type of cancer has not been found. At the third utility, no association between high electric fields and brain cancer or leukemia was observed, but this study was smaller and less likely to have detected small changes, if present (Baris et al. 1996).

An association between Alzheimer's disease and occupational exposure to magnetic fields has recently been suggested (Sobel and Davanipour 1996). However, this effect has not been confirmed.

Laboratory studies. The following paragraphs pro-vide a summary and critical evaluation of laboratory studies on the biological effects of electric and magnetic fields with frequencies below 100 kHz. There are sepa-rate discussions on results obtained in studies of volun-teers exposed under controlled conditions and in labora-tory studies on cellular, tissue, and animal systems.

Volunteer studies. Exposure to a time-varying elec-tric field can result in perception of the field as a result of the alternating electric charge induced on the body surface, which causes the body hairs to vibrate. Several studies have shown that the majority of people can perceive 50/60 Hz electric fields stronger than 20 kV m-l, and that a small minority can perceive fields below 5 kV me1 (UNEP/WHO/IRPA 1984; Tenforde 1991).

Small changes in cardiac function occurred in hu-man volunteers exposed to combined 60-Hz electric and magnetic fields (9 kV rn- ‘, 20 pT) (Cook et al. 1992; Graham et al. 1994). Resting heart rate was slightly, but significantly, reduced (by 3-5 beats per minute) during or immediately after exposure. This response was absent on exposure to stronger (12 kV m-l, 30 pT) or weaker (6 kV m-l, 10 pT) fields and reduced if the subject was mentally alert. None of the subjects in these studies was able to detect the presence of the fields, and there were no other consistent results in a wide battery of sensory and perceptual tests.

No adverse physiological or psychological effects were observed in laboratory studies of people exposed to 50-kHz fields in the range 2-5 mT (Sander et al. 1982; Ruppe et al. 1995). There were no observed changes in blood chemistry, blood cell counts, blood gases, lactate levels, electrocardiogram, electroencephalogram, skin temperature, or circulating hormone levels in studies by Sander et al. (1982) and Graham et al. (1994). Recent studies on volunteers have also failed to show any effect of exposure to 60-Hz magnetic fields on the nocturnal melatonin level in blood (Graham et al. 1996, 1997; Selmaoui et al. 1996).

Sufficiently intense ELF magnetic fields can elicit peripheral nerve and muscle tissue stimulation directly, and short magnetic field pulses have been used clinically to stimulate nerves in the limbs in order to check the integrity of neural pathways. Peripheral nerve and mus-cle stimulation has also been reported in volunteers exposed to l-kHz gradient magnetic fields in experimen-tal magnetic resonance imaging systems. Threshold mag-netic flux densities were several millitesla, and corre-sponding induced current densities in the peripheral tissues were about 1 A rnM2 from pulsed fields produced by rapidly switched gradients. Time-varying magnetic fields that induce current densities above 1 A mm2 in

tissue lead to neural excitation and are capable of producing irreversible biological effects such as cardiac . fibrillation (Tenforde and Kaune 1987; Reilly 1989) In a study involving electromyographic recordings from the human arm (Polson et al. 1982), it was found that a pulsed field with dB/dt greater than 104 T s-l was needed to stimulate the median nerve trunk. The duration of the magnetic stimulus has also been found to be an important parameter in stimulation of excitable tissues. Thresholds lower than 100 mA rnp2 can be derived from studies of visual and mental functions in human volunteers. Changes in response latency for complex reasoning tests have been reported in volunteers subjected to weak power-frequency electric currents passed through electrodes attached to the head and shoulders; current densities were estimated to lie be-tween 10 and 40 mA me2 (Stollery 1986, 1987). Finally, many studies have reported that volunteers experienced faint flickering visual sensations, known as magnetic phosphenes, during exposure to ELF magnetic fields above 3-5 mT (Silny 1986). These visual effects can also be induced by the direct application of weak electric currents to the head. At 20 Hz, current densities of about 10 mA me2 in the retina have been estimated as the threshold for induction of phosphenes, which is above the typical endogenous current densities in electrically excitable tissues. Higher thresholds have been observed for both lower and higher frequencies (Lovsund et al. 1980; Tenforde 1990).

Studies have been conducted at 50 Hz on visually evoked potentials that exhibited thresholds for effects at flux densities of 60 mT (Silny 1986). Consistent with this result, no effects on visually evoked potentials were obtained by either Sander et al. (1982), using a 50-Hz, 5mT field, or Graham et al. (1994), using combined 60-Hz electric and magnetic fields up to 12 kV rn- ’ and 30 PT, respectively.

Cellular and animal studies. Despite the large number of studies undertaken to detect biological effects of ELF electric and magnetic fields, few systematic studies have defined the threshold field characteristics that produce significant perturbations of biological func-tions. It is well established that induced electric current can stimulate nerve and muscle tissue directly once the induced current density exceeds threshold values (UNEP/WHO/IRPA 1987; Bernhardt 1992; Tenforde 1996). Current densities that are unable to stimulate excitable tissues directly may nevertheless affect ongo-ing electrical activity and influence neuronal excitability. The activity of the central nervous system is known to be sensitive to the endogenous electric fields generated by the action of adjacent nerve cells, at levels below those required for direct stimulation.

Many studies have suggested that the transduction of weak electrical signals in the ELF range involves interactions with the cell membrane, leading to cytoplas-mic biochemical responses that in turn involve changes in cellular functional and proliferative states. From sim-ple models of the behavior of single cells in weak fields it has been calculated that an electrical signal in the extracellular field must be greater than approximately lo-100 mV m-l (corresponding to an induced current density of about 2-20 mA mm2) in order to exceed the level of endogenous physical and biological noise in cellular membranes (Astumian et al. 1995). Existing evidence also suggests that several structural and func-tional properties of membranes may be altered in re-sponse to induced ELF fields at or below 100 mV m-l (Sienkiewicz et al. 1991; Tenforde 1993). Neuroendo-crine alterations (e.g., suppression of nocturnal melatonin synthesis) have been reported in response to induced electrical fields of 10 mV m-l or less, corresponding to induced current densities of approximately 2 mA rn- or less (Tenforde 1991, 1996). However, there is no clear evidence that these biological interactions of low-frequency fields lead to adverse health effects.

Induced electric fields and currents at levels exceed-ing those of endogenous bioelectric signals present in tissue have been shown to cause a number of physiolog-ical effects that increase in severity as the induced current density is increased (Bernhardt 1979; Tenforde 1996). In the current density range lo-100 mA me2, tissue effects and changes in brain cognitive functions have been reported (NRPB 1992; NAS 1996). When induced cur-rent density exceeds 100 to several hundred mA rnw2 for frequencies between about 10 Hz and 1 kHz, thresholds for neuronal and neuromuscular stimulation are ex-ceeded. The threshold current densities increase progres-sively at frequencies below several hertz and above 1 kHz. Finally, at extremely high current densities, exceeding 1 A mw2, severe and potentially life-threatening effects such as cardiac extrasystoles, ventric-ular fibrillation, muscular tetanus, and respiratory failure may occur. The severity and the probability of irrevers-ibility of tissue effects becomes greater with chronic exposure to induced current densities above the level 10 to 100 mA mv2. It therefore seems appropriate to limit human exposure to fields that induce current den-sities no greater than 10 mA rnp2 in the head, neck, and trunk at frequencies of a few hertz up to 1 kHz.

It has been postulated that oscillatory magnetome-chanical forces and torques on biogenic magnetite par-ticles in brain tissue could provide a mechanism for the transduction of signals from ELF magnetic fields. Kirschvink et al. (1992b) proposed a model in which ELF magnetic forces on magnetite particles are visual-ized as producing the opening and closing of pressure-sensitive ion channels in membranes. However, one difficulty with this model is the sparsity of magnetite

particles relative to the number of cells in brain tissue. For example, human brain tissue has been reported to contain a few million magnetite particles per gram, distributed in 105 discrete clusters of 5-10 particles (Kirschvink et al. 1992a). The number of cells in brain tissue thus exceeds the number of magnetite particles by a factor of about 100, and it is difficult to envisage how oscillating magnetomechanical interactions of an ELF
field with magnetite crystals could affect a significant number of pressure-sensitive ion channels in the brain.' Further studies are clearly needed to reveal the biological role of magnetite and the possible mechanisms through which this mineral could play a role in the transduction of ELF magnetic signals.

An important issue in assessing the effects of elec-tromagnetic fields is the possibility of teratogenic and developmental effects. On the basis of published scien-tific evidence, it is unlikely that low-frequency fields have adverse effects on the embryonic and postnatal development of mammalian species (Chernoff et al. ' 1992; Brent et al. 1993; Tenforde 1996). Moreover, currently available evidence indicates that somatic mu-tations and genetic effects are unlikely to result from exposure to electric and magnetic fields with frequencies below 100 kHz (Cridland 1993; Sienkiewicz et al. 1993).

There are numerous reports in the literature on the *in-vitro* effects of ELF fields on cell membrane proper-ties (ion transport and interaction of mitogens with cell surface receptors) and changes in cellular functions and growth properties (e.g., increased proliferation and alter-ations in metabolism, gene expression, protein biosyn-thesis, and enzyme activities) (Cridland 1993; Sien-kiewicz et al. 1993; Tenforde 1991, 1992, 1993, 1996). Considerable attention has focused on low-frequency field effects on Ca^{++} transport across cell membranes and the intracellular concentration of this ion (Walleczek and Liburdy 1990; Liburdy 1992; Walleczek 1992), messenger RNA and protein synthesis patterns (Good-man et al. 1983; Goodman and Henderson 1988, 1991; Greene et al. 199 1; Phillips et al. 1992), and the activity of enzymes such as ornithine decarboxylase (ODC) that are related to cell proliferation and tumor promotion (Byus et al. 1987, 1988; Litovitz et al. 1991, 1993). However, before these observations can be used for defining exposure limits, it is essential to establish both their reproducibility and their relevance to cancer or other adverse health outcomes. This point is underscored by the fact that there have been difficulties in replicating some of the key observations of field effects on gene expression and protein synthesis (Lacy-Hulbert et al. 1995; Saffer and Thurston 1995). The authors of these replication studies identified several deficiencies in the earlier studies, including poor temperature control, lack of appropriate internal control samples, and the use of low-resolution techniques for analyzing the production of messenger RNA transcripts. The transient increase in ODC activity reported in response to field exposure is small in magnitude and not associated with *de novo* synthesis of the enzyme (unlike chemical tumor promot-ers such as phorbol esters) (Byus et al. 1988). Studies on ODC have mostly involved cellular preparations; more studies are needed to show whether there are effects on ODC *in vivo,* although there is one report suggesting effects on ODC in a rat mammary tumor promotion assay (Mevissen et al. 1995).

There is no evidence that ELF fields alter the structure of DNA and chromatin, and no resultant muta-tional and neoplastic transformation effects are expected. This is supported by results of laboratory studies de-signed to detect DNA and chromosomal damage, muta-tional events, and increased transformation frequency in response to ELF field exposure (NRPB 1992; Murphy et al. 1993; McCann et al. 1993; Tenforde 1996). The lack of effects on chromosome structure suggests that ELF fields, if they have any effect on the process of carcino-genesis, are more likely to act as promoters than initia-tors, enhancing the proliferation of genetically altered cells rather than causing the initial lesion in DNA or chromatin. An influence on tumor development could be mediated through epigenetic effects of these fields, such as alterations in cell signalling pathways or gene expres-sion. The focus of recent studies has therefore been on detecting possible effects of ELF fields on the promotion and progression phases of tumor development following initiation by a chemical carcinogen.

Studies on *in-vitro* tumor cell growth and the devel-opment of transplanted tumors in rodents have provided no strong evidence for possible carcinogenic effects of exposure to ELF fields (Tenforde 1996). Several studies of more direct relevance to human cancer have involved *in-vivo* tests for tumor-promoting activity of ELF mag-netic fields on skin, liver, brain, and mammary tumors in rodents. Three studies of skin tumor promotion (McLean et al. 1991; Rannug et al. 1993a, 1994) failed to show any effect of either continuous or intermittent exposure to power-frequency magnetic fields in promoting chemi-cally induced tumors. At a 60-Hz field strength of 2 mT, a co-promoting effect with a phorbol ester was reported for mouse skin tumor development in the initial stages of the experiment, but the statistical significance of this was lost by completion of the study in week 23 (Stuchly et al. 1992). Previous studies by the same investigators had shown that 60-Hz, 2-mT field exposure did not promote the growth of DMBA-initiated skin cells (McLean et al. 1991).

Experiments on the development of transformed liver foci initiated by a chemical carcinogen and pro-moted by phorbol ester in partially hepatectomized rats revealed no promotion or co-promotion effect of expo-sure to 50-Hz fields ranging in strength from 0.5 to 50 PT (Rannug et al. 1993b, c).

Studies on mammary cancer development in rodents treated with a chemical initiator have suggested a cancer-promoting effect of exposure to power-frequency mag-netic fields in the range 0.01-30 mT (Beniashvili et al. 1991; Loscher et al. 1993; Mevissen et al. 1993, 1995; Baum et al. 1995; Loscher and Mevissen 1995). These observations of increased tumor incidence in rats ex-posed to magnetic fields have been hypothesized to be related to field-induced suppression of pineal melatonin and a resulting elevation in steroid hormone levels and breast cancer risk (Stevens 1987; Stevens et al. 1992). However, replication efforts by independent laboratories are needed before conclusions can be drawn regarding the implications of these findings for a promoting effect of ELF magnetic fields on mammary tumors. It should Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields 0 ICNIRP **GUIDELINES** also be noted that recent studies have found no evidence **Summary of biological effects and epidemiological**
for a significant effect of exposure to ELF magnetic . **studies** (up **to 100 kHz)** fields on melatonin levels in* humans (Graham <t al. 1996, 1997; Selmaoui et al. 1996).

Indirect effects of electric and magnetic f'ields

Indirect effects of electromagnetic fields may result from physical contact (e.g., touching or brushing against) between a person and an object, such as a metallic structure in the field, at a different electric potential. The result of such contact is the flow of electric charge (contact current) that may have accumulated on the object or on the body of the person. In the frequency range up to approximately 100 kHz, the flow of electric current from an object in the field to the body of the individual may result in the stimulation of muscles

and/or peripheral nerves. With increasing levels of cur-rent
this may be manifested as perception, pain from
electric shock and/or burn, inability to release the object,
difficulty in breathing and, at very high currents, cardiac
ventricular fibrillation (Tenforde and Kaune 1987).
Threshold values for these effects are frequency-dependent,
with the lowest threshold occurring at fre-quencies
between 10 and 100 Hz. Thresholds for periph-eral
nerve responses remain low for frequencies up to
several kHz. Appropriate engineering and/or administra-tive
controls, and even the wearing of personal protective
clothing, can prevent these problems from occurring.
Spark discharges can occur when an individual
comes into very close proximity with an object at a
different electric potential, without actually touching it
(Tenforde and Kaune 1987; UNEP/WHO/IRPA 1993).
When a group of volunteers, who were electrically
insulated from the ground, each held a finger tip close to
a grounded object, the threshold for perception of spark
discharges was as low as 0.6-1.5 kV m-l in 10% of
cases. The threshold field level reported as causing
annoyance under these exposure conditions is about
2.0-3.5 kV m-l. Large contact currents can result in
muscle contraction. In male volunteers, the 50th percen-tile
threshold for being unable to release a charged
conductor has been reported as 9 mA at 50160 Hz, 16 mA
at 1 kHz, about 50 mA at 10 kHz, and about 130 mA at
100 kHz (UNEP/WHO/IRPA 1993).
The threshold currents for various indirect effects of
fields with frequencies up to 100 kHz are summarized in
Table 2 (UNEP/WHO/IRPA 1993).

Table 2. Ranges of threshold currents for indirect effects, includ-ing children, women, and men.

	Threshold current (mA) at frequency:		
Indirect effect	50/60 Hz	1 kHz	100 kHz
Touch perception	0.2-0.4	0.4-0.8	25-40
Pain on finger contact	0.9-1.8	1.6-3.3	33-55
Painful shock/let-go threshold	8-16	12-24	112-224
Severe shock/breathing difficulty	12-23	21-41	160-320

With ihe possible exception of mammary tumors,
there is little evidence from laboratory studies that
power-frequency magnetic fields have a tumor-promoting
effect. Although further animal studies are
needed to clarify the possible effects of ELF fields on
signals produced in cells and on endocrine regulation-both
of which could influence the development of tumors
by promoting the proliferation of initiated cells-it can

only be concluded that there is currently no convincing evidence for carcinogenic effects of these fields and that these data cannot be used as a basis for developing exposure guidelines.

Laboratory studies on cellular and animal systems have found no established effects of low-frequency fields that are indicative of adverse health effects when induced current density is at or below 10 mA mm2. At higher levels of induced current density (lo-100 mA mm2), more significant tissue effects have been consistently observed, such as functional changes in the nervous system and other tissue effects (Tenforde 1996).

Data on cancer risk associated with exposure to ELF fields among individuals living close to power lines are apparently consistent in indicating a slightly higher risk of leukemia among children, although more recent stud-ies question the previously observed weak association.

The studies do not, however, indicate a similarly elevated risk of any other type of childhood cancer or of any form of adult cancer. The basis for the hypothetical link between childhood leukemia and residence in close proximity to power lines is unknown; if the link is not related to the ELF electric and magnetic fields generated by the power lines, then unknown risk factors for leukemia would have to be linked to power lines in some undetermined manner. In the absence of support from laboratory studies, the epidemiological data are insuffi-cient to allow an exposure guideline to be established.

There have been reports of an increased risk of certain types of cancer, such as leukemia, nervous tissue tumors, and, to a limited extent, breast cancer, among electrical workers. In most studies, job titles were used to classify subjects according to presumed levels of mag-netic field exposure. A few more recent studies, however, have used more sophisticated methods of exposure assess-ment; overall, these studies suggested an increased risk of leukemia or brain tumors but were largely inconsistent with regard to the type of cancer for which risk is increased. The data are insufficient to provide a basis for ELF field exposure guidelines. In a large number of epidemiological studies, no consistent evidence of adverse reproductive effects have been provided.

Measurement of biological responses in laboratory studies and in volunteers has provided little indication of adverse effects of low-frequency fields at levels to which people are commonly exposed. A threshold current density of 10 mA mm2 at frequencies up to 1 kHz has been estimated for minor effects on nervous system

functions. Among volunteers, the most consistent effects
of exposure are the appearance of visual phosphenes and a minor reduction in heart rate during or immediately. after exposure to ELF fields, but there is no evidence that these transient effects are associated with any long-term health risk. A reduction in nocturnal pineal melatonin synthesis has been observed in several rodent species following exposure to weak ELF electric and magnetic fields, but no consistent effect has been reported in humans exposed to ELF fields under controlled condi-tions. Studies involving exposures to 60-Hz magnetic fields up to 20 PT have not reported reliable effects on melatonin levels in blood.

BIOLOGICAL BASIS FOR LIMITING EXPOSURE (100 -300 GHz)

The following paragraphs provide a general review of relevant literature on the biological effects and poten-tial health effects of electromagnetic fields with frequen-cies of 100 kHz to 300 GHz. More detailed reviews can be found elsewhere (NRPB 1991; UNEP/WHO/IRPA 1993; M&inlay et al. 1996; Polk and Postow 1996; Repacholi 1998).

Direct effects of electromagnetic fields

Epidemiological studies. Only a limited number of studies have been carried out on reproductive effects and cancer risk in individuals exposed to microwave radia-tion. A summary of the literature was published by UNEP/WHO/IRPA (1993).

Reproductive outcomes. Two extensive studies on women treated with microwave diathermy to relieve the pain of uterine contractions during labor found no evi-dence for adverse effects on the fetus (Daels 1973, 1976). However, seven studies on pregnancy outcomes among workers occupationally exposed to microwave radiation and on birth defects among their offspring produced both positive and negative results. In some of the larger epidemiological studies of female plastic welders and physiotherapists working with shortwave diathermy de-vices, there were no statistically significant effects on rates of abortion or fetal malformation (Kallen et al. 1982). By contrast, other studies on similar populations of female workers found an increased risk of miscarriage and birth defects (Larsen et al. 1991; Ouellet-Hellstrom and Stewart 1993). A study of male radar workers found no association between microwave exposure and the risk of Down’s syndrome in their offspring (Cohen et al. 1977).

Overall, the studies on reproductive outcomes and microwave exposure suffer from very poor assessment of exposure and, in many cases, small numbers of subjects. Despite the generally negative results of these studies, it will be difficult to draw firm conclusions on reproductive risk without further epidemiological data on highly exposed individuals and more precise exposure assess-ment.

Cancer studies. Studies on cancer risk and micro-wave exposure are few and generally lack quantitative exposure assessment. Two epidemiological studies of radar workers in the aircraft industry and in the US. armed forces found no evidence of increased morbidity or mortality from any cause (Barr-on and Baraff 1958; Robinette et al. 1980; UNEP/WHO/IRPA 1993). Similar results were obtained by Lillienfeld et al. (1978) in a study of employees in the U.S. embassy in Moscow, who were chronically exposed to low-level microwave radia-tion. Selvin et al. (1992) reported no increase in cancer risk among children chronically exposed to radiation from a large microwave transmitter near their homes. More recent studies have failed to show significant increases in nervous tissue tumors among workers and military personnel exposed to microwave fields (Beall et al. 1996; Grayson 1996). Moreover, no excess total mortality was apparent among users of mobile tele-phones (Rothman et al. 1996a, b), but it is still too early to observe an effect on cancer incidence or mortality. There has been a report of increased cancer risk among military personnel (Szmigielski et al. 1988) but the results of the study are difficult to interpret because neither the size of the population nor the exposure levels are clearly stated. In a later study, Szmigielski (1996) found increased rates of leukemia and lymphoma among military personnel exposed to EMF fields, but the assess-ment of EMF exposure was not well defined. A few recent studies of populations living near EMF transmit-ters have suggested a local increase in leukemia inci-dence (Hocking et al. 1996; Dolk et at. 1997a, b), but the results are inconclusive. Overall, the results of the small number of epidemiological studies published provide only limited information on cancer risk.

Laboratory studies. The following paragraphs pro-vide a summary and critical evaluation of laboratory studies on the biological effects of electromagnetic fields with frequencies in the range 100 kHz-300 GHz. There are separate discussions on results of studies of volun-teers exposed under controlled conditions and of labora-tory studies on cellular, tissue, and animal systems.

Volunteer studies. Studies by Chatterjee et al. (1986) demonstrated that, as the frequency increases from approximately 100 kHz to 10 MHz, the dominant effect of exposure to a high-intensity electromagnetic field changes from nerve and muscle stimulation to heating. At 100 kHz the primary sensation was one of nerve tingling, while at 10 MHz it was one of warmth on the skin. In this frequency range, therefore, basic health protection criteria should be such as to avoid stimulation of excitable tissues and heating effects. At frequencies from 10 MHz to 300 GHz, heating is the major effect of absorption of electromagnetic energy, and temperature rises of more than 1-2 OC can have adverse health effects such as heat exhaustion and heat stroke (ACGIH 1996). Studies on workers in thermally stressful environments have shown worsening performance of simple tasks as

body temperature rises to a level approaching physiolog-ical heat stress (Ramsey and Kwon 1988).

A sensation of warmth has been reported by volun-teers experiencing high-frequency current of about 100 -200 mA through a limb. The resulting SAR value is unlikely to produce a localized temperature increment of more than l°C in the limbs (Chatterjee et al. 1986; Chen and Gandhi 1988; Hoque and Gandhi 1988), which has been suggested as the upper limit of temperature increase that has no detrimental health effects (UNEP/WHO/ IRPA 1993). Data on volunteers reported by Gandhi et al. (1986) for frequencies up to 50 MHz and by Tofani et al. (1995) for frequencies up to 110 MHz (the upper limit of the FM broadcast band) support a reference level for limb current of 100 mA to avoid excessive heating effects (Dimbylow 1997).

There have been several studies of thermoregulatory responses of resting volunteers exposed to EMF in magnetic resonance imaging systems (Shellock and Crues 1987; Magin et al, 1992). In general, these have demonstrated that exposure for up to 30 min, under conditions in which whole-body SAR was less than 4 W kg-‘, caused an increase in the body core temper-ature of less than l°C.

Cellular and animal studies. There are numerous reports on the behavioral and physiological responses of laboratory animals, including rodents, dogs, and non-human primates, to thermal interactions of EMF at frequencies above 10 MHz. Thermosensitivity and ther-moregulatory responses are associated both with the hypothalamus and with thermal receptors located in the skin and in internal parts of the body. Afferent signals reflecting temperature change converge in the central nervous system and modify the activity of the major neuroendocrine control systems, triggering the physio-logical and behavioral responses necessary for the main-tenance of homeostasis.

Exposure of laboratory animals to EMF producing absorption in excess of approximately 4 W kg-' has revealed a characteristic pattern of thermoregulatory response in which body temperature initially rises and then stabilizes following the activation of thermoregula-tory mechanisms (Michaelson 1983). The early phase of this response is accompanied by an increase in blood volume due to movement of fluid from the extracellular space into the circulation and by increases in heart rate and intraventricular blood pressure. These cardiody-namic changes reflect thermoregulatory responses that facilitate the conduction of heat to the body surface. Prolonged exposure of animals to levels of microwave radiation that raise the body temperature ultimately lead to failure of these thermoregulatory mechanisms.

Several studies with rodents and monkeys have also demonstrated a behavioral component of thermoregula-tory responses. Decreased task performance by rats and monkeys has been observed at SAR values in the range 1-3 W kg-' (Stern et al. 1979; Adair and Adams 1980; de Lorge and Ezell 1980; D'Andrea et al. 1986). In monkeys, altered thermoregulatory behavior starts when the temperature in the hypothalamic region rises by as little as 0.2-0.3'C (Adair et al. 1984). The hypothalamus is considered to be the control center for normal thermo-regulatory processes, and its activity can be modified by a small local temperature increase under conditions in which rectal temperature remains constant.

At levels of absorbed electromagnetic energy that cause body temperature rises in excess of l-2OC, a large number of physiological effects have been characterized in studies with cellular and animal systems (Michaelson and Elson 1996). These effects include alterations in neural and neuromuscular functions; increased blood-brain barrier permeability; ocular impairment (lens opac-ities and cornea1 abnormalities); stress-associated changes in the immune system; hematological changes; reproductive changes (e.g., reduced sperm production); teratogenicity; and changes in cell morphology, water and electrolyte content, and membrane functions.

Under conditions of partial-body exposure to intense

EMF, significant thermal damage can occur in sensitive tissues such as the eye and the testis. Microwave expo-sure of 2-3 h duration has produced cataracts in rabbits' eyes at SAR values from 100-140 W kg-‘, which produced lenticular temperatures of 41-43'C (Guy et al. 1975). No cataracts were observed in monkeys exposed to microwave fields of similar or higher intensities, possibly because of different energy absorption patterns in the eyes of monkeys from those in rabbits. At very high frequencies (lo-300 GHz), absorption of electro-magnetic energy is confined largely to the epidermal layers of the skin, subcutaneous tissues, and the outer part of the eye. At the higher end of the frequency range, absorption is increasingly superficial. Ocular damage at these frequencies can be avoided if the microwave power density is less than 50 W mm2 (Sliney and Wolbarsht 1980; UNEP/WHO/IRPA 1993).

There has been considerable recent interest in the possible carcinogenic effects of exposure to microwave fields with frequencies in the range of widely used communications systems, including hand-held mobile telephones and base transmitters. Research findings in this area have been summarized by ICNIRP (1996). Briefly, there are many reports suggesting that micro-wave fields are not mutagenic, and exposure to these fields is therefore unlikely to initiate carcinogenesis (NRPB 1992; Cridland 1993; UNEP/WHO/IRPA 1993). By contrast, some recent reports suggest that exposure of rodents to microwave fields at SAR levels of the order of 1 W kg-' may produce strand breaks in the DNA of testis and brain tissues (Sarkar et al. 1994; Lai and Singh 1995, 1996), although both ICNIRP (1996) and Williams (1996) pointed out methodological deficiencies that could have significantly influenced these results.

In a large study of rats exposed to microwaves for up to 25 mo, an excess of primary malignancies was noted in exposed rats relative to controls (Chou et al. 1992). However, the incidence of benign tumors did not differ between the groups, and no specific type of tumor

was more prevalent in the exposed group than in stock rats of the same strain maintained under similar specific-. pathogen-free conditions. Taken as a whole, the results of this study cannot be interpreted as indicating a tumor-initiating effect of microwave fields.

Several studies have examined the effects of micro-wave exposure on the development of pre-initiated tumor cells. Szmigielski et al. (1982) noted an enhanced growth rate of transplanted lung sarcoma cells in rats exposed to microwaves at high power densities. It is possible that this resulted from a weakening of the host immune defense in response to thermal stress from the microwave . exposure. Recent studies using athermal levels of micro-wave irradiation have found no effects on the develop-ment of melanoma in mice or of brain glioma in rats (Santini et al. 1988; Salford et al. 1993).

Repacholi et al. (1997) have reported that exposure of 100 female, Ek-@& transgenic mice to 900-MHz fields, pulsed at 217 Hz with pulse widths of 0.6 us for up to 18 mo, produced a doubling in lymphoma inci-dence compared with 101 controls. Because the mice were free to roam in their cages, the variation in SAR was wide (0.01-4.2 W kg-‘). Given that the resting metabolic rate of these mice is 7-15 W kg- ‘, only the upper end of the exposure range may have produced some slight heating. Thus, it appears that this study suggests a non-thermal mechanism may be acting, which needs to be investigated further. However, before any assumptions can be made about health risk, a number of questions need to be addressed. The study needs to be replicated, restraining the animals to decrease the SAR exposure variation and to determine whether there is a dose response. Further study is needed to determine whether the results can be found in other animal models in order to be able to generalize the results to humans. It is also essential to assess whether results found in transgenic animals are applicable to humans.

Special considerations for pulsed and amplitude-modulated waveforms

Compared with continuous-wave (CW) radiation, pulsed microwave fields with the same average rate of energy deposition in tissues are generally more effective in producing a biological response, especially when there is a well-defined threshold that must be exceeded to elicit the effect (ICNIRP 1996). The “microwave hearing” effect is a well known example of this (Frey 1961; Frey and Messenger 1973; Lin 1978): people with normal hearing can perceive pulse-modulated fields with fre-quencies between about 200 MHz and 6.5 GHz. The auditory sensation has been variously described as a buzzing, clicking, or popping sound, depending on the modulation characteristics of the field. The microwave hearing effects have been attributed to a thermoelastic interaction in the auditory cortex of the brain, with a threshold for perception of about 100-400 mJ rnp2 for pulses of duration less than 30 us at 2.45 GHz (corre-sponding to an SA of 4-16 mJ kg-‘). Repeated or prolonged exposure to microwave auditory effects may be stressful and potentially harmful.

Some reports suggest that retina, iris, and cornea1 endothelium of the primate eye are sensitive to low levels of pulsed microwave radiation (Kues et al. 1985; UNEP/ WHO/IRPA 1993). Degenerative changes in light-sensitive cells of the retina were reported for absorbed energy levels as low as 26 mJ kg- ‘. After administration of timolol maleate, which is used in the treatment of glaucoma, the threshold for retinal damage by pulsed fields dropped to 2.6 mJ kg- ‘. However, an attempt in an independent laboratory to partially replicate these find-ings for CW fields (i.e., not pulsed) was unsuccessful (Kamimura et al. 1994), and it is therefore impossible at present to assess the potential health implications of the initial findings of Kues et al. (1985).

Exposure to intense pulsed microwave fields has been reported to suppress the startle response in con-scious mice and to evoke body movements (NRPB 1991; Sienkiewicz et al. 1993; UNEP/WHO/IRPA 1993). The threshold specific energy absorption level at midbrain that evoked body movements was 200 J kg-’ for 10 ps pulses. The mechanism for these effects of pulsed mi-crowaves remains to be determined but is believed to be related to the microwave hearing phenomenon. The auditory thresholds for rodents are about an order of magnitude lower than for humans, that is 1-2 mJ kg-’ for pulses <30 ps in duration. Pulses of this magnitude have also been reported to affect neurotransmitter me-tabolism and the concentration of the neural receptors involved in stress and anxiety responses in different regions of the rat brain.

The issue of athermal interactions of high-frequency EMF has centered largely on reports of biological effects of amplitude modulated (AM) fields under *in-vitro* con-ditions at SAR values well below those that produce measurable tissue heating. Initial studies in two indepen-dent laboratories led to reports that VHF fields with amplitude modulation at extremely low frequencies (6-20 Hz) produced a small, but statistically significant, release of Ca++ from the surfaces of chick brain cells (Bawin et al. 1975; Blackman et al. 1979). A subsequent attempt to replicate these findings, using the same type of AM field, was unsuccessful (Albert et al. 1987). A number of other studies of the effects of AM fields on Ca++ homeostasis have produced both positive and negative results. For example, effects of AM fields on

Ca^{++} binding to cell surfaces have been observed with neuroblastoma cells, pancreatic cells, cardiac tissue, and cat brain cells, but not with cultured rat nerve cells, chick skeletal muscle, or rat brain cells (Postow and Swicord 1996).

Amplitude-modulated fields have also been reported to alter brain electrical activity (Bawin et al. 1974), inhibit T-lymphocyte cytotoxic activity (Lyle et al. 1983), decrease the activities of non-cyclic-AMP-dependent kinase in lymphocytes (Byus et al. 1984), and cause a transient increase in the cytoplasmic activity of ornithine decarboxylase, an essential enzyme for cell proliferation (Byus et al. 1988; Litovitz et al. 1992). In contrast, no effects have been observed on a wide variety

of other cellular systems and functional end-points, including lymphocyte capping, neoplastic cell transfor-mation, and various membrane electrical and enzymatic properties (Postow and Swicord 1996). Of particular relevance to the potential carcinogenic effects of pulsed fields is the observation by Balcer-Kubiczek and Harri-son (199 1) that neoplastic transformation was acceler-ated in C3H/lOTl/2 cells exposed to 2,450-MHz micro-waves that were pulse-modulated at 120 Hz. The effect was dependent on field strength but occurred only when a chemical tumor-promoter, TPA, was present in the cell culture medium. This finding suggests that pulsed micro-waves may exert co-carcinogenic effects in combination with a chemical agent that increases the rate of prolifer-ation of transformed cells. To date, there have been no attempts to replicate this finding, and its implication for human health effects is unclear.

Interpretation of several observed biological effects of AM electromagnetic fields is further complicated by the apparent existence of "windows" of response in both the power density and frequency domains. There are no accepted models that adequately explain this phenome-non, which challenges the traditional concept of a mono-tonic relationship between the field intensity and the severity of the resulting biological effects.

Overall, the literature on athermal effects of AM electromagnetic fields is so complex, the validity of reported effects so poorly established, and the relevance of the effects to human health is so uncertain, that it is impossible to use this body of information as a basis for setting limits on human exposure to these fields.

Indirect effects of electromagnetic fields

In the frequency range of about 100 kHz-110 MHz, shocks and burns can result either from an individual touching an ungrounded metal object that has acquired a charge in a field or from contact between a charged individual and a grounded metal object. It should be noted that the upper frequency for contact current (I 10 MHz) is imposed by a lack of data on higher frequencies rather than by the absence of effects. However, 110 MHz is the upper frequency limit of the FM broadcast band. Threshold currents that result in biological effects rang-ing in severity from perception to pain have been measured in controlled experiments on volunteers (Chat-terjee et al. 1986; Tenforde and Kaune 1987; Bernhardt 1988); these are summarized in Table 3. In general, it has been shown that the threshold currents that produce perception and pain vary little over the frequency range 100 kHz-1 MHz and are unlikely to vary significantly over the frequency range up to about 110 MHz. As noted earlier for lower frequencies, significant variations be-tween the sensitivities of men, women, and children also exist for higher frequency fields. The data in Table 3 represent the range of 50th percentile values for people of different sizes and different levels of sensitivity to contact currents.

Table 3. Ranges of threshold currents for indirect effects, includ-ing children, women, and men.

Indirect effect	Threshold current (mA) at frequency: 100 kHz	1 MHz
Touch perception	25-40	25-40
Pain on finger contact	33-55	28-50
Painful shock/let-go threshold	112-224	Not determined
Severe shock/breathing difficulty	160-320	Not determined

Summary of biological effects and epidemiological studies (100 kHz-300 GHz)

Available experimental evidence indicates that the exposure of resting humans for approximately 30 min to EMF producing a whole-body SAR of between land4Wkg-’ results in a body temperature increase of less than 1 ‘C. Animal data indicate a threshold for behavioral responses in the same SAR range. Exposure to more intense fields, producing SAR values in excess of 4 W kg-‘, can overwhelm the thermoregulatory capacity of the body and produce harmful levels of tissue heating. Many laboratory studies with rodent and non-human primate models have demonstrated the broad range of tissue damage resulting from either partial-body or whole-body heating producing temperature rises in excess of l-2’C. The sensitivity of various types of tissue to thermal damage varies widely, but the threshold for irreversible effects in even the most sensitive tissues is greater than 4 W kg-’ under normal environmental conditions. These data form the basis for an occupational exposure restriction of 0.4 W kg-‘, which provides a large margin of safety for other limiting conditions such as high ambient temperature, humidity, or level of physical activity.

Both laboratory data and the results of limited human studies (Michaelson and Elson 1996) make it clear that thermally stressful environments and the use of drugs or alcohol can compromise the thermoregulatory capacity of the body. Under these conditions, safety factors should be introduced to provide adequate protec-tion for exposed individuals.

Data on human responses to high-frequency EMF that produce detectable heating have been obtained from controlled exposure of volunteers and from epidemiolog-ical studies on workers exposed to sources such as radar, medical diathermy equipment, and heat sealers. They are fully supportive of the conclusions drawn from labora-tory work, that adverse biological effects can be caused by temperature rises in tissue that exceed l°C. Epidemi-ological studies on exposed workers and the general public have shown no major health effects associated with typical exposure environments. Although there are deficiencies in the epidemiological work, such as poor exposure assessment, the studies have yielded no con-vincing evidence that typical exposure levels lead to adverse reproductive outcomes or an increased cancer risk in exposed individuals. This is consistent with the results of laboratory research on cellular and animal 508 Health Physics models, which have demonstrated neither teratogenic nor carcinogenic effects of exposure to athermal levels of. high-frequency EMF.

Exposure to pulsed EMF of sufficient intensity leads to certain predictable effects such as the microwave

hearing phenomenon and various behavioral responses. Epidemiological studies on exposed workers and the general public have provided limited information and failed to demonstrate any health effects. Reports of severe retinal damage have been challenged following unsuccessful attempts to replicate the findings.
A large number of studies of the biological effects of amplitude-modulated EMF, mostly conducted with low levels of exposure, have yielded both positive and neg-ative results. Thorough analysis of these studies reveals that the effects of AM fields vary widely with the exposure parameters, the types of cells and tissues involved, and the biological end-points that are exam-ined. In general, the effects of exposure of biological systems to athermal levels of amplitude-modulated EMF are small and very difficult to relate to potential health effects. There is no convincing evidence of frequency and power density windows of response to these fields.
Shocks and burns can be the adverse indirect effects of high-frequency EMF involving human contact with metallic objects in the field. At frequencies of 100 kHz-110 MHz (the upper limit of the FM broadcast band), the threshold levels of contact current that produce effects ranging from perception to severe pain do not vary significantly as a function of the field frequency. The threshold for perception ranges from 25 to 40 mA in individuals of different sizes, and that for pain from approximately 30 to 55 mA; above 50 mA there may be severe burns at the site of tissue contact with a metallic conductor in the field.

GUIDELINES FOR LIMITING EMF EXPOSURE

Occupational and general public exposure limitations

The occupationally exposed population consists of adults who are generally exposed under known condi-tions and are trained to be aware of potential risk and to take appropriate precautions. By contrast, the general public comprises individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals. In many cases, members of the public are unaware of their exposure to EMF. Moreover, individual members of the public cannot reasonably be expected to take precautions to minimize or avoid expo-sure. It is these considerations that underlie the adoption of more stringent exposure restrictions for the public than for the occupationally exposed population.

Basic restrictions and reference levels

Restrictions on the effects of exposure are based on

established health effects and are termed basic restric-tions. Depending on frequency, the physical quantities used to specify the basic restrictions on exposure to EMF
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are current density, SAR, and power density. Protection against adverse health effects requires that these basic restrictions are not exceeded.

Reference levels of exposure are provided for com-parison with measured values of physical quantities; compliance with all reference levels given in these guide-lines will ensure compliance with basic restrictions. If measured values are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to assess compliance with the basic restrictions.

General statement on safety factors

There is insufficient information on the biological and health effects of EMF exposure of human popula-tions and experimental animals to provide a rigorous basis for establishing safety factors over the whole frequency range and for all frequency modulations. In addition, some of the uncertainty regarding the appropri-ate safety factor derives from a lack of knowledge regarding the appropriate dosimetry (Repacholi 1998).

The following general variables were considered in the development of safety factors for high-frequency fields:
effects of EMF exposure under severe environ-mental conditions (high temperature, etc.) and/or high activity levels; and
the potentially higher thermal sensitivity in cer-tain population groups, such as the frail and/or elderly, infants and young children, and people with diseases or taking medications that compro-mise thermal tolerance.

The following additional factors were taken into ac-count in deriving reference levels for high-frequency fields:
l differences in absorption of electromagnetic en-ergy by individuals of different sizes and different orientations relative to the field; and
l reflection, focusing, and scattering of the incident field, which can result in enhanced localized absorption of high-frequency energy.

Basic restrictions

Different scientific bases were used in the develop-ment of basic exposure restrictions for various frequency ranges:

Between 1 Hz and 10 MHz, basic restrictions are provided on current density to prevent effects on

nervous system functions;
Between 100 kHz and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating; in the 100 kHz-10 MHz range, restrictions are provided on both current density and SAR; and
Between 10 and 300 GHz, basic restrictions are provided on power density to prevent excessive heating in tissue at or near the body surface. Guidelines for Limiting exposure to time-varying electric, magnetic, and electromagnetic fields 0 KNIRP **GUIDELINES 509**
In the frequency range from a few Hz to 1 kHz, for levels of induced current density above 100 mA m-2, the thresholds for acute changes in central nervous system excitability and other acute effects such as reversal of the visually evoked potential are exceeded. In view of the safety considerations above, it was decided that, for frequencies in the range 4 Hz to 1 kHz, occupational exposure should be limited to fields that induce current densities less than 10 mA me2, i.e., to use a safety factor of 10. For the general public an additional factor of 5 is applied, giving a basic exposure restriction of 2 mA mY2.
Below 4 Hz and above 1 kHz, the basic restriction on induced current density increases progressively, corre-sponding to the increase in the threshold for nerve stimulation for these frequency ranges.
Established biological and health effects in the frequency range from 10 MHz to a few GHz are consistent with responses to a body temperature rise of more than l°C This level of temperature increase results from exposure of individuals under moderate environ-mental conditions to a whole-body SAR of approxi-mately 4 W kg- ’ for about 30 min. A whole-body average SAR of 0.4 W kg-’ has therefore been chosen as the restriction that provides adequate protection for occupational exposure. An additional safety factor of 5 is introduced for exposure of the public
whole-body SAR limit of 0.08 W kg
:fiving an average
.
The lower basic restrictions for exposure of the general public take into account the fact that their age and health status may differ from those of workers.
In the low-frequency range, there are currently few data relating transient currents to health effects. The ICNIRP therefore recommends that the restrictions on current densities induced by transient or very short-term peak fields be regarded as instantaneous values which should not be time-averaged.

The basic restrictions for current densities, whole-body average SAR, and localized SAR for frequencies between 1 Hz and 10 GHz are presented in Table 4, and those for power densities for frequencies of lo-300 GHz are presented in Table 5.

REFERENCE LEVELS

Where appropriate, the reference levels are obtained from the basic restrictions by mathematical modeling and by extrapolation from the results of laboratory investiga-tions at specific frequencies. They are given for the condi-tion of maximum coupling of the field to the exposed individual, thereby providing maximum protection. Tables 6 and 7 summarize the reference levels for occupational exposure and exposure of the general public, respectively, and the reference levels are illustrated in Figs. 1 and 2. The reference levels are intended to be spatially averaged values over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded.

For low-frequency fields, several computational and measurement methods have been developed for deriving field-strength reference levels from the basic restrictions.

Table 4. Basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz.~

Exposure
characteristics Frequency range
Current density for
head and trunk
(mA rn-*) (rms)
Whole-body
average S AR
(W kg-‘)
Localized SAR
(head and trunk)
(W kg-‘)
Localized SAR
(limbs) (W kg-‘)
Occupational
exposure
General public
exposure
up to 1 Hz
1-4 Hz
4 Hz-l kHz
1-100 kHz
100 kHz-10 MHz
10 MHz-10 GHz
up to 1 Hz

1-4 Hz
4 Hz-l kHz
1-100 kHz
100 kHz-10 MHz
10 MHz-10 GHz
40 - - -4olf
- - -$
0 - - - - - -f/
l00 0.4 10 20
- 0.4 10 20
8 - - -?
f - - -f/
5:0 - - - - - -fl500
0.08 2 4
- 0.08 2 4
a Note:
1. f is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm2 perpendicular
to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by ,/2 (- 1.414). For pulses
of duration $ the equivalent frequency to apply in the basic restrictions should be calculated as f = 1/(2$).
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be
calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then
be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the
estimation of exposure.
7. For pulses of duration tp the equivalent frequency to apply in the basic restrictions should be calculated asf = 1/(2$,). Additionally,
for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory
effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed
10 mJ kg- ' for workers and ZmJ kg- ' for the general public, averaged over 10 g tissue.

Table 5. Basic restrictions for power density for frequencies
between 10 and 300 GHz.~
Exposure characteristics Power density (W mp2)
Occupational exposure
General public
50
10

a Note:
1. Power densities are to be averaged over any 20 cm2 of exposed area and any 681"'.'~-min period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases.
2. Spatial maximum power densities, averaged over 1 cm2, should not exceed 20 times the values above.

The simplifications that have been used to date did not account for phenomena such as the inhomogeneous distri-bution and anisotropy of the electrical conductivity and other tissue factors of importance for these calculations.
The frequency dependence of the reference field levels is consistent with data on both biological effects and coupling of the field.

Magnetic field models assume that the body has a homogeneous and isotropic conductivity and apply sim-ple circular conductive loop models to estimate induced currents in different organs and body regions, e.g., the head, by using the following equation for a pure sinusoi-dal field at frequency f derived from Faraday's law of induction:

J = nRfcrB, w

where B is the magnetic flux density and *R* is the radius of the loop for induction of the current. More complex models use an ellipsoidal model to represent the trunk or the whole body for estimating induced current densities at the surface of the body (Reilly 1989, 1992).

If, for simplicity, a homogeneous conductivity of 0.2 S mm1 is assumed, a 50-Hz magnetic flux density of 100 PT generates current densities between 0.2 and 2 mA mm2 in the peripheral area of the body (CRP 1997). According to another analysis (NAS 1996), 60-Hz exposure levels of 100 PT correspond to average current densities of 0.28 mA mm2 and to maximum current densities of approximately 2 mA me2. More realistic calculations based on anatomically and electri-cally refined models (Xi and Stuchly 1994) resulted in maximum current densities exceeding 2 mA me2 for a lOO-PT field at 60 Hz. However, the presence of biolog-ical cells affects the spatial pattern of induced currents and fields, resulting in significant differences in both magnitude (a factor of 2 greater) and patterns of flow of the induced current compared with those predicted by simplified analyses (Stuchly and Xi 1994).

Electric field models must take into account the fact that, depending on the exposure conditions and the size, shape, and position of the exposed body in the field, the surface charge density can vary greatly, resulting in a variable and non-uniform distribution of currents inside the body. For sinusoidal electric fields at frequencies below about 10 MHz, the magnitude of the induced current density inside the body increases with frequency. The induced current density distribution varies inversely with the body cross-section and may be relatively high in the neck and ankles. The exposure level of 5 kV mm1 for exposure of the general public corresponds, under worst-case conditions, to an induced current density of about 2 mA rnp2 in the neck and trunk of the body if the E-field vector is parallel to the body axis (IL0 1994; CRP 1997). However, the current density induced by 5 kV m-l will comply with the basic restrictions under realistic worst-case exposure conditions.

For purposes of demonstrating compliance with the basic restrictions, the reference levels for the electric and magnetic fields should be considered separately and not additively. This is because, for protection purposes, the currents induced by electric and magnetic fields are not additive.

For the specific case of occupational exposures at frequencies up to 100 kHz, the derived electric fields can be increased by a factor of 2 under conditions in which adverse indirect effects from contact with electrically charged conductors can be excluded.

At frequencies above 10 MHz, the derived electric and magnetic field strengths were obtained from the whole-body SAR basic restriction using computational and experimental data. In the worst case, the energy coupling reaches a maximum between 20 MHz and several hundred MHz. In this frequency range, the derived reference levels have minimum values. The derived magnetic field strengths were calculated from the electric field strengths by using the far-field relationship between E and H (E/H = 377 ohms). In the near-field, the SAR frequency dependence curves are no longer valid; moreover, the contributions of the electric and magnetic field components have to be considered sepa-rately. For a conservative approximation, field exposure levels can be used for near-field assessment since the coupling of energy from the electric or magnetic field contribution cannot exceed the SAR restrictions. For a less conservative assessment, basic restrictions on the whole-body average and local SAR should be used.

Reference levels for exposure of the general public have been obtained from those for occupational exposure by using various factors over the entire frequency range. These factors have been chosen on the basis of effects that are recognized as specific and relevant for the

various frequency ranges. Generally speaking, the factors
follow the basic restrictions over the entire frequency
range, and their values correspond to the mathematical
relation between the quantities of the basic restrictions
and the derived levels as described below:
l In the frequency range up to 1 kHz, the general
public reference levels for electric fields are
one-half of the values set for occupational expo-sure.
The value of 10 kV mm1 for a 50-Hz or 8.3
kV me1 for a 60-Hz occupational exposure in-cludes
a sufficient safety margin to prevent stim-ulation
effects from contact currents under all
possible conditions. Half of this value was cho-sen
for the general public reference levels, i.e., Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic tields 0 ICNIRP **GUIDELINES** 511

Table 6. Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms
values).a

Frequency range
E-field strength H-field strength B-field Equivalent plane wave
(V m-l) (A m-l) (pT) power density Seq (W rn-*)
up to 1 Hz - 1.63 X 105 2 x lo5 -1-
8 Hz 20,000 1.63 X 105g2 2 x 1oYf* -8-
25 Hz 20,000 2 x 104y 2.5 X 104v -0.025-
0.82 kHz 5oo/f 2olf 25v -0.82-
65 kHz 610 24.4 30.7 -0.0651
MHz 610 1.6/'f 2.o/f -1-
10 MHz 6lOv 1.6/'f 2.og -10-
400 MHz 61 0.16 0.2
400-2,000 MHz 3f U2 0.008~ "2 . O.Olf "2 ;0
2-300 GHz 137 0.36 0.45 50

a Note:
1.
2.
3.
4.
5.
6.
7.
f as indicated in the frequency range column.
Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
For frequencies between 100 kHz and 10 GHz, &, E2, H*, and B* are to be averaged over any 6-min period.
For peak values at frequencies up to 100 kHz see Table 4, note 3.
For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field

strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding
10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000
times the Seq restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
For frequencies exceeding 10 GHz, L?,_, E2, H*, and B2 are to be averaged over any 68F '.05-min period v in GHz).
No E-field value is provided for frequencies < 1 Hz, which are effectively static electric fields. Electric shock from low impedance
sources is prevented by established electrical safety procedures for such equipment.
Table 7. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms
values).a
Frequency range
E-field strength H-field strength B-field Equivalent plane wave
(V m-l) (A m-i) (pT) power density & (W me*)
up to 1 Hz -1-
8 Hz 10,000
8-25 Hz 10,000
0.025-0.8 kHz 25OF
0.8-3 kHz 2501'j"
3-150 kHz 87
0.15-1 MHz 87
1-10 MHz 87lf "*
lo-400 MHz 28
400-2,000 MHz 1.375f 'I2
2-300 GHz 61
3.2 X 104
3.2 X 104v2
4,ooo/f
4!f
5
C
;.73/f
0.73r
0.073
0.0037f I;*
0.16
4 x lo4 -4
x 104y* -5
,ooo/f -5Y
-6.25
-6.25
-0.92v
-0.92w
-0.092
0.0046f "' ;200

0.20 10
a Note:
1.
2.
3.
4.
5.
6.
7.
f as indicated in the frequency range column.
Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
For frequencies between 100 kHz and 10 GHz, &, E*, H*, and B* are to averaged over any 6-min period.
For peak values at frequencies up to 100 kHz see Table 4, note 3.
For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field
strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding
10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000
times the L& restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
For frequencies exceeding 10 GHz, ,&, E*, H2, and B2 are to be averaged over any 68/f '.05-min period v in GHz).
No E-field value is provided for frequencies < 1 Hz, which are effectively static electric fields. perception of surface electric charges
will not occur at field strengths less than 25 kVm-'. Spark discharges causing stress or annoyance should be avoided.
5 kV m-l for 50 Hz or 4.2 kV me1 for 60 Hz, to l In the frequency range 100 kHz- lO,MHz, the
prevent adverse indirect effects for more than general public reference levels for magnetic
90% of exposed individuals; fields have been increased compared with the
l In the low-frequency range up to 100 kHz, the limits given in the 1988 IRPA guideline. In that
general public reference levels for magnetic fields guideline, the magnetic field strength reference
are set at a factor of 5 below the values set for levels were calculated from the electric field
occupational exposure; strength reference levels by using the far-field
Fig. 1. Reference levels for exposure to time varying electric fields (compare Tables 6 and 7).
-E 2
lu
lo4
103

lo2
I I I
I I I
I I I
I I I
I I I
I
I
I
I
I
I
-I--__I_--
I I
I I
I I
____-_---_----__
I I
I I
I I
I **I**
I I
I
I I
I I
I I I
_L__-J---__L___A__
I I
I I
I **I**
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I
I
I
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I I
I I
I I I
I I I
general public
peak g.p.
occupational
peak occup. I i

I I I I I I I mm,-m.mm
I 1 \ I I I I
- general public
-,-,-,- peak g.p.
---m occupatlonal I I I I I I
mm,m-smw peak occup. I I I I I I
I I I I I I
F ' , , 1 I 1 , I I , ,

Fig. 2. Reference levels for exposure to time varying magnetic fields (compare Tables 6 and 7).

formula relating E and H. These reference levels are too conservative, since the magnetic field at frequencies below 10 MHz does not contribute significantly to the risk of shocks, burns, or surface charge effects that form a major basis for limiting occupational exposure to electric fields in that frequency range;

l In the high-frequency range 10 MHz-10 GHz, the general public reference levels for electric and magnetic fields are lower by a factor of 2.2 than those set for occupational exposure. The factor of 2.2 corresponds to the square root of 5, which is the safety factor between the basic restrictions for occupational exposure and those for general public Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields 0 ICNIRP GUIDELINES 513

exposure. The square root is used to relate the threshold contact currents that elicit biological responses

quantities "field strength" and "power density;" . in children and adult women are approximately one-half

l ln the high-frequency range lb-300 GHz,- the general public reference levels are defined by the power density, as in the basic restrictions, and are lower by a factor of 5 than the occupational exposure restrictions;

and two-thirds, respectively, of those for adult men, the reference levels for contact current for the general public are set lower by a factor of 2 than the values for occupational exposure.

l Although little information is available on the relation between biological effects and peak val-ues of pulsed fields, it is suggested that, for frequencies exceeding 10 MHz, Seq as averaged over the pulse width should not exceed 1,000 times the reference levels or that field strengths should not exceed 32 times the field strength reference levels given in Tables 6 and 7 or shown in Figs. 1 and 2. For frequencies between about

0.3 GHz and several GHz, and for localized
exposure of the head, in order to limit or avoid
auditory effects caused by thermoelastic expan-sion
the specific absorption from pulses must
limited. In this frequency range, the threshold SA
of 4-16 mJ kg-' for producing this effect corre-sponds,
for 30-ps pulses, to peak SAR values of
130-520 W kg- ' in the brain. Between 100 kHz
and 10 MHz, peak values for the field strengths in
Figs. 1 and 2 are obtained by interpolation from
the 1.5-fold peak at 100 kHz to the 32-fold peak
at 10 MHz.

For the frequency range 10-110 MHz, reference
levels are provided for limb currents that are below the
basic restrictions on localized SAR (see Table 9).

SIMULTANEOUS EXPOSURE TO MULTIPLE
FREQUENCY FIELDS

It is important to determine whether, in situations of
simultaneous exposure to fields of different frequencies,
these exposures are additive in their effects. Additivity
should be examined separately for the effects of thermal
and electrical stimulation, and the basic restrictions
below should be met. The formulae below apply to
relevant frequencies under practical exposure situations.

For electrical stimulation, relevant for frequencies
up to 10 MHz, induced current densities should be added
according to

10 MHz
Ji
Ix-i=
l Hz *JL,i 5* 1. (5)

l In Tables 6 and 7, as well as in Figs. 1 and 2,
different frequency break-points occur for occu-pational
and general public derived reference
levels. This is a consequence of the varying
factors used to derive the general public reference
levels, while generally keeping the frequency
dependence the same for both occupational and
general public levels.

For thermal effects, relevant above 100 kHz, SAR
and power density values should be added according to:

10 GHz
2
SARi
300 GHz
Ix
si
SARL + g 1, W

i= 100 kHz i>lO GHz
where
REFERENCE LEVELS FOR CONTACT AND
INDUCED CURRENTS
Up to 110 MHz, which includes the FM radio
transmission frequency band, reference levels for contact
current are given above which caution must be exercised
to avoid shock and burn hazards. The point contact
reference levels are presented in Table 8. Since the
Ji = the current density induced at frequency *i;*
JL, i = the induced current density restriction at
frequency *i* as given in Table 4;
SARi = the SAR caused by exposure at frequency *i;*
SARL = the SAR limit given in Table 4;
SL = the power density limit given in Table 5;
and
Si = the power density at frequency *i.*
For practical application of the basic restrictions, the
following criteria regarding reference levels of field
strengths should be applied.
Table 8. Reference levels for time varying contact currents from **Table 9.** Reference
levels for current induced in any limb at
conductive objects.a frequencies between 10 and 110 MHz.~
Maximum contact
Exposure characteristics Frequency range current (mA)
Occupational exposure up to 2.5 kHz 1.0
2.5-100 kHz 0.4f
100 kHz-110 MHz 40
General public exposure up to 2.5 kHz 0.5
2.5-100 kHz 0.2f
100 kHz-110 MHz 20
‘fis the frequency in kHz.
Exposure characteristics Current (mA)
Occupational exposure
General public
100
45
a Note:
1. The public reference level is equal to the occupational reference level
divided by J5.
2. For compliance with the basic restriction on localized SAR, the square
root of the time-averaged value of the square of the induced current over
any 6-min period forms the basis of the reference levels. 514 Health Physics April 1998,
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For induced current density and electrical stimula-tion
effects, relevant up to 10 MHz, the following two
requirements should be applied to the field levels:
and

65 kHz
IZ
j=l Hz
where
Ei = the electric field strength at frequency I;
EL, i = the electric field reference level from Tables
6 and 7;
Hj = the magnetic field strength at frequency j;
HL, j = the magnetic field reference level from Ta-bles
6 and 7;
a **=** 610 V m-l for occupational exposure and
87 V m-l for general public exposure; and
b = 24.4 A m-l (30.7 pT) for occupational expo-sure
and 5 A rn- ' (6.25 pT) for general public
exposure.
The constant values ***a*** and *b* are used above 1 MHz
for the electric field and above 65 kHz for the magnetic
field because the summation is based on induced current
densities and should not be mixed with thermal consider-ations.
The latter forms the basis for *EL i* and *H~j* above 1
MHz and 65 kHz, respectively, found in Tables 6 and 7.
For thermal considerations, relevant above 100 kHz,
the following two requirements should be applied to the
field levels:
(9)
and
(10)
where
Ei = the electric field strength at frequency I;
EL, i = the electric field reference level from Tables
6 and 7;
Hj = the magnetic field strength at frequency j;
HL, i = the magnetic field reference level from Ta-bles
6 and 7;
c = 610/' V m-l v in MHz) for occupational
exposure and 87/"" V mm1 for general
public exposure; and
d = 1.6@ A m-l (f in MHz) for occupational
exposure and 0.73/ffor general public expo-sure.
For limb current and contact current, respectively,
the following requirements should be applied:
where
1k = the limb current component at frequency *k;*
I = the reference level of limb current (see Table
L, k 9);
1n = the contact current component at frequency
n; and
I c> n = the reference level of contact current at

frequency n (see Table 8).
The above summation formulae assume worst-case conditions among the fields from the multiple sources. As a result, typical exposure situations may in practice require less restrictive exposure levels than indicated by the above formulae for the reference levels.

PROTECTIVE MEASURES

ICNIRP notes that the industries causing exposure to electric and magnetic fields are responsible for ensur-ing compliance with all aspects of the guidelines,
Measures for the protection of workers include engineering and administrative controls, personal protec-tion programs, and medical surveillance (IL0 1994).
Appropriate protective measures must be implemented when exposure in the workplace results in the basic restrictions being exceeded. As a first step, engineering controls should be undertaken wherever possible to reduce device emissions of fields to acceptable levels. Such controls include good safety design and, where necessary, the use of interlocks or similar health protec-tion mechanisms.
Administrative controls, such as limitations on ac-cess and the use of audible and visible warnings, should be used in conjunction with engineering controls. Per-sonal protection measures, such as protective clothing, though useful in certain circumstances, should be re-garded as a last resort to ensure the safety of the worker; priority should be given to engineering and administra-tive controls wherever possible. Furthermore, when such items as insulated gloves are used to protect individuals from high-frequency shock and burns, the basic restric-tions must not be exceeded, since the insulation protects only against indirect effects of the fields.
With the exception of protective clothing and other personal protection, the same measures can be applied to the general public whenever there is a possibility that the general public reference levels might be exceeded. It is also essential to establish and implement rules that will prevent:
l interference with medical electronic equipment and devices (including cardiac pacemakers);
0
0
detonation of electro-explosive devices (detona-tors); and
fires and explosions resulting from ignition of flammable materials by sparks caused by induced

fields, contact currents, or spark discharges.
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APPENDIX

Glossary Dielectric constant. See permittivity.

Absorption. In radio wave propagation, attenuation of a radio wave due to dissipation of its energy, i.e., conversion of its energy into another form, such as heat.

Athermal effect. Any effect of electromagnetic energy on a body that is not a heat-related effect.

Dosimetry. Measurement, or determination by cal-culation, of internal electric field strength or induced current density, of the specific energy absorption, or specific energy absorption rate distribution, in humans or animals exposed to electromagnetic fields.

Blood-brain barrier. A functional concept devel-oped to explain why many substances that are trans-ported by blood readily enter other tissues but do not enter the brain; the “barrier” functions as if it were a continuous membrane lining the vasculature of the brain. These brain capillary endothelial cells form a nearly continuous barrier to entry of substances into the brain from the vasculature.

Electric field strength. The force (E) on a station-ary unit positive charge at a point in an electric field; measured in volt per meter (V rn- ‘).

Electromagnetic energy. The energy stored in an electromagnetic field. Expressed in joule (J).

ELF. Extremely low frequency; frequency below

300 Hz.
Conductance. The reciprocal of resistance. Ex-pressed in siemens (S). **EMF.** Electric, magnetic, and electromagnetic fields.
Conductivity, electrical. The scalar or vector quan-tity which, when multiplied by the electric field strength, yields the conduction current density; it is the reciprocal of resistivity. Expressed in siemens per meter (S m-l).
Continuous wave. A wave whose successive oscil-lations are identical under steady-state conditions.
Far field. The region where the distance from a radiating antenna exceeds the wavelength of the radiated EMF; in the far-field, field components (E and H) and the direction of propagation are mutually perpendicular, and the shape of the field pattern is independent of the distance from the source at which it is taken.
Current density. A vector of which the integral over a given surface is equal to the current flowing through the surface; the mean density in a linear conduc-tor is equal to the current divided by the cross-sectional area of the conductor. Expressed in ampere per square meter (A mW2).
Frequency. The number of sinusoidal cycles com-pleted by electromagnetic waves in 1 s; usually ex-pressed in hertz (Hz).
Depth of penetration. For a plane wave electro-magnetic field (EMF), incident on the boundary of a good conductor, depth of penetration of the wave is the depth at which the field strength of the wave has been reduced to l/e, or to approximately 37% of its original value.
Impedance, wave. The ratio of the complex number (vector) representing the transverse electric field at a point to that representing the transverse magnetic field at that point. Expressed in ohm (a).
Magnetic field strength. An axial vector quantity, H, which, together with magnetic flux density, specifies a magnetic field at any point in space, and is expressed in ampere per meter (A rn- ‘).
Magnetic flux density. A vector field quantity, B, that results in a force that acts on a moving charge or. charges, and is expressed in tesla (T).
Magnetic permeability. The scalar or vector quan-tity which, when multiplied by the magnetic field strength, yields magnetic flux density; expressed in henry per meter (H m-l). *Note:* For isotropic media, magnetic permeability is a scalar; for anisotropic media, it is a tensor quantity.

Microwaves. Electromagnetic radiation of suffi- a
ciently short wavelength for which practical use can be made of waveguide and associated cavity techniques in its transmission and reception. *Note:* The term is taken to signify radiations or fields having a frequency range of 300 MHz-300 GHz.

Near field. The region where the distance from a radiating antenna is less than the wavelength of the radiated EMF. *Note:* The magnetic field strength (multi-plied by the impedance of space) and the electric field strength are unequal and, at distances less than one-tenth of a wavelength from an antenna, vary inversely as the square or cube of the distance if the antenna is small compared with this distance.

Non-ionizing radiation (NIR). Includes all radia-tions and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter; characterized by energy per photon less than about 12 eV, wavelengths greater than 100 nm, and frequencies lower than 3 *X* 1015 Hz.

Occupational exposure. All exposure to EMF ex-perienced by individuals in the course of performing their work.

Permittivity. A constant defining the influence of an isotropic medium on the forces of attraction or repulsion between electrified bodies, and expressed in farad per metre (F m-l); *reZative pennittivity* is the permittivity of a material or medium divided by the permittivity of vacuum.

Plane wave. An electromagnetic wave in which the electric and magnetic field vectors lie in a plane perpen-dicular to the direction of wave propagation, and the magnetic field strength (multiplied by the impedance space) and the electric field strength are equal.
of

Power density. In radio wave propagation, the power crossing a unit area normal to the direction of wave propagation; expressed in watt per square meter (W mm2).

Public exposure. All exposure to EMF experienced by members of the general public, excluding occupa-tional exposure and exposure during medical procedures.

Radiofrequency (RF). Any frequency at which electromagnetic radiation is useful for telecommunica-tion. *Note:* In this publication, radiofrequency refers to the frequency range 300 Hz -300 GHz.

Resonance. The change in amplitude occurring as the frequency of the wave approaches or coincides with a natural frequency of the medium; whole-body absorp-tion of electromagnetic waves presents its highest value, i.e., the resonance, for frequencies (in MHz) correspond-ing approximately to 114/L, where L is the height of the individual in meters.

Root mean square (rms). Certain electrical effects are proportional to the square root of the mean of the square of a periodic function (over one period). This value is known as the effective, or root-mean-square (rms) value, since it is derived by first squaring the function, determining the mean value of the squares obtained, and taking the square root of that mean value.

Specific energy absorption. The energy absorbed per unit mass of biological tissue, (SA) expressed in joule per kilogram (J kg- ‘); specific energy absorption is the time integral of specific energy absorption rate.

Specific energy absorption rate (SAR). The rate at which energy is absorbed in body tissues, in watt per kilogram (W kg-‘); SAR is the dosimetric measure that has been widely adopted at frequencies above about 100 kHZ.

Wavelength. The distance between two successive points of a periodic wave in the direction of propagation, at which the oscillation has the same phase.

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Annex 4: Italian "Framework law" (Law No. 36/2001)

The Italian and English versions of Law No. 36/2001 are given below

LAW 22 February 2001, n.36

Framework law on protection from exposure to electrical, magnetic and electromagnetic fields.

The Chamber of Deputies and the Senate of the Republic have approved;

THE PRESIDENT OF THE REPUBLIC

Promulgates the following law:

Art 1.

(Purpose of the law)

1. The aim of the present law is to establish basic principles directed towards:

a) ensuring protection of the health of workers and the population from the effects of exposure to determined levels of electrical, magnetic and electromagnetic fields for aims of and in compliance with article 32 of the Constitution;

b) promoting scientific research for the evaluation of the long-term effects and implementing protective measures to be adopted in application of the precautionary principle set forth in art. 174, paragraph 2, of the treaty establishing the European Union;

c) ensuring protection of the environment and landscape and promoting technological innovation and reclamation actions aimed at minimising the intensity and effects of electrical, magnetic and electromagnetic fields using the best available technologies.

2. The special-status regions and the autonomous provinces of Trento and Bolzano are taking measures for the aims of the present law as part of the competences assigned to them in accordance with their statutes and relevant implementing regulations and according to the provisions of their respective structures.

Art 2.

(Scope of application)

1. The present law refers to installations, systems and equipment for civil, military and police use that may involve the exposure of workers and the population to electrical, magnetic and electromagnetic fields at frequencies of between 0 Hz and 300 GHz.

In particular, the present law applies to transmission lines and radio-electrical installations, including mobile-telephone installations, radars and radio-broadcasting installations.
2. The present law's provisions do not apply in cases of intentional exposure for diagnostic or therapeutic aims. Only those provisions set forth at articles 10 and 12 of the present law apply to appliances and devices for domestic, individual and work use.
3. With regard to the armed forces and the police forces, the provisions of the present law are applied taking into account the special needs of the service performed, identified by the decree referred to at article 4, paragraph 2, letter a).
4. Jurisdiction in matters of worker safety and health attributed by current provisions to the health and technical services established for the armed forces and for the police forces remain unchanged; the aforesaid services also have jurisdiction for reserved or operational areas and for those having analogous needs identified by the decree referred to at paragraph 3.

Art 3.
(Definitions)
1. For aims of application of the present law, the following definitions are assumed:
a) exposure: this is the condition of a person subjected to electrical, magnetic and electromagnetic fields, or to contact currents, of artificial origin;
b) exposure limit: this is the electrical, magnetic and electromagnetic field value, considered as input value, defined for aims of protecting health from acute effects, which is not to be exceeded under any condition of exposure of the population and workers for the aims set forth at article 1, paragraph 1, letter a);
c) caution value: this is the electrical, magnetic and electromagnetic field value considered as input value, which is not to be exceeded in home and school environments and in places used for extended stays for the aims referred to at article 1, paragraph 1, letter b) and c). This is a cautionary measure for aims of protecting from possible long-term effects and must be reached in the times and manner prescribed by the law;
d) quality objectives are:
1) localising criteria, urban-planning standards, instructions and incentives for the use of the best available technologies, indicated by regional laws according to the jurisdictions defined at article 8;
the electrical, magnetic and electromagnetic field values defined by the State according to the assessments set forth at article 4, paragraph 1, letter a) for aims of the progressive mitigation of exposure to those fields;

e) transmission line: refers to all power lines, substations and transformer rooms;
f) exposure of workers: this is any type of exposure of workers who, by virtue of their own specific work activity, are exposed to electrical, magnetic and electromagnetic fields;
g) exposure of the population: this is any type of exposure to electrical, magnetic and electromagnetic fields, with the exception of the exposure cited at letter f) and of intentional exposure for diagnostic or therapeutic aims;
h) radio-electrical stations and systems or installations: these are one or more transformers and receivers, or a group of transmitters and receivers, including accessory equipment, necessary at a given site to ensure radio broadcasting, radio communication or radio astronomy; i) mobile-telephone installation: this is the radio land station of the mobile telephony service, intended for radio linkage of mobile terminals with the mobile telephony service network;
l) fixed radio broadcasting installation: this is the land station for television or radio broadcasting service.

Art 4.
(The State's functions)
1. The State exercises functions relating to:
a) determining exposure limits, caution values and quality objectives, inasmuch as they are field values as defined by article 3, paragraph 1, letter d), number 2), in consideration of the nation's overriding interest in establishing unified criteria and consistent regulations in regard to the aims set forth at article 1;
b) promoting research activity and technical and scientific testing, as well as coordinating the gathering, processing and diffusion of data, annually informing the Parliament on this activity; in particular the Health Ministry promotes. through public and private not-for-profit institutions having proven experience in the scientific field, a multi-year programme of epidemiological research and experimental oncogenesis, in order to explore the risks associated with exposure to low- and high-frequency electromagnetic fields;
c) establishing a naional registry of the fixed and mobile sources of electrical, magnetic and electromagnetic fields and of the geographical areas involved, in order to survey the field levels present in the environment;
d) determining criteria for drawing up recovery plans as set forth at article 9, paragraph 2, with special reference to intervention priorities, implementation times, and means of coordinating activities involving multiple regions, as well as to the best technologies available with regard to implications of an economic and infrastructure nature;

e) identifying techniques for measuring and surveying electromagnetic pollution;
f) achieving planning agreements with transmission-line or transmission-grid managers or their owners, or with those who in any case who have same available to them, as well as with operators of installations for radio and television broadcasting and mobile telephony, in order to promote technologies and installation construction techniques that make it possible to minimise environmental emissions and to protect the landscape;
g) defining routes for transmission lines greater than 150 kV;
h) determining parameters for setting transmission-line restricted zones for transmission lines; within these restricted zones, no building is allowed to be used for residential, school, health or any other use that would involve a stay of at least four hours;
2. The exposure limits, caution values and quality objectives, techniques for measuring and surveying electromagnetic pollution, and parameters for establishing the restricted zone for transmission lines as described at paragraph 1, letter a), e) and h) are established within sixty days from the date on which the present law takes effect:
a) for the population, by decree of the President of the Council of Ministers at the proposal of the Ministry of the Environment in concert with the Minister of Health, having consulted the opinion of the Committee described at article 6 and the competent parliamentary commissions, following agreement in the jopint conference described at article 8 of Legislative Decree 28 August 1997, n. 281, hereinafter the "Joint Conference;"
b) for workers, without prejudice to the provisions set forth in Legislative Decree 19 September 1994, n. 626, and subsequent modifications, by decree of the President of the Council of Ministers at the proposal of the Minister of Health, having consulted the opinion of the Ministers of the Environment and of Labour and Social Welfare, the Committee described at article 6, and the competent parliamentary commissions, upon agreement reached in the Joint Conference. This same decree also governs the system of medical monitoring of works exposed on the job.
3. If agreements are not reached by the Joint Conference by the deadline set at paragraph 2, the President of the Council of Ministers, within thirty days, adopts the decrees described at paragraph 2, letters a) and b).
4. Within one hundred twenty days from the date on which the present law takes effect, the criteria for preparation of the recovery plans, in accordance with paragraph 1, letter d), are determined by decree of the President of the Council of Ministers at the proposal of the Minister of the Environment, having consulted the Committee described at article 6 and the Joint Conference.

5. The regions adapt their own legislation to the exposure limits, caution values and, within the limits of the definition at article 3, paragraph 1 letter d), number 2), quality objectives set forth by the decrees described at paragraph 2 of the present article.
6. For aims of the present article, the expenditure of Lire 8,000 million is authorised for each of the years 2001, 2002 and 2003 for the activities described at paragraph 1, letter b); Lire 2,000 million annually is authorised starting with 2001 for the activities described at paragraph 1, letter c); and Lire 5,000 million is authorised for each of the years 2001, 2002 and 2003 for realisation of the planning agreements described at paragraph 1, letter f), as well as for the subsequent planning agreements described at articles 12 and 13.

Art 5.

(Measures to protect the environment and landscape) Procedure for authorisation of construction and operation of transmission lines

1. In order to protect the environment and the landscape, by special regulation adopted within one hundred twenty days from the date on which the present law takes effect, in accordance with article 17, paragraph 2, of the Law 23 August 1988, n. 400, and article 29, paragraph 2, letter g) of legislative decree 31 March 1998, n. 112, at the proposal of the Ministers of Public Works and of Cultural Properties and Activities, upon the opinion of the Committee mentioned at article 6 and having consulted the competent parliamentary commissions, specific measures are adopted relating to the technical characteristics of installations and the location of routes for the design, construction, and modification of transmission lines and installations for mobile telephony and broadcasting. The same regulation indicates the particular measures likely to avoid damage to environmental and landscape values, and further specific measures may be adopted for the design, construction and modification of transmission lines in areas subject to constraints imposed by national and regional laws as well as by regional and urban planning instruments to protect historic, artistic, architectural, archaeological, landscape and environmental interests, without prejudice to the provisions of the consolidation act of legislative provisions regarding cultural and environmental properties, approved by legislative decree 29 October 1999, n. 490, and without prejudice to compliance with the aforesaid constraints and planning instruments.
2. By the same regulation described at paragraph 1, measures are adopted to contain the electrical risk of the installations described at the same paragraph 1, and in particular the risk of electrocution and avian collisions.
3. By the same regulation described at paragraph 1, a new regulation is defined for authorisation procedures for the construction and operation of power lines greater than 150 kV, so as to ensure

compliance with the principles of the present law, without prejudice to current provisions regarding environmental impact assessment. This latter regulation also conforms to the following criteria and principles:
a) simplification of administrative procedures;
b) identification of the types of infrastructure having less impact on the environment, the landscape and on citizen health;
c) coordination with the affected regions and local entities in the administrative procedures for defining routes;
d) identification of responsibilities and of monitoring and control procedures, e) adjustment of procedures relating to transmission-line easements and the relevant compensation;
f) advance evaluation of pre-existing electromagnetic fields.
4. The standards, including those of law, that govern the procedures described at paragraph 3, identified by the regulation described at the same paragraph, are abrogated with effect on the date on which the regulation takes effect.

Art 6.

(Interministerial committee for the prevention and reduction of electromagnetic pollution)

1. The Interministerial Committee for the Prevention and Reduction of Electromagnetic Pollution, hereinafter the "Committee," is established.
2. The Committee is presided over by the Minister of the Environment or by the delegated Undersecretary for the environment, and is composed of the ministers, or by the delegated undersecretaries of Health, Universities and Scientific and Technological Research, Public Works, Industry, Commerce and Handicrafts, Cultural Properties and Activities, Transport and Navigation, Communications, Defence, and the Interior.
3. The Committee carries out the activities described at articles 4, paragraph 1, letters b) and f), and 12, paragraph 2, and 13.
4. The Committee expresses the opinions described at articles 4, paragraph 2, letters a) and b), 4, paragraph 4, 5, paragraph 1, and 12, paragraph 1.
5. The Committee monitors the procedures prescribed by the present law and prepares an annual report to the Parliament on its activity.
6. The Committee avails itself of the freely rendered contributions of entities, agencies, institutions and organisations of a public nature having specific competences in the various areas of interest under the present law.

7. For the creation and operation of the Committee a maximum expenditure of Lire 1,000 million annually is authorised, beginning in 2001.

Art 7.

(National land registry)

1. The national land registry described at article 4, paragraph 1, letter c) is established within one hundred twenty days from the date on which the present law takes effect by the Minister of the Environment, having consulted the Minister of Health and the Minister of Industry, Trade and Handicrafts, as part of the informational and monitoring system described at article 8 of the Decree of the President of the Republic 4 June 1997, n. 335. The national land registry operates in coordination with the regional registries described at article 8, paragraph 1, letter d). The means of data input are defined by the Minister of the Environment, in concert with the Minister of Communications with regard to the input of data relating to fixed sources associated with radio-electric installations, systems and equipment for civil telecommunication uses, with the Minister of Public Works and with the Minister of Industry, Commerce and Handicrafts with regard to the input of data relating to transmission lines, with the Minister of Transport and Navigation with regard to the input of data relating to transport facilities, and with the Ministers of Defence and the Interior with regard to the input of data relating to fixed sources associated with installations, systems and equipment for military and police uses.

Art 8.

(Competences of the regions, provinces and municipalities)

1. The following, in compliance with exposure limits, caution values and quality objectives as well as the criteria and methods established by the State, without prejudice to the competences of the State and of independent authorities, are competences of the regions:

a) exercise of functions relating to the identification of transmission sites and installations for mobile telephony, of radio-electric installations and broadcasting installations, in accordance with Law 31 July 1997, n. 249, and in compliance with the decree described at article 4, paragraph 2, letter a), and with the principles established by the regulation described at article 5);

b) definition of the routes of transmission lines not exceeding 150 kV, with establishment of restricted zones according to the parameters set in accordance with article 4 and with the obligation to indicate them;

c) procedures for the issue of authorisations for the installation of the facilities described in the present article, in accordance with criteria of administrative simplification, taking into account pre-existing electrical, magnetic and electromagnetic fields;
d) the creation and management, in coordination with the national land registry described at article 4, paragraph 1, letter c), of a registry of fixed sources of electrical, magnetic and electromagnetic fields, in order to survey the levels of those fields regionally, with reference to population exposure conditions;
e) identification of instruments and actions to achieve the quality objectives described at article 3, paragraph 1, letter d), number 1);
f) contributing to increased scientific understanding of the effects on health, especially long-term, deriving from exposure to electrical, magnetic and electromagnetic fields.
2. In exercising the functions described at paragraph 1, letters a) and c), the regions following principles relating to the protection of the public health, environmental compatibility and the need to protect the environment and landscape.
3. In the event of noncompliance by the regions, article 5 of Legislative Decree 31 March 1998, n. 112, is applied.
4. In the areas described at paragraph 1, the regions define the competences of the provinces and municipalities, in compliance with the provisions of the Law 31 July 1997, n. 249.
5. The activities described at paragraph 1 regarding areas affected by military installations or those belonging to other State bodies having functions affecting public order and safety are defined through specific agreements by the joint equal committees described at article 3 of the Law 24 December 1976, n. 898, and subsequent modifications.
6. Municipalities may adopt a regulation to ensure proper urban and regional siting of installations and to minimise the population’s exposure to electromagnetic fields.

Art 9.

(Recovery plans)

1. Within twelve months of the date on which the decree described at article 4, paragraph 2, letter a) takes effect, the region, at the proposal of operators and having consulted the interested parties, adopts a recovery plan in order to upgrade gradually, and in any case within twenty-four months, those radio-electrical installations already existing to the exposure limits, caution values and quality objectives established according to the present law.   Twelve months after the date on

which the decree described at article 4, paragraph 2, letter a) takes effect, in the event of inaction or noncompliance by operators, the recovery plan is adopted by the regions, having consulted the municipalities and interested parties, within the following three months. The plan, implementation of which is monitored by the regions, may also call for the relocation of broadcasting installations to sites complying with planning in this area, and of other types of installations to suitable sites. The recovery is carried out with costs borne by the owners of the installations.

2. Within twelve months from the date on which the decree described at article 4, paragraph 4, takes effect, transmission-line operators present a proposed recovery plan in order to ensure protection of health and the environment. Owners of portions of the national grid, or those who in any case have access to it, are required to promptly provide to the national grid operator, within six months of the date on which the decree described at article 4, paragraph 2, letter a) takes effect, proposed measures for reorganising the lines under their jurisdiction, as well as all information necessary for aims of presentation of the proposed recovery plan. The plan must cover those projects which it is intended to carry out in order to comply with the exposure limits and caution values, and to achieve the quality objectives established by the decree described at article 4, paragraph 2, letter a). It must indicate a chronological implementation schedule, adapted to the priorities set forth in the aforementioned decree, considering in any case as priority situations those subject to the highest levels of electromagnetic pollution, in proximity to residential, school, and health-care buildings or in any case buildings used for stays of no less than four hours, with particular reference to protection of infant health.

Twelve months after the date on which the decree described at article 4, paragraph 2, letter a) takes effect, in the event of inaction or noncompliance by operators, the recovery plan described at the first point of paragraph 3 is proposed by the region within the following three months.

3. For transmission lines greater than 150 kV, the proposed recovery plan is presented to the Ministry of the Environment. The plan is approved, with any modifications, supplements and instructions, within sixty days, by the Minister of the Environment, in concert with the Ministers of Industry, Trade and Handicrafts and of Public Works, having consulted the Minister of Health and the regions and municipalities affected. For transmission lines less than 150 kV, the proposed recovery plan is presented to the region, which approves the plan, with any modifications, supplements and instructions, within sixty days, having consulted the municipalities affected. Twelve months after the date on which the decree described at article 4, paragraph 2, letter a) takes effect, in the event of inaction or noncompliance by operators, the

recovery plan for transmission lines greater than 150 kV is adopted by the region, within the period described at the third point of the present paragraph.

4. Recovery of the transmission lines must be completed within ten years from the date on which the present law takes effect.

Recovery of those transmission lines not complying with the limits described at article 4 and with the conditions described at article 5 of the decree of the president of the Council of Ministers 23 April 1992, published in the Official Gazette n. 104 of 6 May 1992, must be completed by 31 December 2004 and by 31 December 2008, respectively, in order to meet the exposure limits, caution values and quality objectives established according to article 4, paragraph 2, letter a) of the present law. Recovery is carried out with costs borne by the owners of the transmission lines, as defined according to Legislative Decree 16 March 1999, n. 79. The Electrical Energy and Gas Authority, in accordance with article 2, paragraph 12, of the Law 14 November 1995, n. 481, within sixty days of approval of the recovery plan, evaluates the costs directly associated with carrying out the reorganisaiton measures, as well as the criteria, terms and conditions for their eventual recovery.

5. For aims of granting subsidies to the regions for preparation of the recovery plans, creation of the regional land registries and monitoring and control activities, a maximum expenditure of Lire 2,000 million annually is authorised beginning in 2001. Sums deriving from application of the sanctions called for by article 15, paid into the State budget, are entirely reassigned by decree of the Minister of the Treasury, Budget and Economic Planing to special basic forecast units of the estimate of the Ministry of the Environment; based on the criteria set by the Joint Conference, these sums are assigned to subsidies granted to the regions to supplement the resources assigned to them according to the first point of the present paragraph, for aims of preparing the recovery plans, establishing the regional land registries, and carrying out monitoring and control activities.

6. Failure to reorganise the transmission lines, radio-electric stations and systems, mobile-telephony installations and broadcasting installations according to the plan's instructions, owing to inaction or noncompliance by the owners of the transmission lines or those who in any case have access to them, carries with it, without prejudice to the provisions of article 15, non-recognition by the national grid operator of the use fee for the unreorganised line and deactivation of the aforesaid installations for a period of up to six months, ensuring however the rights of users to the public-utility service. Deactivation is imposed:

a) by disposition of the Minister of the Environment in concert with the Minister of Industry, Commerce and Handicrafts, having consulted the Minister of Health and of Labour and Social Welfare, as well as the regions affected, for transmission lines greater than 150 kV;
b) by disposition of the chairman of the regional council for transmission lines less than 150 kV and radio-electrical systems, with the exclusion of mobile-telephony and broadcasting installations and fixed-telephony installations as well as radio-electrical stations for data transmission, deactivation of which is effected by disposition of the Minister of Communications, who ensures uniform application of the regulations throughout the country.
7. Within one hundred eighty days from the date on which the present law takes effect, an easily visible informational label must be affixed to each structure described at letters e), h) and l) of paragraph 1 of article 3, showing the voltage produced, the exposure limits and caution values prescribed by national and regional laws, and the restriction distances.

Art 10.

(Environmental education)

1. The Minister of the Environment, in concert with the Ministers of Health, of Universities and Scientific and Technological Research, and of Public Education, promotes environmental information and education campaigns according to the Law 8 July 1986, n. 349. To this end, expenditure of Lire 2,000 million annually is authorised beginning with 2001.

Art 11.

(Participation in the administrative procedure)

1. The provisions of Chapter III of the Law 7 August 1990, n. 241, and subsequent modifications regarding participation in the administrative procedure are applied to procedures for defining transmission-line routes as described at articles 4 and 8, as well as to procedures for adoption and approval of recovery plans as described at article 9, paragraph 2.

Art 12.

(Appliances for household, individual and work use)

1. By decree of the Minister of the Environment in concert with the Minister of Health, upon receiving the opinion of the Committee and having consulted the competent parliamentary commissions, within one hundred twenty days of the date on which the present law takes effect, and taking into account the European Union’s guidelines and acts regarding electromagnetic pollution, consumer protection and instructions for product use, the information which the manufacturers of appliances and devices, particularly of those for household, individual or work use, generating electrical, magnetic and electromagnetic fields, are required to provide to users and workers through special labels or informational materials, are established. This information

must cover, in particular, the exposure levels produced by the appliance or device, the recommended distance for use to reduce exposure to the electrical, magnetic and electromagnetic field, and the main safety instructions. This same decree identifies the types of appliances and devices for which there is no electrical, magnetic and electromagnetic field emission, or for which such emissions are to be considered so low as not to require any precaution.

2. The Committee promotes the concluding of accords and planning agreements with firms producing appliances for household, individual or work use that produce electrical, magnetic and electromagnetic fields, in order to promote and develop technologies that make it possible to minimise emissions.

Art 13.

(Planning agreements for public-transport services)

2. The Minister of the Environment, at the proposal of the Committee, promotes the conclusion of accords and planning agreements with operators of public-transport services that produce electrical, magnetic and electromagnetic fields, in order to promote and develop technologies that make it possible to minimise emissions.

Art 14.

(Controls)

1. In order to exercise health and environmental control and oversight functions for implementation of the present law, provincial and municipal governments utilise the offices of the regional environmental protection agencies, as described by the Decree-Law 4 December 1993, n. 496, converted with modifications by the Law 21 January 1994, n. 61. This is without prejudice to the oversight competences in work places attributed by current legislation.

2. In regions where regional environmental protection agencies are not yet operating, for the aims of paragraph 1 provincial and municipal governments make use of the technical support of the National Environmental Protection Agency, the PMP (multi-zone prevention facilities), the ISPESL (Higher Institute for Job Safety and Prevention), and the regional inspectors of the Communications Ministry, in compliance with the specific competences attributed by current legislation.

3. Monitoring inside the fixed or mobile installations used for the institutional activities of the armed forces, police and fire departments is governed by specific sectoral regulations. In particular, the provisions for the armed forces and police at articles 1, paragraph 2, and 23, paragraph 4, of the Legislative Decree 19 September 1994, n. 626, and subsequent modifications, remain in force.

4. Personnel responsible for said monitoring, in exercising their functions of oversight and control, may have access to installations that are sources of electromagnetic emissions and, in accordance with the provisions of the Law 7 August 1990, n. 241 and subsequent modifications, may request the data, information and documents necessary to perform their functions. These personnel bear an identifying document from the agency to which they belong.

Art 15.

(Sanctions)

1. Unless the act constitutes a crime, anyone who, in operating or using a source or installation that generates electrical, magnetic and electromagnetic fields, exceeds the exposure limits and caution values set forth in the decrees of the President of the Council of Ministers described at article 4, paragraph 2, and in the decrees described at article 16, is punished by administrative sanction to pay the sum of from Lire 2 million to Lire 600 million. The aforesaid sanction is applied as well to anyone who, during implementation of recovery plans, does not comply with the prescribed limits and deadlines.

2. Unless the act constitutes a crime, violation of the protective measures described at article 5, paragraph 1, is punished by administrative sanction to pay the sum of from Lire 2 million to Lire 200 million. In the event of recidivism, the penalty is doubled.

3. Unless the act constitutes a crime, the penalties described at paragraphs 1 and 2 are meted out by the competent authorities based on the investigations conducted by the authorities authorised to conduct the monitoring described at article 14. The authorities competent to inflict the penalties described at paragraphs 1 and 2 are identified by the decrees described at article 4, paragraph 2.

4. In the event of noncompliance with the prescriptions established, for aims of protecting the environment and health, by the authorisation, concession or licensing for the installation and operation of the installations regulated by the present law, a penalty of suspension of the aforesaid authorised acts is applied, of from two to four months. In the event of a second infraction, the authorising act is revoked.

5. The penalty described at paragraph 4 is applied by the authority competent on the basis of current legislation to issue the authorising act, based on inspections conducted by the authorities authorised to monitor.

6. Noncompliance with the decree described at article 12, paragraph 1, is punished by administrative sanction to payment of a sum of from Lire 2 million to Lire 600 million.

7. In reference to the penalties provided under the present article, the reduced payment described at article 16 of the Law 24 November 1981, n 698, and subsequent modifications, is not allowed.

Art 16.

(Interim regimen)

1. Until the date on which the decree of the President of the Council of Ministers described at article 4, paragraph 2) letter a) takes effect, the provisions of the decree of the President of the Council of Ministers 23 April 1992, published in the Official Gazette n. 104 of 6 May 1992, and subsequent modifications, the provisions of the decree of the president of the Council of Ministers 28 September 1995, published in the Official Gazette n. 232 of 4 October 1995, and the provisions of the decree of the Minister of the Environment 10 September 1998, n. 381, are applied insofar as they are compatible with the present law.

Art 17.

(Financial coverage)

The cost deriving from implementation of the present law, equal to Lire 20,000 million for each of the years 2001, 2002 and 2003, is provided for:

a) with regard to Lire 7,000 million beginning in 2001, by use of projections for those years of the appropriation entered for aims of the 2001-2003 three-year budget as part of the basic anticipatory unit, Special Fund current account, of the estimate of the Ministry of the Treasury, Budget and Economic Planning for the year 2001, partially utilising for this aim the allocation for the Environment Ministry;

b) with regard to Lire 13,000 million for each of the years 2001, 2002 and 2003, by use of projections for those years of the appropriation entered for aims of the 2001-2003 three-year budget as part of the basic anticipatory unit, Special Fund capital account, of the estimate of the Ministry of the Treasury, Budget and Economic Planning for the year 2001, partially utilising for this aim the allocation for the Environment Ministry.

2. The Minister of the Treasury, Budget and Economic Planning is authorised to make by his decree the necessary budget changes.

The present law, bearing the State seal, shall be inserted into the Official Record of regulatory acts of the Republic of Italy. Compliance and enforcement of compliance with it as a law of the State is mandatory for all.

Given in Rome, 22 February 2001

CIAMPI

Amato, President of the Council of Ministers

Bordon, Minister of the Environment

Approval by the Keeper of the Seals: Fassino

PREPARATORY WORKS

Chamber of Deputies (act n. 4816):

Presented by the Minister of the Environment (Ronchi) on 24 April 1998.

Assigned to the VIII commission (Environment), in reporting session, on 11 May 1998, with opinions from commissions I, II, IV, V, VII, IX, X, XI, and XII.

Examined by the VIII commission, in reporting session, on 11 and 18 February; 26 May: 9 July; 17 November;

9 December 1998; 27 January: 3, 17 and 24 February; 3 and 17 March; 21 and 28 April; and 26 May 1999.

Again assigned to the VIII commission (Environment), in drafting session, on 30 June 1999.

Examined by the VIII commission in drafting session on 30 June, 7, 14 and 21 July 1999; 22 and 28 September and 6 October, 1999.

Presentation of the text of the articles announced on 7 October 1999 (act. n. 4816-342-452-2095-4036-4464-4467-4487-4561-5212-5982-A/RED), Sen. Vigni reporting.

Examined on the floor and approved on 14 October 1999.

Senate of the Republic (act. n. 4273):

Assigned to the 13th commission (Territory), in deliberating session, on 27 October 1999, with opinions from commissions 1a, 2a, 4a, 5a, 7a, 8a, 10a, 11a, 12a, Board for European Community affairs and parliamentary commission for regional matters.

Examined by the 13th commission, in deliberating session, on 16 December 1999.

Again assigned to the 13th commission, in reporting session, on 16 December 1999.

Examined by the 13th commission in reporting session on 16 December 1999; 2, 9, 14, 15, 16 March; 5 April; 9, 10, 11, 23, 24, 30, 31 May; 1, 6, 7, 8, 14, 22, 27, 28 June; 5 and 6 July 2000.

Examined on the floor on 6 December 2000; 17, 18 and 23 January 2001, and approved with modifications on 24 January 2001.

Chamber of Deputies (act n. 4816-B):

Assigned to the VIII commission (Environment), in reporting session, on 29 January 2001, with opinions from commissions I, II, IV, V, VII, IX, X, XI, XII, XIV and parliamentary commission for regional matters.

Examined by the VIII commission on 30 January; 1, 6 and 7 February 2001.

Examined on the floor on 9 February 2001 and approved on 14 February 2001.

N O T ES:

Notice:

The text of the notes published here was prepared by the competent office, in accordance with art. 10, paragraph 3, of the consolidation act of provisions on the promulgation of laws and decrees of the President of the Republic and on official publications of the Republic of Italy, approved by Pr. D. 28 December 1985, n. 1092, for the sole aim of facilitating the reading of the provisions of law to which reference was made. The value and effectiveness of the legislative acts here transcribed remain unchanged.

Notes to art. 1:

- Art. 32 of the Constitution is as follows:

Art. 32 – The Republic protects health as a fundamental right of the individual and interest of society, and ensures free care for the indigent.

No one may be obligated to undergo a given health treatment except by provision of law. The law may in no case violate the limits imposed by respect for the human person."

- Paragraph 2 of art. 174 of the treaty establishing the European Union is as follows:

"2. The Community's policy in environmental matters aims at a high degree of protection, taking into account the diversity of situations in the various regions of the Community. The policy is founded on principles of precaution and preventive action, on the principal of priority correction at the source of damage caused to the environment, and on the principle of 'the polluter pays.'

In this context, harmonising measures meeting the needs of environmental protection include, in due cases, a safeguarding clause that authorises member states to take provisional measures, for environmental reasons of a non-economic nature, subject to a Community monitoring procedure."

Notes to art. 4:

- Art. 8 of the Legislative Decree 28 August 1997, n. 281, is as follows:

Art. 8 (State-city and local autonomy conference and Joint Conference). - 1. The State-City and local autonomy Conference is combined for matters and tasks of joint interest to the regions, provinces, municipalities and mountain communities, with the State-Region Conference.

The State-City and local autonomy Conference is presided over by the President of the Council of Ministers or, by his delegation, by the Minister of the Interior or by the Minister for Regional Affairs; the Minister of the Treasury, Budget and Economic Planning, the Minister of Finance, the Minister of Public Works, the Minister of Health, the president of the National Association of Italian Municipalities – ANCI, the president of the Italian Provinces Union – UPI, and the president of the National Union of Municipalities and Mountain Communities and Entities – UNCEM are also part of it. In addition, fourteen mayors designated by ANCI and six provincial presidents designated by UPI also belong to it.

Notes to art. 5:

- Art. 17, paragraph 2, of the Law 23 August 1998, n. 400, is as follows:

"2. By decree of the President of the Republic, after deliberation by the Council of Ministers, having consulted the State Council, regulations are issued to govern matters not covered by absolute reservation of law as provided by the Constitution, for which the laws of the Republic, authorising exercise of the government's regulatory powers, set general regulatory standards and provide for the abrogation of current legislation, taking effect when the regulatory standards take effect."

- Art. 29, paragraph 2, letter g) of the Legislative Decree 31 March 1998, n. 112, is as follows:

"2. Reserved for the State are, in addition, administrative functions concerning:

a)-f) (omission);

g) the construction and operation of installations for the production of electrical energy greater than 300 MW, except those producing energy from renewable sources and from waste in accordance with Legislative Decree 5 February 1997, n. 22, and transmission grids greater than 150 kV, the issue of technical standards relating to the construction of transmission lines, the issue of concessions for electrical operations of State competence, and other oil and gas pipeline networks of national interest."

- Legislative Decree 29 October 1999, n. 490, establishes:

"Consolidation act for legislative provisions in the area of cultural and environmental properties, in accordance with art. 1 1 of the Law 8 October 1997, n. 352".

Of the fourteen mayors designated by ANCI, five represent the cities identified by art. 17 of the Law 8 June 1990, n. 142. Other members of the government may be invited to the meetings, as well as representatives of State and local government offices and public entities.

3. The State-City and local autonomy Conference is convened every three months, and in any case whenever the president deems it necessary or should the president of ANCI, UPI or UNCEM so request.

4. The Joint Conference described at paragraph 1 is convened by the President of the Council of Ministers.
Meetings are chaired by the President of the Council of Ministers or, at his delegation, by the Minister for Regional Affairs or, if that office is not filled, by the Minister of the Interior.
- Legislative Decree 19 September 1994, n. 626, implementing the directives 89/391/CEE, 89/654/CEE, 89/655/CEE, 89/656/CEE, 90/269/CEE, 90/270/CEE, 90/394/CEE, 90/679/CEE, 93/88/CEE, 97/42/CE and 1999/38/CE regarding improvement of worker safety and health on the job, is published in the ordinary supplement to the Official Gazette n. 265 of 12 November 1994.
Note to art. 7:
- Art. 8 of the decree of the President of the Republic 4 June 1997, n. 335, is as follows:
"Art. 8 (Environmental information and monitoring system). - 1. The measures adopted in implementation of art. 18, par. 1, letter e) of the Law 11 March 1988, n. 67. relating to the environmental monitoring and information system (SINA) and the relevant technical endowments are transferred to ANPA in accordance with art. 1b, paragraph 4, of the Decree-Law 4 December 1993, n. 496, converted with modifications by the Law 21 January 1994, n. 61.
2. For recognition of the measures implemented or being implemented as part of the system described at paragraph 1, and of the relevant technical endowments to be transferred to ANPA, the Ministry of the Environment, within sixty days from the date on which the present regulation takes effect, adopts a decree that identifies:
a) the measures already taken by the Ministry of the Environment, with the relevant technical endowments;
b) the measures, with their relevant technical endowments, in any case aimed at the completion, strengthening or implementation of the environmental monitoring and information system still being realised or carried out by virtue of contracts, conventions, agreements and measures stipulated or adopted by the Ministry of the Environment;
c) the financial resources aimed at realising, strengthening, implementing or managing the SINA to be made available to ANPA;
d) the measures of the autonomous regions and provinces for completion and strengthening of the environmental monitoring and information system funded by the Ministry of the Environment, which funds are kept in the spending estimate of the Ministry pending their transfer to the parties responsible for the measures in accordance with the decision of the Interministerial Committee for Economic Planning 21 December 1993, and subsequent modifications and supplements.

3. The decree described at paragraph 2 also defines, after a functional check with ANPA, the technical and administrative methods for transfer and logistical relocation at ANPA of the measures and technical endowments described at paragraph 2, letters a) and b), and of the funding described at letter c), in order to ensure prompt resumption of the operational capabilities of the system transferred, which takes into account the informational situation at the Agency and the functional needs of the Ministry of the Environment, as well as methods for managing the transition period. In addition, the same decree defines the methods for coordinating the measures described at paragraph 2, letter d) necessary to ensure functional liaison with the SINA nationwide, in order to allow consistent maintenance of data flows between the principals of the measures and ANPA.
4. This decree is submitted to the Permanent Conference for relations between the State and the regions and autonomous provinces for aspects relating to the environmental monitoring and information systems of the regions and autonomous provinces, promoted and coordinated within the SINA and to the relevant funding.
5. The State's agencies, including those that are autonomous, as well as public, regional and local entities and joint-stock companies operating under an exclusive concession that in any case gather data in the environmental sector transmit the data to ANPA according to the specifications provided by ANPA in relation to the type of information, as well as the methods and frequencies to be used for effecting those exchanges.
6. The specifications may in particular involve the structure of the data, transmission frequency, and the transmission medium, normally via online network.
7. Integration with environmental data regarding the enterprise system is achieved according to the methods established in the planning agreement with Unioncamere described at art. 1, paragraph 6 of the Decree-Law 4 December 1993, n. 496, converted with modifications into the Law 21 January 1994, n. 61.
8. These activities are carried out in collaboration with the regional agencies and those of the autonomous provinces, including through those instruments prescribed at art. 10, paragraph 4. The diagrams for the technical specifications, including the levels of data aggregation and processing, are approved by the Minister of the Environment, having consulted the Permanent Conference for relations between the State and the regions and autonomous provinces.
9. Based on the decree described at paragraphs 2 and 3, ANPA draws up a schedule of activities that takes into account the measures adopted nationally and locally relating to information systems of environmental interest for the coordinated development and evolution of the environmental information system. This schedule is forwarded to the Ministry of the

Environment to be submitted for examination by the Permanent Conference for relations between the State and the regions and autonomous provinces for the relevant agreement."

Notes to art. 8:

- Law 31 July 1997, n. 249, authorising:

"Establishment of the Telecommunications Authority and standards on telecommunications and radio and television systems" is published in the Official Gazette n. 177 of 31 July 1997.

- Following is the text of art. 5 of the Legislative Decree 31 March 1998, n. 112:

"Art. 5 (Substitutive powers) – 1. With respect to the functions and tasks falling to the regions and local entities, in the event of proven inactivity that results in noncompliance with the obligations deriving from membership in the European Union or serious harm to national interests, the President of the Council of Ministers, at the proposal of the minister competent for that area, assigns an appropriate deadline to the noncompliant entity to perform.

2. If the deadline passes without effect, the Council of Ministers, after having consulted the noncompliant party, appoints a commissioner to act in its stead.

3. In cases of absolute urgency, the procedures described at paragraph 1 are not applied, and the Council of Ministers may adopt the measure described at paragraph 2, at the proposal of the President of the Council of Ministers and in concert with the competent minister. The measure thus adopted is immediately executed and immediately communicated to the Permanent Conference for relations between the State and the regions and autonomous provinces of Trento and Bolzano, hereinafter the "State-region Conference," and to the State-City and local autonomy Conference expanded to include the representatives of the mountain communities, who may seek reexamination, under the terms and for the aims envisioned by art. 8, paragraph 3, of the Law 15 March 1997, n. 59.

4. Provisions in the matter of substitutive powers provided by current legislation remain unchanged."

- Art. 3 of the Law 24 December 1976, n. 898, is as follows:

"Art. 3 – In each region, a mixed joint consultation committee is established to examine, including with alternative proposals from the region and the military authorities, problems associated with harmonisation among territorial and economic and social-development plans of the regions and sub-regions, and the programmes of military installations and consequent limitations.

In the Trentino-Alto Adige the regional committee is replaced by two provincial committees, one each for Trento and Bolzano.

Consequently any indication of the region, regional council and president of the regional board is intended to refer, for Trentino-Alto Adige, to the province, the provincial council and the president of the provincial board.
Should military-secrecy requirements make an in-depth examination impossible, the president of the regional board may ask the competent authority to authorise communication of the necessary information.
The committee is consulted every six months on all corps or unit firing exercise schedules in order to define the locations, regional air and sea spaces, time and means of the exercises, as well as use of firing ranges in the region. Should a majority of the members designated by the region be opposed, the Minister of Defence makes the final decision on training schedules.
Each committee, having consulted the local entities and interested bodies, defines the zones suitable for a concentration of firing exercises in the region for the creation of firing ranges, giving priority where possible to the use of State-owned land.
Once these military areas are established, firing exercises must be held for the most part within these areas. For training, land, sea and air areas both temporary and permanent, regulations for use are stipulated between the military authority and the region affected. In the absence of agreement, the regulatory project is referred to the Minister of Defence who decides, having consulted the competent president of the regional board and the president of the mixed joint committee.
The committee is formed of five representatives from the Ministry of Defence, one representative from the Treasury Ministry, one representative from the Finance Ministry, designated by their respective ministries, and of seven representatives of the region appointed by the president of the regional board, at the designation, with limited vote, of the regional council. For each member, an alternate is named.
The committee meets at the request of the regional military commander or the commander-in-chief of the navy department or the regional air force commander or the president of the region; the highest or most senior general or admiral presides; the lowest or least senior officer serves as secretary.
Minutes of committee meetings will be kept, which will keep track of proposals from members dissenting on the entire matter at hand or on specific points within it.
Final decisions on plans for military installations and related limitations as described at the first paragraph are reserved for the Minister of Defence. The affected region may, within fifteen days of publication or communication of the minister’s decision, ask the President of the Council of Ministers that the matter be submitted for reexamination by the Council of Ministers.

In particular cases, the President of the Council of Ministers may provide that ownership-limiting measures be suspended pending the decision of the Council of Ministers. The Council of Ministers issues its decision on the request for reexamination within ninety days.
The president of the regional board involved is invited to the meeting of the Council of Ministers."

Notes to art. 9:

- Art. 4 of the decree of the President of the Council of Ministers 23 April 1992 published in the Official Gazette n. 104 of 6 May 1992 is as follows:

"Art. 4 (Exposure limits and application criteria) - The following limits are set:
5 kV/m and 0.1 mT, respectively, for the intensity of the electrical field and the magnetic induction, in areas and environments where it may be reasonably expected that individuals will spend a significant part of the day;
10 kV/m and 1 mT, respectively, for the intensity of the electrical field and the magnetic induction, when the exposure is reasonably limited to a few hours a day.
The electrical-field values are referred to the undisturbed electrical field, this being understood as the electrical field measurable at a point in the absence of people, animals and things not fixed."

- Legislative Decree 16 March 1999, n. 79, setting:

"Implementation of the directive 96/1992/CE setting standards for the domestic electrical energy market" is published in the Official Gazette n. 75 of 31 March 1999.

- Art. 2, paragraph 12, of the Law 14 November 1995, n. 481, is as follows:

"12. In pursuing the goals set at art. 1, each authority performs the following functions:
a) formulates comments and proposals to be sent to the government and the parliament regarding services to be subjected to concession or authorisation and on the relevant market forms, within the limits of existing laws, proposing to the government the necessary legislative and regulatory modifications in relation to the technological dynamics, market conditions and evolution of Community law;
b) proposes to the competent ministers outlines for change and for possible variations in individual concession or authorisation acts and planning agreements and contracts;
c) checks that the conditions and means of access for operators providing the services, however established, are implemented in compliance with the principles of competition and transparency, including in reference to individual cost items, in order to establish the requirement that the service be provided under conditions of equality, so that all reasonable user needs are met, including those of the elderly and the disabled, ensuring respect for: the environment, installation safety, and worker health;

d) proposes modification of concession clauses and agreements, including those relating to exclusive operation, authorisations, current planning contracts and service conditions, where this is required by the market or by reasonable user demands, setting technical-economic conditions for access and interconnection to the grids, where called for by current legislation;

e) establishes and updates according to market trends the basic rate, parameters and other reference factors to determine the rates described at paragraphs 17, 18 and 19, and the means for recovering any costs incurred in the general interest so as to ensure the quality and efficiency of the service and adequate diffusion of same throughout the country, as well as the achievement of general objectives of a social nature, for environmental protection and efficient use of resources as described at paragraph 1 of art. 1, keeping separate from the rate any improper tax or charge; checks compliance with the criteria described at the present letter for proposals for updating rates presented annually and issues an opinion, having consulted any service providers, within ninety days from receiving the proposal; should the opinion not be issued within that time, the rates are understood to have been approved;

f) issues directives for accounting and administrative separation and checks the costs of individual services to ensure among other things that they are correctly broken down and attributed by function performed, by geographical area and by user category, separately showing costs resulting from universal supply of the service defined by the agreement, then comparing them with analogous costs in other countries and seeing to the publication of the data;

g) checks how the services are provided, with powers of inspection, access, acquisition of documentation and useful information, determining cases of automatic payment of compensation by service providers to users when the provider does not comply with contractual clauses or provides the service with qualitative levels lower than those established in the service rules as described at paragraph 37, in the planning contract or in accordance with letter h);

h) issues directives concerning the production and delivery of services by the service providers, in particular setting the general quality levels for the complex of services provided and specific quality levels referring to the individual service to be guaranteed to the user, having consulted the service providers and user and consumer representatives, possibly differentiating them by sector and type of service; these determinations produce the effects described at paragraph 37;

i) ensures the broadest possible communication of the service conditions; studies the evolution of the sector and of individual services, in order to modify technical, legal and economic conditions relating to delivery of the services; promotes measures aimed at improving means for delivery of the services; annually presents to the Parliament and to the President of the Council of Ministers a report on the state of the services and on the activity carried out;

l) publicises and disseminates awareness of the conditions for delivering services in order to ensure the maximum transparency, competition and chances for better choices by intermediate and final users;
m) evaluates claims, petitions and reports presented by users or consumers, individual or in groups, regarding compliance with quality and rate levels by service operators, with whom he intervenes to impose, where appropriate, modifications in the way they provide the service or revising the service regulations described at paragraph 37;
n) checks the consistency of the measures adopted by service operators in order to ensure equal treatment of users, ensure the continuity of the services, periodically check the quality and efficiency of the service, seeking for this aim user evaluations, ensure all information regarding delivery of the services and their quality levels, allow users and consumers the easiest possible access to offices open to the public, reduce the number of bureaucratic steps required of users by simplifying procedures for delivery of the service, and assure timely response to claims, petitions and reports regarding quality levels and rates;
o) proposes to the competent minister suspension or termination of the concession for those cases in which such measures are allowed by regulations;
p) checks that each service operator, based on the directive on principles for the delivery of public services of the President of the Council of Ministers of 27 January 1994, published in the Official Gazette n. 43 of 22 February 1994, adopts a public service charter, indicating the standards for individual services, and ensures that they are met."

Note to art. 10:

- Law 8 July 1986, n. 349, setting: "Establishment of the Ministry of the Environment and standards for environmental damage" is published in the ordinary supplement to the Official Gazette n. 162 of 15 July 1986.

Note to art. 11:

- Chapter III of the Law 7 August 1990, n. 241, sets:

"Participation in the administrative proceeding."

Notes to art. 14:

- Law 21 January 1994, n. 61, setting:

"Urgent provisions on recovery of environmental controls and establishment of the national environmental protection agency" is published in the Official Gazette n. 21 of 27 January 1994.

- Art. 1, paragraph 2, of the Legislative Decree 19 September 1994, n. 626, is as follows:

"2. In regard to the armed forces and the police and civil protection services, as well as within judicial and penitentiary structures and those intended for institutional aims to the activities of bodies responsible for public order and safety, universities, institutions of university education, educational institutions of every type and level, archives, libraries, museums and archaeological areas of the State, diplomatic and consular offices and air and sea transport means, the standards of the present decree are applied taking into account the special needs associated with the service provided, identified by decree of the competent minister in concert with the Ministers of Labour and Social Welfare, Health, and Public Office."

- Art. 23, paragraph 4, of the Legislative Decree 19 September 1994, n. 626, is as follows:

"4. Competences in matters of worker safety and health attributed by current provisions to air and sea health officers and maritime, port and airport authorities, and to health and technical services established for the armed forces and the police remain unchanged; the aforesaid services are also competent for reserved or operational areas and for those having similar needs, to be identified with regard to means of implementation by a decree of the competent minister in concert with the Ministers of Labour and Social Welfare and Health.

The administration of justice may avail itself of the services established for the armed forces and police, including through agreements with the respective ministries, and of services established with reference to penitentiary structures."

- Law 7 August 1990, n. 241, sets: "New standards regarding administrative proceedings and rights of access to administrative documents."

Note to art. 15:

- Following is the text of art. 16 of the Law 24 November 1981, n. 689 (Modifications to the penal system):

"Art. 16 (Reduced payment). - The payment of a reduced sum is acceptable, equal to one-third the maximum penalty set for the violation committed, or, if more favourable or if the minimum statutory penalty is established, equal to twice the relevant amount, plus costs of the proceeding, within thirty days of the immediate protest or, if no protest was made, from notification of the particulars of the violation.

In cases of violation of municipal and provincial regulations, art. 107 of the consolidation act for municipal and provincial laws approved by royal decree 3 March 1934, n. 383, continues to be applied.

Reduced payment is accepted even in cases in which the standards predating the effective date of the present law did not allow such payment."

Notes to art. 16:

- The decree of the President of the Council of Ministers 28 September 1995, setting "Technical and procedural standards for implementation of the decree of the President of the Council of

Ministers 23 April 1992, relating to transmission lines” is published in the Official Gazette n. 232 of 4 October 1995.

- The decree of the Minister of the Environment 10 September 1998, n. 381, setting: “Regulations setting standards for determining radio frequency ceilings compatible with human health” is published in the Official Gazette n. 257 of 3 November 1998.

GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC, AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz)

International Commission on Non-Ionizing Radiation Protection*†

INTRODUCTION

In 1974, the International Radiation Protection Association (IRPA) formed a working group on non-ionizing radiation (NIR), which examined the problems arising in the field of protection against the various types of NIR. At the IRPA Congress in Paris in 1977, this working group became the International Non-Ionizing Radiation Committee (INIRC).

In cooperation with the Environmental Health Division of the World Health Organization (WHO), the IRPA/INIRC developed a number of health criteria documents on NIR as part of WHO's Environmental Health Criteria Programme, sponsored by the United Nations Environment Programme (UNEP). Each document includes an overview of the physical characteristics, measurement and instrumentation, sources, and applications of NIR, a thorough review of the literature on biological effects, and an evaluation of the health risks of exposure to NIR. These health criteria have provided the scientific database for the subsequent development of exposure limits and codes of practice relating to NIR.

At the Eighth International Congress of the IRPA (Montreal, 18-22 May 1992), a new, independent scientific organization-the International Commission on Non-Ionizing Radiation Protection (ICNIRP)-was established as a successor to the IRPA/INIRC. The functions of the Commission are to investigate the hazards that may be associated with the different forms of NIR, develop international guidelines on NIR exposure limits, and deal with all aspects of NIR protection.

Biological effects reported as resulting from exposure to static and extremely-low-frequency (ELF) electric and magnetic fields have been reviewed by UNEP/WHO/IRPA (1984, 1987). Those publications and a number of others, including UNEP/WHO/IRPA (1993) and Allen et al. (199 1), provided the scientific rationale for these guidelines.

A glossary of terms appears in the Appendix.

PURPOSE AND SCOPE

The main objective of this publication is to establish guidelines for limiting EMF exposure that will provide protection against known adverse health effects. An adverse health effect causes detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

Studies on both direct and indirect effects of EMF are described; direct effects result from direct interaction of fields with the body, indirect effects involve interactions with an object at a different electric potential from the body. Results of laboratory and epidemiological studies, basic exposure criteria, and reference levels for practical hazard assessment are discussed, and the guidelines presented apply to occupational and public exposure.

Guidelines on high-frequency and 50/60 Hz electromagnetic fields were issued by IRPA/INIRC in 1988 and 1990, respectively, but are superseded by the present guidelines which cover the entire frequency range of time-varying EMF (up to 300 GHz). Static magnetic fields are covered in the ICNIRP guidelines issued in 1994 (ICNIRP 1994).

In establishing exposure limits, the Commission recognizes the need to reconcile a number of differing expert opinions. The validity of scientific reports has to be considered, and extrapolations from animal experi-

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ments to effects on humans have to be made. The restrictions in these guidelines were based on scientific data alone; currently available knowledge, however, indicates that these restrictions provide an adequate level of protection from exposure to time-varying EMF. Two classes of guidance are presented:

- Basic restrictions: Restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects are termed "basic restrictions." Depending upon the frequency of the field, the physical quantities used to specify these restrictions are current density (**J**), specific energy absorption rate (SAR), and power density (S). Only power density in air, outside the body, can be readily measured in exposed individuals.
- Reference levels: These levels are provided for practical exposure assessment purposes to determine whether the basic restrictions are likely to be exceeded. Some reference levels are derived from relevant basic restrictions using measurement and/or computational techniques, and some address perception and adverse indirect effects of exposure to EMF. The derived quantities are electric field strength (**E**), magnetic field strength (**H**), magnetic flux density (**B**), power density (S), and currents flowing through the limbs (I_L). Quantities that address perception and other indirect effects are contact current (I_C) and, for pulsed fields, specific energy absorption (SA). In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the reference level, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a reference level is exceeded it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary.

These guidelines do not directly address product performance standards, which are intended to limit EMF emissions under specified test conditions, nor does the document deal with the techniques used to measure any of the physical quantities that characterize electric, magnetic, and electromagnetic fields, Comprehensive descriptions of instrumentation and measurement techniques for accurately determining such physical quantities may be found elsewhere (NCRP 1981; IEEE 1992; NCRP 1993; DIN VDE 1995).

Compliance with the present guidelines may not necessarily preclude interference with, or effects on, medical devices such as metallic prostheses, cardiac pacemakers and defibrillators, and cochlear implants. Interference with pacemakers may occur at levels below the recommended reference levels. Advice on avoiding these problems is beyond the scope of the present document but is available elsewhere (UNEP/WHO/IRPA 1993).

These guidelines will be periodically revised and updated as advances are made in identifying the adverse health effects of time-varying electric, magnetic, and electromagnetic fields.

QUANTITIES AND UNITS

Whereas electric fields are associated only with the presence of electric charge, magnetic fields are the result of the physical movement of electric charge (electric current). An electric field, **E, exerts** forces on an electric charge and is expressed in volt per meter (V m^{-1}). Similarly, magnetic fields can exert physical forces on electric charges, but only when such charges are in motion. Electric and magnetic fields have both magnitude and direction (i.e., they are vectors). A magnetic field can be specified in two ways-as magnetic flux density, **B,** expressed in tesla (T), or as magnetic field strength, **H,** expressed in ampere per meter (A m^{-1}). The two quantities are related by the expression:

$$\mathbf{B} = \mu \mathbf{H}, \quad (1)$$

where μ is the constant of proportionality (the magnetic permeability); in a vacuum and in air, as well as in non-magnetic (including biological) materials, μ has the value $4\pi \times 10^{-7}$ when expressed in henry per meter (H m^{-1}). Thus, in describing a magnetic field for protection purposes, only one of the quantities **B** or **H** needs to be specified.

In the far-field region, the plane-wave model is a good approximation of the electromagnetic field propagation. The characteristics of a plane wave are:

- The wave fronts have a planar geometry;
- The **E** and **H** vectors and the direction of propagation are mutually perpendicular;
- The phase of the **E** and **H** fields is the same, and the quotient of the amplitude of E/H is constant throughout space. In free space, the ratio of their amplitudes E/H = 377 ohm, which is the characteristic impedance of free space;
- Power density, S, i.e., the power per unit area normal to the direction of propagation, is related to the electric and magnetic fields by the expression:

$$S = \mathbf{EH} = E^2/377 = 377H^2. \quad (2)$$

The situation in the near-field region is rather more complicated because the maxima and minima of E and H fields do not occur at the same points along the direction of propagation as they do in the far field. In the near field, the electromagnetic field structure may be highly inhomogeneous, and there may be substantial variations from the plane-wave impedance of 377 ohms; that is, there may be almost pure E fields in some regions and almost pure H fields in others. Exposures in the near field are

Table 1. Electric, magnetic, electromagnetic, and dosimetric quantities and corresponding SI units.

Quantity	Symbol	Unit
Conductivity	σ	siemens per meter (S m^{-1})
Current	I	ampere (A)
Current density	**J**	ampere per square meter (A m^{-2})
Frequency	f	hertz (Hz)
Electric field strength	**E**	volt per meter (V m^{-1})
Magnetic field strength	**H**	ampere per meter (A m^{-1})
Magnetic flux density	**B**	tesla (T)
Magnetic permeability	μ	henry per meter (H m^{-1})
Permittivity		farad per meter (F m^{-1})
Power density	S	watt per square meter (W m^{-2})
Specific energy absorption	SA	joule per kilogram (J kg^{-1})
Specific energy absorption rate	SAR	watt per kilogram (W kg^{-1})

more difficult to specify, because both E and H fields must be measured and because the field patterns are morecomplicated; in this situation, power density is no longer an appropriate quantity to use in expressing exposure restrictions (as in the far field).

Exposure to time-varying EMF results in internal body currents and energy absorption in tissues that depend on the coupling mechanisms and the frequency involved. The internal electric field and current density are related by Ohm's Law:

$$\mathbf{J} = \sigma \mathbf{E}, \quad (3)$$

where σ is the electrical conductivity of the medium. The dosimetric quantities used in these guidelines, taking into account different frequency ranges and waveforms, are as follows:

- Current density, **J,** in the frequency range up to 10 MHz;
- Current, ***I,*** in the frequency range up to 110 MHz;
- Specific energy absorption rate, SAR, in the frequency range 100 kHz–10 GHz;
- Specific energy absorption, SA, for pulsed fields in the frequency range 300 MHz-10 GHz; and
- Power density, S, in the frequency range 10–300 GHz.

A general summary of EMF and dosimetric quantities and units used in these guidelines is provided in Table 1.

BASIS FOR LIMITING EXPOSURE

These guidelines for limiting exposure have been developed following a thorough review of all published scientific literature. The criteria applied in the course of the review were designed to evaluate the credibility of the various reported findings (Repacholi and Stolwijk 1991; Repacholi and Cardis 1997); only established effects were used as the basis for the proposed exposure restrictions. Induction of cancer from long-term EMF exposure was not considered to be established, and so these guidelines are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and elevated tissue temperatures resulting from absorption of energy during exposure to EMF. In the case of potential long-term effects of exposure, such as an increased risk of cancer, ICNIRP concluded that available data are insufficient to provide a basis for setting exposure restrictions, although epidemiological research has provided suggestive, but unconvincing, evidence of an association between possible carcinogenic effects and exposure at levels of 50/60 Hz magnetic flux densities substantially lower than those recommended in these guidelines.

In-vitro effects of short-term exposure to ELF or ELF amplitude-modulated EMF are summarized. Transient cellular and tissue responses to EMF exposure have been observed, but with no clear exposure-response relationship. These studies are of limited value in the assessment of health effects because many of the responses have not been demonstrated *in vivo.* Thus, *in-vitro* studies alone were not deemed to provide data that could serve as a primary basis for assessing possible health effects of EMF.

COUPLING MECHANISMS BETWEEN FIELDS AND THE BODY

There are three established basic coupling mechanisms through which time-varying electric and magnetic fields interact directly with living matter (UNEP/WHO/IRPA 1993):

- coupling to low-frequency electric fields;
- coupling to low-frequency magnetic fields; and
- absorption of energy from electromagnetic fields.

Coupling to low-frequency electric fields

The interaction of time-varying electric fields with the human body results in the flow of electric charges (electric current), the polarization of bound charge (formation of electric dipoles), and the reorientation of electric dipoles already present in tissue. The relative magnitudes of these different effects depend on the electrical properties of the body-that is, electrical conductivity (governing the flow of electric current) and permittivity (governing the magnitude of polarization effects). Electrical conductivity and permittivity vary with the type of body tissue and also depend on the frequency of the applied field. Electric fields external to the body induce a surface charge on the body; this results in induced currents in the body, the distribution of which depends on exposure conditions, on the size and shape of the body, and on the body's position in the field.

Coupling to low-frequency magnetic fields

The physical interaction of time-varying magnetic fields with the human body results in induced electric fields and circulating electric currents. The magnitudes of the induced field and the current density are proportional to the radius of the loop, the electrical conductivity of the tissue, and the rate of change and magnitude of the magnetic flux density. For a given magnitude and frequency of magnetic field, the strongest electric fields are induced where the loop dimensions are greatest. The exact path and magnitude of the resulting current induced in any part of the body will depend on the electrical conductivity of the tissue.

The body is not electrically homogeneous; however, induced current densities can be calculated using anatomically and electrically realistic models of the body and computational methods, which have a high degree of anatomical resolution.

Absorption of energy from electromagnetic fields

Exposure to low-frequency electric and magnetic fields normally results in negligible energy absorption and no measurable temperature rise in the body. However, exposure to electromagnetic fields at frequencies above about 100 kHz can lead to significant absorption of energy and temperature increases. In general, exposure to a uniform (plane-wave) electromagnetic field results in a highly non-uniform deposition and distribution of energy within the body, which must be assessed by dosimetric measurement and calculation.

As regards absorption of energy by the human body, electromagnetic fields can be divided into four ranges (Durney et al. 1985):

- frequencies from about 100 kHz to less than about 20 MHz, at which absorption in the trunk decreases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs;
- frequencies in the range from about 20 MHz to 300 MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g., head) resonances are considered;
- frequencies in the range from about 300 MHz to several GHz, at which significant local, non-uniform absorption occurs; and
- frequencies above about 10 GHz, at which energy absorption occurs primarily at the body surface.

In tissue, SAR is proportional to the square of the internal electric field strength, Average SAR and SAR distribution can be computed or estimated from laboratory measurements. Values of SAR depend on the following factors:

- the incident field parameters, i.e., the frequency, intensity, polarization, and source- object configuration (near- or far-field);
- the characteristics of the exposed body, i.e., its size and internal and external geometry, and the dielectric properties of the various tissues; and
- ground effects and reflector effects of other objects in the field near the exposed body.

When the long axis of the human body is parallel to the electric field vector, and under plane-wave exposure conditions (i.e., far-field exposure), whole-body SAR reaches maximal values. The amount of energy absorbed depends on a number of factors, including the size of the exposed body. "Standard Reference Man" (ICRP1994), if not grounded, has a resonant absorption frequency close to 70 MHz. For taller individuals the resonant absorption frequency is somewhat lower, and for shorter adults, children, babies, and seated individuals it may exceed 100 MHz. The values of electric field reference levels are based on the frequency-dependence of human absorption; in grounded individuals, resonant frequencies are lower by a factor of about 2 (UNEP/WHO/IRPA 1993).

For some devices that operate at frequencies above 10 MHz (e.g., dielectric heaters, mobile telephones), human exposure can occur under near-field conditions. The frequency-dependence of energy absorption under these conditions is very different from that described for far-field conditions. Magnetic fields may dominate for certain devices, such as mobile telephones, under certain exposure conditions.

The usefulness of numerical modeling calculations, as well as measurements of induced body current and tissue field strength, for assessment of near-field exposures has been demonstrated for mobile telephones, walkie-talkies, broadcast towers, shipboard communication sources, and dielectric heaters (Kuster and Balzano 1992; Dimbylow and Mann 1994; Jokela et al. 1994; Gandhi 1995; Tofani et al, 1995). The importance of these studies lies in their having shown that near-field exposure can result in high local SAR (e.g., in the head, wrists, ankles) and that whole-body and local SAR are strongly dependent on the separation distance between the high-frequency source and the body. Finally, SAR data obtained by measurement are consistent with data obtained from numerical modeling calculations. Whole-body average SAR and local SAR are convenient quantities for comparing effects observed under various exposure conditions. A detailed discussion of SAR can be found elsewhere (UNEP/WHO/IRPA 1993).

At frequencies greater than about 10 GHz, the depth of penetration of the field into tissues is small, and SAR is not a good measure for assessing absorbed energy; the incident power density of the field (in $W m^{-2}$) is a more appropriate dosimetric quantity.

INDIRECT COUPLING MECHANISMS

There are two indirect coupling mechanisms:

- contact currents that result when the human body comes into contact with an object at a different electric potential (i.e., when either the body or the object is charged by an EMF); and
- coupling of EMF to medical devices worn by, or implanted in, an individual (not considered in this document).

The charging of a conducting object by EMF causes electric currents to pass through the human body in. contact with that object (Tenforde and Kaune 1987; UNEP/WHO/IRPA 1993). The magnitude and spatial distribution of such currents depend on frequency, the size of the object, the size of the person, and the area of contact; transient discharges-sparks-can occur when an individual and a conducting object exposed to a strong field come into close proximity.

BIOLOGICAL BASIS FOR LIMITING EXPOSURE (UP TO 100 KHZ)

The following paragraphs provide a general review of relevant literature on the biological and health effects of electric and magnetic fields with frequency ranges up to 100 kHz, in which the major mechanism of interaction is induction of currents in tissues. For the frequency range >0 to 1 Hz, the biological basis for the basic restrictions and reference levels are provided in ICNIRP (1994). More detailed reviews are available elsewhere (NRPB 1991, 1993; UNEP/WHO/IRPA 1993; Blank 1995; NAS 1996; Polk and Postow 1996; Ueno 1996).

Direct effects of electric and magnetic fields

Epidemiological studies. There have been many reviews of epidemiological studies of cancer risk in relation to exposure to power-frequency fields (NRPB 1992, 1993, 1994b; ORAU 1992; Savitz 1993; Heath 1996; Stevens and Davis 1996; Tenforde 1996; NAS 1996). Similar reviews have been published on the risk of adverse reproductive outcomes associated with exposure to EMF (Chernoff et al. 1992; Brent et al. 1993; Shaw and Croen 1993; NAS 1996; Tenforde 1996).

Reproductive outcome. Epidemiological studies on pregnancy outcomes have provided no consistent evidence of adverse reproductive effects in women working with visual display units (VDUs) (Bergqvist 1993; Shaw and Croen 1993; NRPB 1994a; Tenforde 1996). For example, meta-analysis revealed no excess risk of spontaneous abortion or malformation in combined studies comparing pregnant women using VDUs with women not using VDUs (Shaw and Croen 1993). Two other studies concentrated on actual measurements of the electric and magnetic fields emitted by VDUs; one reported a suggestion of an association between ELF magnetic fields and miscarriage (Lindbohm et al. 1992), while the other found no such association (Schnorr et al. 1991). A prospective study that included large numbers of cases, had high participation rates, and detailed exposure assessment (Bracken et al. 1995) reported that neither birth weight nor intra-uterine growth rate was related to any ELF field exposure. Adverse outcomes were not associated with higher levels of exposure. Exposure measurements included current-carrying capacity of power lines outside homes, 7-d personal exposure measurements, 24-h measurements in the home, and self-reported use of electric blankets, heated water beds, and VDUs. Most currently available information fails to support an association between occupational exposure to VDUs and harmful reproductive effects (NRPB 1994a; Tenforde 1996).

Residential cancer studies. Considerable controversy surrounds the possibility of a link between exposure to ELF magnetic fields and an elevated risk of cancer. Several reports on this topic have appeared since Wertheimer and Leeper reported (1979) an association between childhood cancer mortality and proximity of homes to power distribution lines with what the researchers classified as *high current configuration.* The basic hypothesis that emerged from the original study was that the contribution to the ambient residential 50/60 Hz magnetic fields from external sources such as power lines could be linked to an increased risk of cancer in childhood.

To date there have been more than a dozen studies on childhood cancer and exposure to power-frequency magnetic fields in the home produced by nearby power lines. These studies estimated the magnetic field exposure from short term measurements or on the basis of distance between the home and power line and, in most cases, the configuration of the line; some studies also took the load of the line into account. The findings relating to leukemia are the most consistent. Out of 13 studies (Wertheimer and Leeper 1979; Fulton et al. 1980; Myers et al. 1985; Tomenius 1986; Savitz et al. 1988; Coleman et al. 1989; London et al. 1991; Feychting and Ahlbom 1993; Olsen et al. 1993; Verkasalo et al. 1993; Michaelis et al. 1997; Linet et al. 1997; Tynes and Haldorsen 1997), all but five reported relative risk estimates of between 1.5 and 3.0.

Both direct magnetic field measurements and estimates based on neighboring power lines are crude proxy measures for the exposure that took place at various times before cases of leukemia were diagnosed, and it is not clear which of the two methods provides the more valid estimate. Although results suggest that indeed the magnetic field may play a role in the association with leukemia risk, there is uncertainty because of small sample numbers and because of a correlation between the magnetic field and proximity to power lines (Feychting et al. 1996).

Little is known about the etiology of most types of childhood cancer, but several attempts to control for potential confounders such as socioeconomic status and air pollution from motor vehicle exhaust fumes have had little effect on results. Studies that have examined the use of electrical appliances (primarily electric blankets) in relation to cancer and other health problems have reported generally negative results (Preston-Martin et al. 1988; Verreault et al. 1990; Vena et al. 1991, 1994; Li et al. 1995). Only two case-control studies have evaluated use of appliances in relation to the risk of childhood leukemia. One was conducted in Denver (Savitz et al. 1990) and suggested a link with prenatal use of electric blankets; the other, carried out in Los Angeles (London et al. 1991), found an association between leukemia and children using hair dryers and watching monochrome television.

The fact that results for leukemia based on proximity of homes to power lines are relatively consistent led the U.S. National Academy of Sciences Committee to conclude that children living near power lines appear to be at increased risk of leukemia (NAS 1996). Because of small numbers, confidence intervals in the individual studies are wide; when taken together, however, the results are consistent, with a pooled relative risk of 1.5 (NAS 1996). In contrast, short-term measurements of magnetic field in some of the studies provided no evidence of an association between exposure to 50/60 Hz fields and the risk of leukemia or any other form of cancer in children. The Committee was not convinced that this increase in risk was explained by exposure to magnetic fields, since there was no apparent association when exposure was estimated from magnetic field meter readings in the homes of both leukemia cases and controls. It was suggested that confounding by some unknown risk factor for childhood leukemia, associated with residence in the vicinity of power lines, might be the explanation, but no likely candidates were postulated.

After the NAS committee completed its review, the results of a study performed in Norway were reported (Tynes and Haldorsen 1997). This study included 500 cases of all types of childhood cancer. Each individual's exposure was estimated by calculation of the magnetic field level produced in the residence by nearby transmission lines, estimated by averaging over an entire year. No association between leukemia risk and magnetic fields for the residence at time of diagnosis was observed. Distance from the power line, exposure during the first year of life, mothers' exposure at time of conception, and exposure higher than the median level of the controls showed no association with leukemia, brain cancer, or lymphoma. However, the number of exposed cases was small.

Also, a study performed in Germany has been reported after the completion of the NAS review (Michaelis et al. 1997). This was a case-control study on childhood leukemia based on 129 cases and 328 controls. Exposure assessment comprised measurements of the magnetic field over 24 h in the child's bedroom at the residence where the child had been living for the longest period before the date of diagnosis. An elevated relative risk of 3.2 was observed for $>0.2\ \mu T$.

A large U.S. case-control study (638 cases and 620 controls) to test whether childhood acute lymphoblastic leukemia is associated with exposure to 60-Hz magnetic fields was published by Linet et al. (1997). Magnetic field exposures were determined using 24-h time-weighted average measurements in the bedroom and 30-s measurements in various other rooms. Measurements were taken in homes in which the child had lived for 70% of the 5 y prior to the year of diagnosis, or the corresponding period for the controls. Wire-codes were assessed for residentially stable case-control pairs in which both had not changed their residence during the years prior to diagnosis. The number of such pairs for which assessment could be made was 416. There was no indication of an association between wire-code category and leukemia. As for magnetic field measurements, the results are more intriguing. For the cut off point of 0.2 μT the unmatched and matched analyses gave relative risks of 1.2 and 1.5, respectively. For a cut off point of 0.3 μT, the unmatched relative risk estimate is 1.7 based on 45 exposed cases. Thus, the measurement results are suggestive of a positive association between magnetic fields and leukemia risk. This study is a major contribution in terms of its size, the number of subjects in high exposure categories, timing of measurements relative to the occurrence of the leukemia (usually within 24 mo after diagnosis), other measures used to obtain exposure data, and quality of analysis allowing for multiple potential confounders. Potential weaknesses include the procedure for control selection, the participation rates, and the methods used for statistical analysis of the data. The instruments used for measurements took no account of transient fields or higher order harmonics. The size of this study is such that its results, combined with those of other studies, would significantly weaken (though not necessarily invalidate) the previously observed association with wire code results.

Over the years there also has been substantial interest in whether there is an association between magnetic field exposure and childhood brain cancer, the second most frequent type of cancer found in children. Three recent studies completed after the NAS Committee's review fail to provide support for an association between brain cancer and children's exposure to magnetic fields, whether the source was power lines or electric blankets, or whether magnetic fields were estimated by calculations or by wire codes (Guénel et al. 1996; Preston-Martin et al. 1996a, b; Tynes and Haldorsen 1997).

Data on cancer in adults and residential magnetic field exposure are sparse (NAS 1996). The few studies published to date (Wertheimer and Leeper 1979; McDowall 1985; Seversen et al. 1988; Coleman et al. 1989; Schreiber et al. 1993; Feychting and Ahlbom 1994; Li et al. 1996; Verkasalo 1996; Verkasalo et al. 1996) all suffer to some extent from small numbers of exposed cases, and no conclusions can be drawn.

It is the view of the ICNIRP that the results from the epidemiological research on EMF field exposure and cancer, including childhood leukemia, are not strong enough in the absence of support from experimental research to form a scientific basis for setting exposure guidelines. This assessment is also in agreement with recent reviews (NRPB 1992, 1994b; NAS 1996; CRP 1997).

Occupational studies. A large number of epidemiological studies have been carried out to assess possible links between exposure to ELF fields and cancer risk among workers in electrical occupations. The first study of this type (Milham 1982) took advantage of a death certificate database that included both job titles and information on cancer mortality. As a crude method of assessing exposure, Milham classified job titles accord: ing to presumed magnetic field exposure and found an excess risk for leukemia among electrical workers. Subsequent studies (Savitz and Ahlbom 1994) made use of similar databases; the types of cancer for which elevated rates were noted varied across studies, particularly when cancer subtypes were characterized. Increased risks of various types of leukemia and nervous tissue tumors, and, in a few instances, of both male and female breast cancer, were reported (Demers et al. 199 1; Matanoski et al. 1991; Tynes et al. 1992; Loomis et al. 1994). Aswell as producing somewhat inconsistent results, these studies suffered from very crude exposure assessment and from failure to control for confounding factors such as exposure to benzene solvent in the workplace.

Three recent studies have attempted to overcome some of the deficiencies in earlier work by measuring ELF field exposure at the workplace and by taking duration of work into consideration (Floderus et al. 1993; Theriault et al. 1994; Savitz and Loomis 1995). An elevated cancer risk among exposed individuals was observed, but the type of cancer of which this was true varied from study to study. Floderus et al. (1993) found a significant association with leukemia; an association was also noted by Theriault et al.(1994), but one that was weak and not significant, and no link was observed by Savitz and Loomis (1995). For subtypes of leukemia there was even greater inconsistency, but numbers in the analyses were small. For tumors of nervous tissue, Floderus et al. (1993) found an excess for glioblastoma (astrocytoma III-IV), while both Theriault et al. (1994) and Savitz and Loomis (1995) found only suggestive evidence for an increase in glioma (astrocytoma I-II). If there is truly a link between occupational exposure to magnetic fields and cancer, greater consistency and stronger associations would be expected of these recent studies based on more sophisticated exposure data.

Researchers have also investigated the possibility that ELF electric fields could be linked to cancer. The three utilities that participated in the Theriault et al. (1994) study of magnetic fields analyzed electric field data as well. Workers with leukemia at one of the utilities were reported to be more likely to have been exposed to electric fields than were control workers. In addition, the association was stronger in a group that had been exposed to high electric and magnetic fields combined (Miller et al. 1996). At the second utility, investigators reported no association between leukemia and higher cumulative exposure to workplace electric fields, but some of the analyses showed an association with brain cancer (Guénel et al. 1996). An association with colon cancer was also reported, yet in other studies of large populations of electric utility workers this type of cancer has not been found. At the third utility, no association between high electric fields and brain cancer or leukemia was observed, but this study was smaller and less likely to have detected small changes, if present (Baris et al. 1996).

An association between Alzheimer's disease and occupational exposure to magnetic fields has recently been suggested (Sobel and Davanipour 1996). However, this effect has not been confirmed.

Laboratory studies. The following paragraphs provide a summary and critical evaluation of laboratory studies on the biological effects of electric and magnetic fields with frequencies below 100 kHz. There are separate discussions on results obtained in studies of volunteers exposed under controlled conditions and in laboratory studies on cellular, tissue, and animal systems.

Volunteer studies. Exposure to a time-varying electric field can result in perception of the field as a result of the alternating electric charge induced on the body surface, which causes the body hairs to vibrate. Several studies have shown that the majority of people can perceive 50/60 Hz electric fields stronger than 20 kV m^{-1}, and that a small minority can perceive fields below 5 kV m^{-1} (UNEP/WHO/IRPA 1984; Tenforde 1991).

Small changes in cardiac function occurred in human volunteers exposed to combined 60-Hz electric and magnetic fields (9 kV m^{-1}, 20 μT) (Cook et al. 1992; Graham et al. 1994). Resting heart rate was slightly, but significantly, reduced (by 3-5 beats per minute) during or immediately after exposure. This response was absent on exposure to stronger (12 kV m^{-1}, 30 μT) or weaker (6 kV m^{-1}, 10 μT) fields and reduced if the subject was mentally alert. None of the subjects in these studies was able to detect the presence of the fields, and there were no other consistent results in a wide battery of sensory and perceptual tests.

No adverse physiological or psychological effects were observed in laboratory studies of people exposed to 50-kHz fields in the range 2-5 mT (Sander et al. 1982; Ruppe et al. 1995). There were no observed changes in blood chemistry, blood cell counts, blood gases, lactate levels, electrocardiogram, electroencephalogram, skin temperature, or circulating hormone levels in studies by Sander et al. (1982) and Graham et al. (1994). Recent studies on volunteers have also failed to show any effect of exposure to 60-Hz magnetic fields on the nocturnal melatonin level in blood (Graham et al. 1996, 1997; Selmaoui et al. 1996).

Sufficiently intense ELF magnetic fields can elicit peripheral nerve and muscle tissue stimulation directly, and short magnetic field pulses have been used clinically to stimulate nerves in the limbs in order to check the integrity of neural pathways. Peripheral nerve and muscle stimulation has also been reported in volunteers exposed to 1-kHz gradient magnetic fields in experimental magnetic resonance imaging systems. Threshold magnetic flux densities were several millitesla, and corresponding induced current densities in the peripheral tissues were about 1 A m^{-2} from pulsed fields produced by rapidly switched gradients. Time-varying magnetic fields that induce current densities above 1 A m^{-2} in tissue lead to neural excitation and are capable of producing irreversible biological effects such as cardiac fibrillation (Tenforde and Kaune 1987; Reilly 1989). In a study involving electromyographic recordings from the human arm (Polson et al. 1982), it was found that a pulsed field with dB/dt greater than 10^4 T s^{-1} was needed to stimulate the median nerve trunk. The duration of the magnetic stimulus has also been found to be an important parameter in stimulation of excitable tissues.

Thresholds lower than 100 mA m^{-2} can be derived from studies of visual and mental functions in human volunteers. Changes in response latency for complex reasoning tests have been reported in volunteers subjected to weak power-frequency electric currents passed through electrodes attached to the head and shoulders; current densities were estimated to lie between 10 and 40 mA m^{-2} (Stollery 1986, 1987). Finally, many studies have reported that volunteers experienced faint flickering visual sensations, known as magnetic phosphenes, during exposure to ELF magnetic fields above 3–5 mT (Silny 1986). These visual effects can also be induced by the direct application of weak electric currents to the head. At 20 Hz, current densities of about 10 mA m^{-2} in the retina have been estimated as the threshold for induction of phosphenes, which is above the typical endogenous current densities in electrically excitable tissues. Higher thresholds have been observed for both lower and higher frequencies (Lövsund et al. 1980; Tenforde 1990).

Studies have been conducted at 50 Hz on visually evoked potentials that exhibited thresholds for effects at flux densities of 60 mT (Silny 1986). Consistent with this result, no effects on visually evoked potentials were obtained by either Sander et al. (1982), using a 50-Hz, 5-mT field, or Graham et al. (1994), using combined 60-Hz electric and magnetic fields up to 12 kV m^{-1} and 30 μT, respectively.

Cellular and animal studies. Despite the large number of studies undertaken to detect biological effects of ELF electric and magnetic fields, few systematic studies have defined the threshold field characteristics that produce significant perturbations of biological functions. It is well established that induced electric current can stimulate nerve and muscle tissue directly once the induced current density exceeds threshold values (UNEP/WHO/IRPA 1987; Bernhardt 1992; Tenforde 1996). Current densities that are unable to stimulate excitable tissues directly may nevertheless affect ongoing electrical activity and influence neuronal excitability. The activity of the central nervous system is known to be sensitive to the endogenous electric fields generated by the action of adjacent nerve cells, at levels below those required for direct stimulation.

Many studies have suggested that the transduction of weak electrical signals in the ELF range involves interactions with the cell membrane, leading to cytoplasmic biochemical responses that in turn involve changes in cellular functional and proliferative states. From simple models of the behavior of single cells in weak fields it has been calculated that an electrical signal in the extracellular field must be greater than approximately 10–100 mV m^{-1} (corresponding to an induced current density of about 2-20 mA m^{-2}) in order to exceed the level of endogenous physical and biological noise in cellular membranes (Astumian et al. 1995). Existing evidence also suggests that several structural and functional properties of membranes may be altered in response to induced ELF fields at or below 100 mV m^{-1} (Sienkiewicz et al. 1991; Tenforde 1993). Neuroendocrine alterations (e.g., suppression of nocturnal melatonin synthesis) have been reported in response to induced electrical fields of 10 mV m^{-1} or less, corresponding to induced current densities of approximately 2 mA m^{-} or less (Tenforde 1991, 1996). However, there is no clear evidence that these biological interactions of low-frequency fields lead to adverse health effects.

Induced electric fields and currents at levels exceeding those of endogenous bioelectric signals present in tissue have been shown to cause a number of physiological effects that increase in severity as the induced current density is increased (Bernhardt 1979; Tenforde 1996). In the current density range 10–100 mA m^{-2}, tissue effects and changes in brain cognitive functions have been reported (NRPB 1992; NAS 1996). When induced current density exceeds 100 to several hundred mA m^{-2} for frequencies between about 10 Hz and 1 kHz, thresholds for neuronal and neuromuscular stimulation are exceeded. The threshold current densities increase progressively at frequencies below several hertz and above 1 kHz. Finally, at extremely high current densities, exceeding 1 A m^{-2}, severe and potentially life-threatening effects such as cardiac extrasystoles, ventricular fibrillation, muscular tetanus, and respiratory failure may occur. The severity and the probability of irreversibility of tissue effects becomes greater with chronic exposure to induced current densities above the level 10 to 100 mA m^{-2}. It therefore seems appropriate to limit human exposure to fields that induce current densities no greater than 10 mA m^{-2} in the head, neck, and trunk at frequencies of a few hertz up to 1 kHz.

It has been postulated that oscillatory magnetomechanical forces and torques on biogenic magnetite particles in brain tissue could provide a mechanism for the transduction of signals from ELF magnetic fields. Kirschvink et al. (1992b) proposed a model in which ELF magnetic forces on magnetite particles are visualized as producing the opening and closing of pressure-sensitive ion channels in membranes. However, one difficulty with this model is the sparsity of magnetite particles relative to the number of cells in brain tissue. For example, human brain tissue has been reported to contain a few million magnetite particles per gram, distributed in 10^5 discrete clusters of 5-10 particles (Kirschvink et al. 1992a). The number of cells in brain tissue thus exceeds the number of magnetite particles by a factor of about 100, and it is difficult to envisage how oscillating magnetomechanical interactions of an ELF field with magnetite crystals could affect a significant number of pressure-sensitive ion channels in the brain.' Further studies are clearly needed to reveal the biological role of magnetite and the possible mechanisms through which this mineral could play a role in the transduction of ELF magnetic signals.

An important issue in assessing the effects of electromagnetic fields is the possibility of teratogenic and developmental effects. On the basis of published scientific evidence, it is unlikely that low-frequency fields have adverse effects on the embryonic and postnatal development of mammalian species (Chernoff et al. 1992; Brent et al. 1993; Tenforde 1996). Moreover, currently available evidence indicates that somatic mutations and genetic effects are unlikely to result from exposure to electric and magnetic fields with frequencies below 100 kHz (Cridland 1993; Sienkiewicz et al. 1993).

There are numerous reports in the literature on the *in-vitro* effects of ELF fields on cell membrane properties (ion transport and interaction of mitogens with cell surface receptors) and changes in cellular functions and growth properties (e.g., increased proliferation and alterations in metabolism, gene expression, protein biosynthesis, and enzyme activities) (Cridland 1993; Sienkiewicz et al. 1993; Tenforde 1991, 1992, 1993, 1996). Considerable attention has focused on low-frequency field effects on Ca^{++} transport across cell membranes and the intracellular concentration of this ion (Walleczek and Liburdy 1990; Liburdy 1992; Walleczek 1992), messenger RNA and protein synthesis patterns (Goodman et al. 1983; Goodman and Henderson 1988, 1991; Greene et al. 199 1; Phillips et al.1992), and the activity of enzymes such as ornithine decarboxylase (ODC) that are related to cell proliferation and tumor promotion (Byus et al. 1987, 1988; Litovitz et al. 1991, 1993). However, before these observations can be used for defining exposure limits, it is essential to establish both their reproducibility and their relevance to cancer or other adverse health outcomes. This point is underscored by the fact that there have been difficulties in replicating some of the key observations of field effects on gene expression and protein synthesis (Lacy-Hulbert et al. 1995; Saffer and Thurston 1995). The authors of these replication studies identified several deficiencies in the earlier studies, including poor temperature control, lack of appropriate internal control samples, and the use of low-resolution techniques for analyzing the production of messenger RNA transcripts. The transient increase in ODC activity reported in response to field exposure is small in magnitude and not associated with *de novo* synthesis of the enzyme (unlike chemical tumor promoters such as phorbol esters)(Byus et al. 1988). Studies on ODC have mostly involved cellular preparations; more studies are needed to show whether there are effects on ODC *in vivo*, although there is one report suggesting effects on ODC in a rat mammary tumor promotion assay (Mevissen et al. 1995).

There is no evidence that ELF fields alter the structure of DNA and chromatin, and no resultant mutational and neoplastic transformation effects are expected. This is supported by results of laboratory studies designed to detect DNA and chromosomal damage, mutational events, and increased transformation frequency in response to ELF field exposure (NRPB 1992; Murphy et al. 1993; McCann et al. 1993; Tenforde 1996). The lack of effects on chromosome structure suggests that ELF fields, if they have any effect on the process of carcinogenesis, are more likely to act as promoters than initiators, enhancing the proliferation of genetically altered cells rather than causing the initial lesion in DNA or chromatin. An influence on tumor development could be mediated through epigenetic effects of these fields, such as alterations in cell signalling pathways or gene expression. The focus of recent studies has therefore been on detecting possible effects of ELF fields on the promotion and progression phases of tumor development following initiation by a chemical carcinogen.

Studies on *in-vitro* tumor cell growth and the development of transplanted tumors in rodents have provided no strong evidence for possible carcinogenic effects of exposure to ELF fields (Tenforde 1996). Several studies of more direct relevance to human cancer have involved *in-vivo* tests for tumor-promoting activity of ELF magnetic fields on skin, liver, brain, and mammary tumors in rodents. Three studies of skin tumor promotion (McLean et al. 1991; Rannug et al. 1993a, 1994) failed to show any effect of either continuous or intermittent exposure to power-frequency magnetic fields in promoting chemically induced tumors. At a 60-Hz field strength of 2 mT, a co-promoting effect with a phorbol ester was reported for mouse skin tumor development in the initial stages of the experiment, but the statistical significance of this was lost by completion of the study in week 23 (Stuchly et al. 1992). Previous studies by the same investigators had shown that 60-Hz, 2-mT field exposure did not promote the growth of DMBA-initiated skin cells (McLean et al. 1991).

Experiments on the development of transformed liver foci initiated by a chemical carcinogen and promoted by phorbol ester in partially hepatectomized rats revealed no promotion or co-promotion effect of exposure to 50-Hz fields ranging in strength from 0.5 to 50 μT (Rannug et al. 1993b, c).

Studies on mammary cancer development in rodents treated with a chemical initiator have suggested a cancer-promoting effect of exposure to power-frequency magnetic fields in the range 0.01-30 mT (Beniashvili et al. 1991; Loscher et al. 1993; Mevissen et al. 1993, 1995; Baum et al. 1995; Loscher and Mevissen 1995). These observations of increased tumor incidence in rats exposed to magnetic fields have been hypothesized to be related to field-induced suppression of pineal melatonin and a resulting elevation in steroid hormone levels and breast cancer risk (Stevens 1987; Stevens et al. 1992). However, replication efforts by independent laboratories are needed before conclusions can be drawn regarding the implications of these findings for a promoting effect of ELF magnetic fields on mammary tumors. It should also be noted that recent studies have found no evidence for a significant effect of exposure to ELF magnetic fields on melatonin levels in* humans (Graham et al. 1996, 1997; Selmaoui et al. 1996).

Indirect effects of electric and magnetic fields

Indirect effects of electromagnetic fields may result from physical contact (e.g., touching or brushing against) between a person and an object, such as a metallic structure in the field, at a different electric potential. The result of such contact is the flow of electric charge (contact current) that may have accumulated on the object or on the body of the person. In the frequency range up to approximately 100 kHz, the flow of electric current from an object in the field to the body of the individual may result in the stimulation of muscles and/or peripheral nerves. With increasing levels of current this may be manifested as perception, pain from electric shock and/or burn, inability to release the object, difficulty in breathing and, at very high currents, cardiac ventricular fibrillation (Tenforde and Kaune 1987). Threshold values for these effects are frequency-dependent, with the lowest threshold occurring at frequencies between 10 and 100 Hz. Thresholds for peripheral nerve responses remain low for frequencies up to several kHz. Appropriate engineering and/or administrative controls, and even the wearing of personal protective clothing, can prevent these problems from occurring.

Spark discharges can occur when an individual comes into very close proximity with an object at a different electric potential, without actually touching it (Tenforde and Kaune 1987; UNEP/WHO/IRPA 1993). When a group of volunteers, who were electrically insulated from the ground, each held a finger tip close to a grounded object, the threshold for perception of spark discharges was as low as 0.6–1.5 kV m^{-1} in 10% of cases. The threshold field level reported as causing annoyance under these exposure conditions is about 2.0–3.5 kV m^{-1}. Large contact currents can result in muscle contraction. In male volunteers, the 50th percentile threshold for being unable to release a charged conductor has been reported as 9 mA at 50/60 Hz, 16 mA at 1 kHz, about 50 mA at 10 kHz, and about 130 mA at 100 kHz (UNEP/WHO/IRPA 1993).

The threshold currents for various indirect effects of fields with frequencies up to 100 kHz are summarized in Table 2 (UNEP/WHO/IRPA 1993).

Table 2. Ranges of threshold currents for indirect effects, including children, women, and men.

Indirect effect	Threshold current (mA) at frequency:		
	50/60 Hz	1 kHz	100 kHz
Touch perception	0.2-0.4	0.4-0.8	25-40
Pain on finger contact	0.9-1.8	1.6-3.3	33–55
Painful shock/let-go threshold	8-16	12-24	112-224
Severe shock/breathing difficulty	12-23	21-41	160-320

Summary of biological effects and epidemiological studies (up to 100 kHz)

With the possible exception of mammary tumors, there is little evidence from laboratory studies that power-frequency magnetic fields have a tumor-promoting effect. Although further animal studies are needed to clarify the possible effects of ELF fields on signals produced in cells and on endocrine regulation—both of which could influence the development of tumors by promoting the proliferation of initiated cells-it can only be concluded that there is currently no convincing evidence for carcinogenic effects of these fields and that these data cannot be used as a basis for developing exposure guidelines.

Laboratory studies on cellular and animal systems have found no established effects of low-frequency fields that are indicative of adverse health effects when induced current density is at or below 10 mA m^{-2}. At higher levels of induced current density (lo-100 mA m^{-2}), more significant tissue effects have been consistently observed, such as functional changes in the nervous system and other tissue effects (Tenforde 1996).

Data on cancer risk associated with exposure to ELF fields among individuals living close to power lines are apparently consistent in indicating a slightly higher risk of leukemia among children, although more recent studies question the previously observed weak association. The studies do not, however, indicate a similarly elevated risk of any other type of childhood cancer or of any form of adult cancer. The basis for the hypothetical link between childhood leukemia and residence in close proximity to power lines is unknown; if the link is not related to the ELF electric and magnetic fields generated by the power lines, then unknown risk factors for leukemia would have to be linked to power lines in some undetermined manner. In the absence of support from laboratory studies, the epidemiological data are insufficient to allow an exposure guideline to be established.

There have been reports of an increased risk of certain types of cancer, such as leukemia, nervous tissue tumors, and, to a limited extent, breast cancer, among electrical workers. In most studies, job titles were used to classify subjects according to presumed levels of magnetic field exposure. A few more recent studies, however, have used more sophisticated methods of exposure assessment; overall, these studies suggested an increased risk of leukemia or brain tumors but were largely inconsistent with regard to the type of cancer for which risk is increased. The data are insufficient to provide a basis for ELF field exposure guidelines. In a large number of epidemiological studies, no consistent evidence of adverse reproductive effects have been provided.

Measurement of biological responses in laboratory studies and in volunteers has provided little indication of adverse effects of low-frequency fields at levels to which people are commonly exposed. A threshold current density of 10 mA m^{-2} at frequencies up to 1 kHz has been estimated for minor effects on nervous system functions. Among volunteers, the most consistent effects of exposure are the appearance of visual phosphenes and a minor reduction in heart rate during or immediately. after exposure to ELF fields, but there is no evidence that these transient effects are associated with any long-term health risk. A reduction in nocturnal pineal melatonin synthesis has been observed in several rodent species following exposure to weak ELF electric and magnetic fields, but no consistent effect has been reported in humans exposed to ELF fields under controlled conditions. Studies involving exposures to 60-Hz magnetic fields up to 20 μT have not reported reliable effects on melatonin levels in blood.

BIOLOGICAL BASIS FOR LIMITING EXPOSURE (100 -300 GHz)

The following paragraphs provide a general review of relevant literature on the biological effects and potential health effects of electromagnetic fields with frequencies of 100 kHz to 300 GHz. More detailed reviews can be found elsewhere (NRPB 1991; UNEP/WHO/IRPA 1993; McKinlay et al. 1996; Polk and Postow 1996; Repacholi 1998).

Direct effects of electromagnetic fields

Epidemiological studies. Only a limited number of studies have been carried out on reproductive effects and cancer risk in individuals exposed to microwave radiation. A summary of the literature was published by UNEP/WHO/IRPA (1993).

Reproductive outcomes. Two extensive studies on women treated with microwave diathermy to relieve the pain of uterine contractions during labor found no evidence for adverse effects on the fetus (Daels 1973, 1976). However, seven studies on pregnancy outcomes among workers occupationally exposed to microwave radiation and on birth defects among their offspring produced both positive and negative results. In some of the larger epidemiological studies of female plastic welders and physiotherapists working with shortwave diathermy devices, there were no statistically significant effects on rates of abortion or fetal malformation (Källen et al. 1982). By contrast, other studies on similar populations of female workers found an increased risk of miscarriage and birth defects (Larsen et al. 1991; Ouellet-Hellstrom and Stewart 1993). A study of male radar workers found no association between microwave exposure and the risk of Down's syndrome in their offspring (Cohen et al. 1977).

Overall, the studies on reproductive outcomes and microwave exposure suffer from very poor assessment of exposure and, in many cases, small numbers of subjects. Despite the generally negative results of these studies, it will be difficult to draw firm conclusions on reproductive risk without further epidemiological data on highly exposed individuals and more precise exposure assessment.

Cancer studies. Studies on cancer risk and microwave exposure are few and generally lack quantitative exposure assessment. Two epidemiological studies of radar workers in the aircraft industry and in the US. armed forces found no evidence of increased morbidity or mortality from any cause (Barr-on and Baraff 1958; Robinette et al. 1980; UNEP/WHO/IRPA 1993). Similar results were obtained by Lillienfeld et al. (1978) in a study of employees in the U.S. embassy in Moscow, who were chronically exposed to low-level microwave radiation. Selvin et al. (1992) reported no increase in cancer risk among children chronically exposed to radiation from a large microwave transmitter near their homes. More recent studies have failed to show significant increases in nervous tissue tumors among workers and military personnel exposed to microwave fields (Beall et al. 1996; Grayson 1996). Moreover, no excess total mortality was apparent among users of mobile telephones (Rothman et al. 1996a, b), but it is still too early to observe an effect on cancer incidence or mortality.

There has been a report of increased cancer risk among military personnel (Szmigielski et al. 1988), but the results of the study are difficult to interpret because neither the size of the population nor the exposure levels are clearly stated. In a later study, Szmigielski (1996) found increased rates of leukemia and lymphoma among military personnel exposed to EMF fields, but the assessment of EMF exposure was not well defined. A few recent studies of populations living near EMF transmitters have suggested a local increase in leukemia incidence (Hocking et al. 1996; Dolk et at. 1997a, b), but the results are inconclusive. Overall, the results of the small number of epidemiological studies published provide only limited information on cancer risk.

Laboratory studies. The following paragraphs provide a summary and critical evaluation of laboratory studies on the biological effects of electromagnetic fields with frequencies in the range 100 kHz–300 GHz. There are separate discussions on results of studies of volunteers exposed under controlled conditions and of laboratory studies on cellular, tissue, and animal systems.

Volunteer studies. Studies by Chatterjee et al. (1986) demonstrated that, as the frequency increases from approximately 100 kHz to 10 MHz, the dominant effect of exposure to a high-intensity electromagnetic field changes from nerve and muscle stimulation to heating. At 100 kHz the primary sensation was one of nerve tingling, while at 10 MHz it was one of warmth on the skin. In this frequency range, therefore, basic health protection criteria should be such as to avoid stimulation of excitable tissues and heating effects. At frequencies from 10 MHz to 300 GHz, heating is the major effect of absorption of electromagnetic energy, and temperature rises of more than 1-2 °C can have adverse health effects such as heat exhaustion and heat stroke (ACGIH 1996). Studies on workers in thermally stressful environments have shown worsening performance of simple tasks as body temperature rises to a level approaching physiological heat stress (Ramsey and Kwon 1988).

A sensation of warmth has been reported by volunteers experiencing high-frequency current of about 100 – 200 mA through a limb. The resulting SAR value is unlikely to produce a localized temperature increment of more than 1°C in the limbs (Chatterjee et al. 1986; Chen and Gandhi 1988; Hoque and Gandhi 1988), which has been suggested as the upper limit of temperature increase that has no detrimental health effects (UNEP/WHO/IRPA 1993). Data on volunteers reported by Gandhi et al. (1986) for frequencies up to 50 MHz and by Tofani et al. (1995) for frequencies up to 110 MHz (the upper limit of the FM broadcast band) support a reference level for limb current of 100 mA to avoid excessive heating effects (Dimbylow 1997).

There have been several studies of thermoregulatory responses of resting volunteers exposed to EMF in magnetic resonance imaging systems (Shellock and Crues 1987; Magin et al, 1992). In general, these have demonstrated that exposure for up to 30 min, under conditions in which whole-body SAR was less than 4 W kg^{-1}, caused an increase in the body core temperature of less than 1°C.

Cellular and animal studies. There are numerous reports on the behavioral and physiological responses of laboratory animals, including rodents, dogs, and non-human primates, to thermal interactions of EMF at frequencies above 10 MHz. Thermosensitivity and thermoregulatory responses are associated both with the hypothalamus and with thermal receptors located in the skin and in internal parts of the body. Afferent signals reflecting temperature change converge in the central nervous system and modify the activity of the major neuroendocrine control systems, triggering the physiological and behavioral responses necessary for the maintenance of homeostasis.

Exposure of laboratory animals to EMF producing absorption in excess of approximately 4 W kg^{-1} has revealed a characteristic pattern of thermoregulatory response in which body temperature initially rises and then stabilizes following the activation of thermoregulatory mechanisms (Michaelson 1983). The early phase of this response is accompanied by an increase in blood volume due to movement of fluid from the extracellular space into the circulation and by increases in heart rate and intraventricular blood pressure. These cardiodynamic changes reflect thermoregulatory responses that facilitate the conduction of heat to the body surface. Prolonged exposure of animals to levels of microwave radiation that raise the body temperature ultimately lead to failure of these thermoregulatory mechanisms.

Several studies with rodents and monkeys have also demonstrated a behavioral component of thermoregulatory responses. Decreased task performance by rats and monkeys has been observed at SAR values in the range 1-3 W kg^{-1} (Stern et al. 1979; Adair and Adams 1980; de Lorge and Ezell 1980; D'Andrea et al. 1986). In monkeys, altered thermoregulatory behavior starts when the temperature in the hypothalamic region rises by as little as 0.2–0.3°C (Adair et al. 1984). The hypothalamus is considered to be the control center for normal thermoregulatory processes, and its activity can be modified by a small local temperature increase under conditions in which rectal temperature remains constant.

At levels of absorbed electromagnetic energy that cause body temperature rises in excess of1–2°C, a large number of physiological effects have been characterized in studies with cellular and animal systems (Michaelson and Elson 1996). These effects include alterations in neural and neuromuscular functions; increased blood-brain barrier permeability; ocular impairment (lens opacities and cornea1 abnormalities); stress-associated changes in the immune system; hematological changes; reproductive changes (e.g., reduced sperm production); teratogenicity; and changes in cell morphology, water and electrolyte content, and membrane functions.

Under conditions of partial-body exposure to intense EMF, significant thermal damage can occur in sensitive tissues such as the eye and the testis. Microwave exposure of 2-3 h duration has produced cataracts in rabbits' eyes at SAR values from 100-140 W kg^{-1}, which produced lenticular temperatures of 41–43°C (Guy et al. 1975). No cataracts were observed in monkeys exposed to microwave fields of similar or higher intensities, possibly because of different energy absorption patterns in the eyes of monkeys from those in rabbits. At very high frequencies (lo-300 GHz), absorption of electromagnetic energy is confined largely to the epidermal layers of the skin, subcutaneous tissues, and the outer part of the eye. At the higher end of the frequency range, absorption is increasingly superficial. Ocular damage at these frequencies can be avoided if the microwave power density is less than 50 W m^{-2} (Sliney and Wolbarsht 1980; UNEP/WHO/IRPA 1993).

There has been considerable recent interest in the possible carcinogenic effects of exposure to microwave fields with frequencies in the range of widely used communications systems, including hand-held mobile telephones and base transmitters. Research findings in this area have been summarized by ICNIRP (1996). Briefly, there are many reports suggesting that microwave fields are not mutagenic, and exposure to these fields is therefore unlikely to initiate carcinogenesis (NRPB 1992; Cridland 1993; UNEP/WHO/IRPA 1993). By contrast, some recent reports suggest that exposure of rodents to microwave fields at SAR levels of the order of 1 W kg^{-1} may produce strand breaks in the DNA of testis and brain tissues (Sarkar et al. 1994; Lai and Singh 1995, 1996), although both ICNIRP (1996) and Williams (1996) pointed out methodological deficiencies that could have significantly influenced these results.

In a large study of rats exposed to microwaves for up to 25 mo, an excess of primary malignancies was noted in exposed rats relative to controls (Chou et al. 1992). However, the incidence of benign tumors did not differ between the groups, and no specific type of tumor was more prevalent in the exposed group than in stock rats of the same strain maintained under similar specific-. pathogen-free conditions. Taken as a whole, the results of this study cannot be interpreted as indicating a tumor-initiating effect of microwave fields.

Several studies have examined the effects of microwave exposure on the development of pre-initiated tumor cells. Szmigielski et al. (1982) noted an enhanced growth rate of transplanted lung sarcoma cells in rats exposed to microwaves at high power densities. It is possible that this resulted from a weakening of the host immune defense in response to thermal stress from the microwave exposure. Recent studies using athermal levels of microwave irradiation have found no effects on the development of melanoma in mice or of brain glioma in rats (Santini et al. 1988; Salford et al. 1993).

Repacholi et al. (1997) have reported that exposure of 100 female, *Eμ-pim1* transgenic mice to 900-MHz fields, pulsed at 217 Hz with pulse widths of 0.6 μs for up to 18 mo, produced a doubling in lymphoma incidence compared with 101 controls. Because the mice were free to roam in their cages, the variation in SAR was wide (0.01–4.2 W kg^{-1}). Given that the resting metabolic rate of these mice is 7–15 W kg^{-1}, only the upper end of the exposure range may have produced some slight heating. Thus, it appears that this study suggests a non-thermal mechanism may be acting, which needs to be investigated further. However, before any assumptions can be made about health risk, a number of questions need to be addressed. The study needs to be replicated, restraining the animals to decrease the SAR exposure variation and to determine whether there is a dose response. Further study is needed to determine whether the results can be found in other animal models in order to be able to generalize the results to humans. It is also essential to assess whether results found in transgenic animals are applicable to humans.

Special considerations for pulsed and amplitude-modulated waveforms

Compared with continuous-wave (CW) radiation, pulsed microwave fields with the same average rate of energy deposition in tissues are generally more effective in producing a biological response, especially when there is a well-defined threshold that must be exceeded to elicit the effect (ICNIRP 1996). The "microwave hearing" effect is a well known example of this (Frey 1961; Frey and Messenger 1973; Lin 1978): people with normal hearing can perceive pulse-modulated fields with frequencies between about 200 MHz and 6.5 GHz. The auditory sensation has been variously described as a buzzing, clicking, or popping sound, depending on the modulation characteristics of the field. The microwave hearing effects have been attributed to a thermoelastic interaction in the auditory cortex of the brain, with a threshold for perception of about 100-400 mJ m^{-2} for pulses of duration less than 30 μs at 2.45 GHz (corresponding to an SA of 4–16 mJ kg^{-1}). Repeated or prolonged exposure to microwave auditory effects may be stressful and potentially harmful.

Some reports suggest that retina, iris, and corneal endothelium of the primate eye are sensitive to low levels of pulsed microwave radiation (Kues et al. 1985; UNEP/WHO/IRPA 1993). Degenerative changes in light-sensitive cells of the retina were reported for absorbed energy levels as low as 26 mJ kg^{-1}. After administration of timolol maleate, which is used in the treatment of glaucoma, the threshold for retinal damage by pulsed fields dropped to 2.6 mJ kg^{-1}. However, an attempt in an independent laboratory to partially replicate these findings for CW fields (i.e., not pulsed) was unsuccessful (Kamimura et al. 1994), and it is therefore impossible at present to assess the potential health implications of the initial findings of Kues et al. (1985).

Exposure to intense pulsed microwave fields has been reported to suppress the startle response in conscious mice and to evoke body movements (NRPB 1991; Sienkiewicz et al. 1993; UNEP/WHO/IRPA 1993). The threshold specific energy absorption level at midbrain that evoked body movements was 200 J kg^{-1} for 10 μs pulses. The mechanism for these effects of pulsed microwaves remains to be determined but is believed to be related to the microwave hearing phenomenon. The auditory thresholds for rodents are about an order of magnitude lower than for humans, that is 1-2 mJ kg^{-1} for pulses <30 μs in duration. Pulses of this magnitude have also been reported to affect neurotransmitter metabolism and the concentration of the neural receptors involved in stress and anxiety responses in different regions of the rat brain.

The issue of athermal interactions of high-frequency EMF has centered largely on reports of biological effects of amplitude modulated (AM) fields under *in-vitro* conditions at SAR values well below those that produce measurable tissue heating. Initial studies in two independent laboratories led to reports that VHF fields with amplitude modulation at extremely low frequencies (6-20 Hz) produced a small, but statistically significant, release of Ca++ from the surfaces of chick brain cells (Bawin et al. 1975; Blackman et al. 1979). A subsequent attempt to replicate these findings, using the same type of AM field, was unsuccessful (Albert et al. 1987). A number of other studies of the effects of AM fields on Ca++ homeostasis have produced both positive and negative results. For example, effects of AM fields on Ca++ binding to cell surfaces have been observed with neuroblastoma cells, pancreatic cells, cardiac tissue, and cat brain cells, but not with cultured rat nerve cells, chick skeletal muscle, or rat brain cells (Postow and Swicord 1996).

Amplitude-modulated fields have also been reported to alter brain electrical activity (Bawin et al. 1974), inhibit T-lymphocyte cytotoxic activity (Lyle et al. 1983), decrease the activities of non-cyclic-AMP-dependent kinase in lymphocytes (Byus et al. 1984), and cause a transient increase in the cytoplasmic activity of ornithine decarboxylase, an essential enzyme for cell proliferation (Byus et al. 1988; Litovitz et al. 1992). In contrast, no effects have been observed on a wide variety of other cellular systems and functional end-points, including lymphocyte capping, neoplastic cell transformation, and various membrane electrical and enzymatic properties (Postow and Swicord 1996). Of particular relevance to the potential carcinogenic effects of pulsed fields is the observation by Balcer-Kubiczek and Harrison (199 1) that neoplastic transformation was accelerated in C3H/10T1/2 cells exposed to 2,450-MHz microwaves that were pulse-modulated at 120 Hz. The effect was dependent on field strength but occurred only when a chemical tumor-promoter, TPA, was present in the cell culture medium. This finding suggests that pulsed microwaves may exert co-carcinogenic effects in combination with a chemical agent that increases the rate of proliferation of transformed cells. To date, there have been no attempts to replicate this finding, and its implication for human health effects is unclear.

Interpretation of several observed biological effects of AM electromagnetic fields is further complicated by the apparent existence of "windows" of response in both the power density and frequency domains. There are no accepted models that adequately explain this phenomenon, which challenges the traditional concept of a monotonic relationship between the field intensity and the severity of the resulting biological effects.

Overall, the literature on athermal effects of AM electromagnetic fields is so complex, the validity of reported effects so poorly established, and the relevance of the effects to human health is so uncertain, that it is impossible to use this body of information as a basis for setting limits on human exposure to these fields.

Indirect effects of electromagnetic fields

In the frequency range of about 100 kHz–110 MHz, shocks and burns can result either from an individual touching an ungrounded metal object that has acquired a charge in a field or from contact between a charged individual and a grounded metal object. It should be noted that the upper frequency for contact current (I 10 MHz) is imposed by a lack of data on higher frequencies rather than by the absence of effects. However, 110 MHz is the upper frequency limit of the FM broadcast band. Threshold currents that result in biological effects ranging in severity from perception to pain have been measured in controlled experiments on volunteers (Chatterjee et al. 1986; Tenforde and Kaune 1987; Bernhardt 1988); these are summarized in Table 3. In general, it has been shown that the threshold currents that produce perception and pain vary little over the frequency range 100 kHz–1 MHz and are unlikely to vary significantly over the frequency range up to about 110 MHz. As noted earlier for lower frequencies, significant variations between the sensitivities of men, women, and children also exist for higher frequency fields. The data in Table 3 represent the range of 50th percentile values for people of different sizes and different levels of sensitivity to contact currents.

Table 3. Ranges of threshold currents for indirect effects, including children, women, and men.

Indirect effect	Threshold current (mA) at frequency: 100 kHz	1 MHz
Touch perception	25-40	25-40
Pain on finger contact	33-55	28-50
Painful shock/let-go threshold	112-224	Not determined
Severe shock/breathing difficulty	160-320	Not determined

Summary of biological effects and epidemiological studies (100 kHz–300 GHz)

Available experimental evidence indicates that the exposure of resting humans for approximately 30 min to EMF producing a whole-body SAR of between 1 and 4 W kg^{-1} results in a body temperature increase of less than 1 °C. Animal data indicate a threshold for behavioral responses in the same SAR range. Exposure to more intense fields, producing SAR values in excess of 4 W kg^{-1}, can overwhelm the thermoregulatory capacity of the body and produce harmful levels of tissue heating. Many laboratory studies with rodent and non-human primate models have demonstrated the broad range of tissue damage resulting from either partial-body or whole-body heating producing temperature rises in excess of 1–2°C. The sensitivity of various types of tissue to thermal damage varies widely, but the threshold for irreversible effects in even the most sensitive tissues is greater than 4 W kg^{-1} under normal environmental conditions. These data form the basis for an occupational exposure restriction of 0.4 W kg^{-1}, which provides a large margin of safety for other limiting conditions such as high ambient temperature, humidity, or level of physical activity.

Both laboratory data and the results of limited human studies (Michaelson and Elson 1996) make it clear that thermally stressful environments and the use of drugs or alcohol can compromise the thermoregulatory capacity of the body. Under these conditions, safety factors should be introduced to provide adequate protection for exposed individuals.

Data on human responses to high-frequency EMF that produce detectable heating have been obtained from controlled exposure of volunteers and from epidemiological studies on workers exposed to sources such as radar, medical diathermy equipment, and heat sealers. They are fully supportive of the conclusions drawn from laboratory work, that adverse biological effects can be caused by temperature rises in tissue that exceed 1°C. Epidemiological studies on exposed workers and the general public have shown no major health effects associated with typical exposure environments. Although there are deficiencies in the epidemiological work, such as poor exposure assessment, the studies have yielded no convincing evidence that typical exposure levels lead to adverse reproductive outcomes or an increased cancer risk in exposed individuals. This is consistent with the results of laboratory research on cellular and animal models, which have demonstrated neither teratogenic nor carcinogenic effects of exposure to athermal levels of. high-frequency EMF.

Exposure to pulsed EMF of sufficient intensity leads to certain predictable effects such as the microwave hearing phenomenon and various behavioral responses. Epidemiological studies on exposed workers and the general public have provided limited information and failed to demonstrate any health effects. Reports of severe retinal damage have been challenged following unsuccessful attempts to replicate the findings.

A large number of studies of the biological effects of amplitude-modulated EMF, mostly conducted with low levels of exposure, have yielded both positive and negative results. Thorough analysis of these studies reveals that the effects of AM fields vary widely with the exposure parameters, the types of cells and tissues involved, and the biological end-points that are examined. In general, the effects of exposure of biological systems to athermal levels of amplitude-modulated EMF are small and very difficult to relate to potential health effects. There is no convincing evidence of frequency and power density windows of response to these fields.

Shocks and burns can be the adverse indirect effects of high-frequency EMF involving human contact with metallic objects in the field. At frequencies of 100 kHz–110 MHz (the upper limit of the FM broadcast band), the threshold levels of contact current that produce effects ranging from perception to severe pain do not vary significantly as a function of the field frequency. The threshold for perception ranges from 25 to 40 mA in individuals of different sizes, and that for pain from approximately 30 to 55 mA; above 50 mA there may be severe burns at the site of tissue contact with a metallic conductor in the field.

GUIDELINES FOR LIMITING EMF EXPOSURE

Occupational and general public exposure limitations

The occupationally exposed population consists of adults who are generally exposed under known conditions and are trained to be aware of potential risk and to take appropriate precautions. By contrast, the general public comprises individuals of all ages and of varying health status, and may include particularly susceptible groups or individuals. In many cases, members of the public are unaware of their exposure to EMF. Moreover, individual members of the public cannot reasonably be expected to take precautions to minimize or avoid exposure. It is these considerations that underlie the adoption of more stringent exposure restrictions for the public than for the occupationally exposed population.

Basic restrictions and reference levels

Restrictions on the effects of exposure are based on established health effects and are termed basic restrictions. Depending on frequency, the physical quantities used to specify the basic restrictions on exposure to EMF are current density, SAR, and power density. Protection against adverse health effects requires that these basic restrictions are not exceeded.

Reference levels of exposure are provided for comparison with measured values of physical quantities; compliance with all reference levels given in these guidelines will ensure compliance with basic restrictions. If measured values are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to assess compliance with the basic restrictions.

General statement on safety factors

There is insufficient information on the biological and health effects of EMF exposure of human populations and experimental animals to provide a rigorous basis for establishing safety factors over the whole frequency range and for all frequency modulations. In addition, some of the uncertainty regarding the appropriate safety factor derives from a lack of knowledge regarding the appropriate dosimetry (Repacholi 1998). The following general variables were considered in the development of safety factors for high-frequency fields:

- effects of EMF exposure under severe environmental conditions (high temperature, etc.) and/or high activity levels; and
- the potentially higher thermal sensitivity in certain population groups, such as the frail and/or elderly, infants and young children, and people with diseases or taking medications that compromise thermal tolerance.

The following additional factors were taken into account in deriving reference levels for high-frequency fields:

- differences in absorption of electromagnetic energy by individuals of different sizes and different orientations relative to the field; and
- reflection, focusing, and scattering of the incident field, which can result in enhanced localized absorption of high-frequency energy.

Basic restrictions

Different scientific bases were used in the development of basic exposure restrictions for various frequency ranges:

- Between 1 Hz and 10 MHz, basic restrictions are provided on current density to prevent effects on nervous system functions;
- Between 100 kHz and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating; in the 100 kHz–10 MHz range, restrictions are provided on both current density and SAR; and
- Between 10 and 300 GHz, basic restrictions are provided on power density to prevent excessive heating in tissue at or near the body surface.

In the frequency range from a few Hz to 1 kHz, for levels of induced current density above 100 mA m^{-2}, the thresholds for acute changes in central nervous system excitability and other acute effects such as reversal of the visually evoked potential are exceeded. In view of the safety considerations above, it was decided that, for frequencies in the range 4 Hz to 1 kHz, occupational exposure should be limited to fields that induce current densities less than 10 mA m^{-2}, i.e., to use a safety factor of 10. For the general public an additional factor of 5 is applied, giving a basic exposure restriction of 2 mA m^{-2}. Below 4 Hz and above 1 kHz, the basic restriction on induced current density increases progressively, corresponding to the increase in the threshold for nerve stimulation for these frequency ranges.

Established biological and health effects in the frequency range from 10 MHz to a few GHz are consistent with responses to a body temperature rise of more than 1°C. This level of temperature increase results from exposure of individuals under moderate environmental conditions to a whole-body SAR of approximately 4 W kg^{-1} for about 30 min. A whole-body average SAR of 0.4 W kg^{-1} has therefore been chosen as the restriction that provides adequate protection for occupational exposure. An additional safety factor of 5 is introduced for exposure of the public, giving an average whole-body SAR limit of 0.08 W kg^{-1}.

The lower basic restrictions for exposure of the general public take into account the fact that their age and health status may differ from those of workers.

In the low-frequency range, there are currently few data relating transient currents to health effects. The ICNIRP therefore recommends that the restrictions on current densities induced by transient or very short-term peak fields be regarded as instantaneous values which should not be time-averaged.

The basic restrictions for current densities, whole-body average SAR, and localized SAR for frequencies between 1 Hz and 10 GHz are presented in Table 4, and those for power densities for frequencies of 10–300 GHz are presented in Table 5.

REFERENCE LEVELS

Where appropriate, the reference levels are obtained from the basic restrictions by mathematical modeling and by extrapolation from the results of laboratory investigations at specific frequencies. They are given for the condition of maximum coupling of the field to the exposed individual, thereby providing maximum protection. Tables 6 and 7 summarize the reference levels for occupational exposure and exposure of the general public, respectively, and the reference levels are illustrated in Figs. 1 and 2. The reference levels are intended to be spatially averaged values over the entire body of the exposed individual, but with the important proviso that the basic restrictions on localized exposure are not exceeded.

For low-frequency fields, several computational and measurement methods have been developed for deriving field-strength reference levels from the basic restrictions.

Table 4. Basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz.[a]

Exposure characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)	Whole-body average SAR (W kg-‘)	Localized SAR (head and trunk) (W kg-‘)	Localized SAR (limbs) (W kg^{-1})
Occupational exposure	up to 1 Hz	40	—	—	—
	1-4 Hz	40/*f*	—	—	—
	4 Hz-l kHz	10			
	1-100 kHz	*f*/100	--	--	--
	100 kHz–10 MHz	*f*/100	0.4	10	20
	10 MHz-10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/*f*	—	—	—
	4 Hz-l kHz	2			
	1-100 kHz	*f*/500	--	--	--
	100 kHz–10 MHz	*f*/500	0.08	2	4
	10 MHz-10 GHz	—	0.08	2	4

[a] Note:
1. f is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ ($\sim$ 1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and ZmJ kg- 1 for the general public, averaged over 10 g tissue.

Table 5. Basic restrictions for power density for frequencies between 10 and 300 GHz.[a]

Exposure characteristics	Power density (W m^{-2})
Occupational exposure	50
General public	10

[a] Note:
1. Power densities are to be averaged over any 20 cm^2 of exposed area and any $68/f^{1.05}$-min period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases.
2. Spatial maximum power densities, averaged over 1 cm^2, should not exceed 20 times the values above.

The simplifications that have been used to date did not account for phenomena such as the inhomogeneous distribution and anisotropy of the electrical conductivity and other tissue factors of importance for these calculations.

The frequency dependence of the reference field levels is consistent with data on both biological effects and coupling of the field.

Magnetic field models assume that the body has a homogeneous and isotropic conductivity and apply simple circular conductive loop models to estimate induced currents in different organs and body regions, e.g., the head, by using the following equation for a pure sinusoidal field at frequency f derived from Faraday's law of induction:

$$J = \pi R f \sigma B, \qquad (4)$$

where B is the magnetic flux density and R is the radius of the loop for induction of the current. More complex models use an ellipsoidal model to represent the trunk or the whole body for estimating induced current densities at the surface of the body (Reilly 1989, 1992).

If, for simplicity, a homogeneous conductivity of 0.2 S m^{-1} is assumed, a 50-Hz magnetic flux density of 100 μT generates current densities between 0.2 and 2 mA m^{-2} in the peripheral area of the body (CRP 1997). According to another analysis (NAS1996), 60-Hz exposure levels of 100 μT correspond to average current densities of 0.28 mA m^{-2} and to maximum current densities of approximately 2 mA m^{-2}. More realistic calculations based on anatomically and electrically refined models (Xi and Stuchly 1994) resulted in maximum current densities exceeding 2 mA m^{-2} for a 100-μT field at 60 Hz. However, the presence of biological cells affects the spatial pattern of induced currents and fields, resulting in significant differences in both magnitude (a factor of 2 greater) and patterns of flow of the induced current compared with those predicted by simplified analyses (Stuchly and Xi 1994).

Electric field models must take into account the fact that, depending on the exposure conditions and the size, shape, and position of the exposed body in the field, the surface charge density can vary greatly, resulting in a variable and non-uniform distribution of currents inside the body. For sinusoidal electric fields at frequencies below about 10 MHz, the magnitude of the induced current density inside the body increases with frequency. The induced current density distribution varies inversely with the body cross-section and may be relatively high in the neck and ankles. The exposure level of 5 kV m^{-1} for exposure of the general public corresponds, under worst-case conditions, to an induced current density of about 2 mA m^{-2} in the neck and trunk of the body if the E-field vector is parallel to the body axis (IL0 1994; CRP 1997). However, the current density induced by 5 kV m^{-1} will comply with the basic restrictions under realistic worst-case exposure conditions.

For purposes of demonstrating compliance with the basic restrictions, the reference levels for the electric and magnetic fields should be considered separately and not additively. This is because, for protection purposes, the currents induced by electric and magnetic fields are not additive.

For the specific case of occupational exposures at frequencies up to 100 kHz, the derived electric fields can be increased by a factor of 2 under conditions in which adverse indirect effects from contact with electrically charged conductors can be excluded.

At frequencies above 10 MHz, the derived electric and magnetic field strengths were obtained from the whole-body SAR basic restriction using computational and experimental data. In the worst case, the energy coupling reaches a maximum between 20 MHz and several hundred MHz. In this frequency range, the derived reference levels have minimum values. The derived magnetic field strengths were calculated from the electric field strengths by using the far-field relationship between E and H (E/H = 377 ohms). In the near-field, the SAR frequency dependence curves are no longer valid; moreover, the contributions of the electric and magnetic field components have to be considered separately. For a conservative approximation, field exposure levels can be used for near-field assessment since the coupling of energy from the electric or magnetic field contribution cannot exceed the SAR restrictions. For a less conservative assessment, basic restrictions on the whole-body average and local SAR should be used.

Reference levels for exposure of the general public have been obtained from those for occupational exposure by using various factors over the entire frequency range. These factors have been chosen on the basis of effects that are recognized as specific and relevant for the various frequency ranges. Generally speaking, the factors follow the basic restrictions over the entire frequency range, and their values correspond to the mathematical relation between the quantities of the basic restrictions and the derived levels as described below:

- In the frequency range up to 1 kHz, the general public reference levels for electric fields are one-half of the values set for occupational exposure. The value of 10 kV m^{-1} for a 50-Hz or 8.3 kV m^{-1} for a 60-Hz occupational exposure includes a sufficient safety margin to prevent stimulation effects from contact currents under all possible conditions. Half of this value was chosen for the general public reference levels, i.e.,

Table 6. Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).[a]

Frequency range	E-field strength ($V\,m^{-1}$)	H-field strength ($A\,m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\,m^{-2}$)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
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	$1.6/f$	$2.0/f$	—
1-10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10-400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2-300 GHz	137	0.36	0.45	50

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies < 1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table 7. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).[a]

Frequency range	E-field strength ($V\,m^{-1}$)	H-field strength ($A\,m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\,m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1-8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8-25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
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	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2-300 GHz	61	0.16	0.20	10

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies < 1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

5 $kV\,m^{-1}$ for 50 Hz or 4.2 $kV\,m^{-1}$ for 60 Hz, to prevent adverse indirect effects for more than 90% of exposed individuals;

- In the low-frequency range up to 100 kHz, the general public reference levels for magnetic fields are set at a factor of 5 below the values set for occupational exposure;
- In the frequency range 100 kHz–10 MHz, the general public reference levels for magnetic fields have been increased compared with the limits given in the 1988 IRPA guideline. In that guideline, the magnetic field strength reference levels were calculated from the electric field strength reference levels by using the far-field

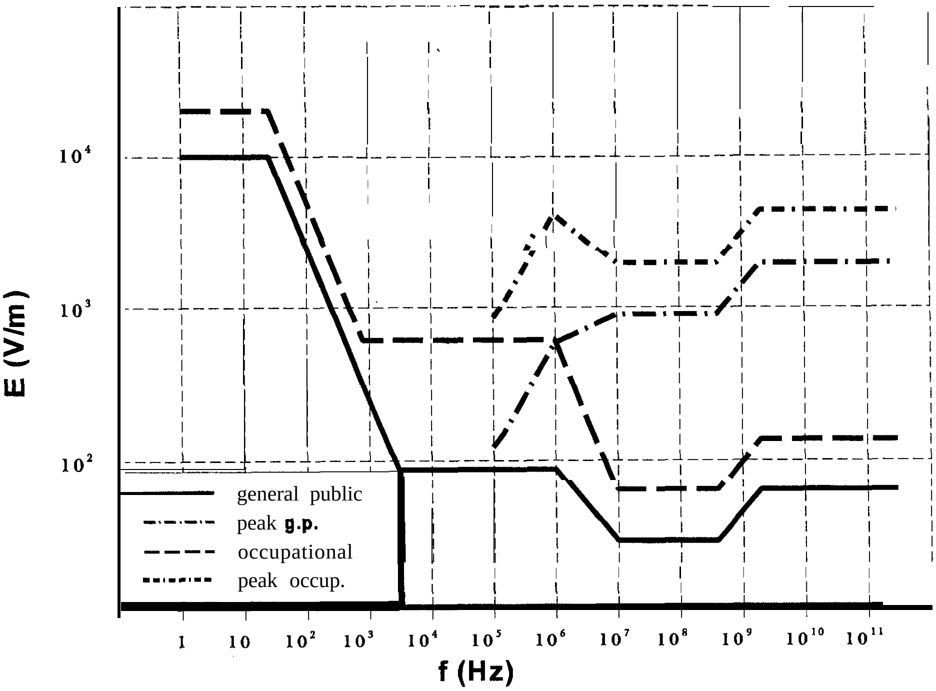

Fig. 1. Reference levels for exposure to time varying electric fields (compare Tables 6 and 7).

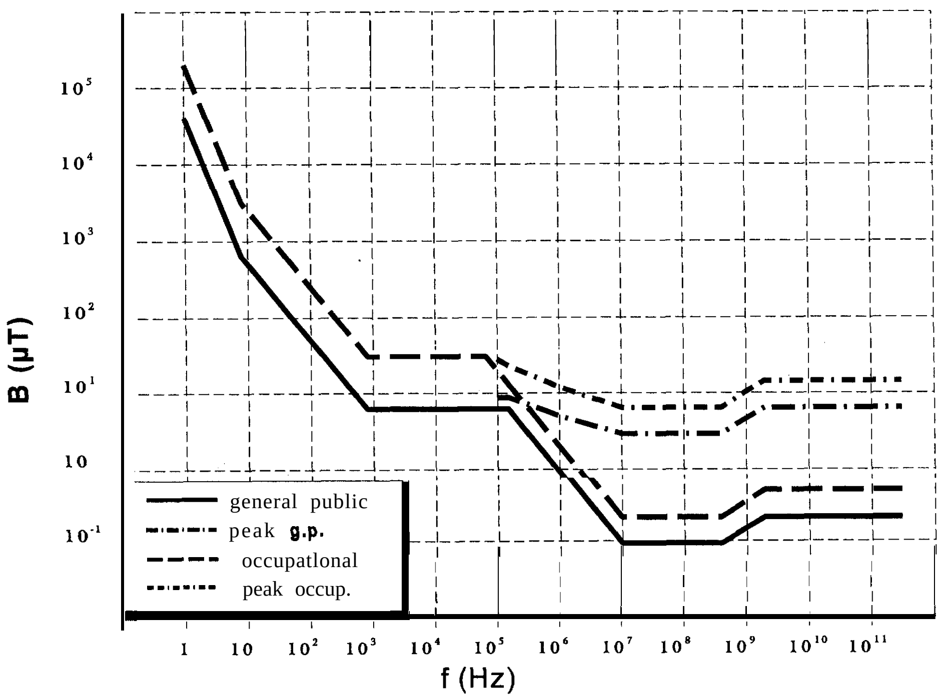

Fig. 2. Reference levels for exposure to time varying magnetic fields (compare Tables 6 and 7).

formula relating E and H. These reference levels are too conservative, since the magnetic field at frequencies below 10 MHz does not contribute significantly to the risk of shocks, burns, or surface charge effects that form a major basis for limiting occupational exposure to electric fields in that frequency range;

In the high-frequency range 10 MHz-10 GHz, the general public reference levels for electric and magnetic fields are lower by a factor of 2.2 than those set for occupational exposure. The factor of 2.2 corresponds to the square root of 5, which is the safety factor between the basic restrictions for occupational exposure and those for general public exposure. The square root is used to relate the quantities "field strength" and "power density;"

- In the high-frequency range 10–300 GHz, the general public reference levels are defined by the power density, as in the basic restrictions, and are lower by a factor of 5 than the occupational exposure restrictions;
- Although little information is available on the relation between biological effects and peak values of pulsed fields, it is suggested that, for frequencies exceeding 10 MHz, S_{eq} as averaged over the pulse width should not exceed 1,000 times the reference levels or that field strengths should not exceed 32 times the field strength reference levels given in Tables 6 and 7 or shown in Figs. 1 and 2. For frequencies between about 0.3 GHz and several GHz, and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion the specific absorption from pulses must limited. In this frequency range, the threshold SA of 4-16 mJ kg^{-1} for producing this effect corresponds, for 30-μs pulses, to peak SAR values of 130-520 W kg^{-1} in the brain. Between 100 kHz and 10 MHz, peak values for the field strengths in Figs. 1 and 2 are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz.
- In Tables 6 and 7, as well as in Figs. 1 and 2, different frequency break-points occur for occupational and general public derived reference levels. This is a consequence of the varying factors used to derive the general public reference levels, while generally keeping the frequency dependence the same for both occupational and general public levels.

REFERENCE LEVELS FOR CONTACT AND INDUCED CURRENTS

Up to 110 MHz, which includes the FM radio transmission frequency band, reference levels for contact current are given above which caution must be exercised to avoid shock and burn hazards. The point contact reference levels are presented in Table 8. Since the threshold contact currents that elicit biological responses in children and adult women are approximately one-half and two-thirds, respectively, of those for adult men, the reference levels for contact current for the general public are set lower by a factor of 2 than the values for occupational exposure.

For the frequency range 10–110 MHz, reference levels are provided for limb currents that are below the basic restrictions on localized SAR (see Table 9).

SIMULTANEOUS EXPOSURE TO MULTIPLE FREQUENCY FIELDS

It is important to determine whether, in situations of simultaneous exposure to fields of different frequencies, these exposures are additive in their effects. Additivity should be examined separately for the effects of thermal and electrical stimulation, and the basic restrictions below should be met. The formulae below apply to relevant frequencies under practical exposure situations.

For electrical stimulation, relevant for frequencies up to 10 MHz, induced current densities should be added according to

$$\sum_{i=1\text{ Hz}}^{10\text{ MHz}} \frac{J_i}{J_{L,i}} \leq 1. \qquad (5)$$

For thermal effects, relevant above 100 kHz, SAR and power density values should be added according to:

$$\sum_{i=100\text{ kHz}}^{10\text{ GHz}} \frac{SAR_i}{SAR_L} + \sum_{i>10\text{ GHz}}^{300\text{ GHz}} \frac{S_i}{S_L} \leq 1, \qquad (6)$$

where

J_i = the current density induced at frequency i;
$J_{L,i}$ = the induced current density restriction at frequency i as given in Table 4;
SAR_i = the SAR caused by exposure at frequency i;
SAR_L = the SAR limit given in Table 4;
S_L = the power density limit given in Table 5; and
S_i = the power density at frequency i.

For practical application of the basic restrictions, the following criteria regarding reference levels of field strengths should be applied.

Table 8. Reference levels for time varying contact currents from conductive objects.[a]

Exposure characteristics	Frequency range	Maximum contact current (mA)
Occupational exposure	up to 2.5 kHz	1.0
	2.5-100 kHz	0.4f
	100 kHz–110 MHz	40
General public exposure	up to 2.5 kHz	0.5
	2.5-100 kHz	0.2f
	100 kHz–110 MHz	20

[a] f is the frequency in kHz.

Table 9. Reference levels for current induced in any limb at frequencies between 10 and 110 MHz.[a]

Exposure characteristics	Current (mA)
Occupational exposure	100
General public	45

[a] Note:
1. The public reference level is equal to the occupational reference level divided by $\sqrt{5}$.
2. For compliance with the basic restriction on localized SAR, the square root of the time-averaged value of the square of the induced current over any 6-min period forms the basis of the reference levels.

For induced current density and electrical stimulation effects, relevant up to 10 MHz, the following two requirements should be applied to the field levels:

$$\sum_{i=1\text{ Hz}}^{1\text{ MHz}} \frac{E_i}{E_{L,i}} + \sum_{i>1\text{ MHz}}^{10\text{ MHz}} \frac{E_i}{a} \leq 1, \qquad (7)$$

and

$$\sum_{j=1\text{ Hz}}^{65\text{ kHz}} \frac{H_j}{H_{L,j}} + \sum_{j>65\text{ kHz}}^{10\text{ MHz}} \frac{H_j}{b} \leq 1, \qquad (8)$$

where

E_i = the electric field strength at frequency I;
$E_{L,i}$ = the electric field reference level from Tables 6 and 7;
H_j = the magnetic field strength at frequency j;
$H_{L,j}$ = the magnetic field reference level from Tables 6 and 7;
a = 610 V m^{-1} for occupational exposure and 87 V m^{-1} for general public exposure; and
b = 24.4 A m^{-1} (30.7 μT) for occupational exposure and 5 A m^{-1} (6.25 μT) for general public exposure.

The constant values a and b are used above 1 MHz for the electric field and above 65 kHz for the magnetic field because the summation is based on induced current densities and should not be mixed with thermal considerations. The latter forms the basis for $E_{L\,i}$ and $H_{L,j}$ above 1 MHz and 65 kHz, respectively, found in Tables 6 and 7.

For thermal considerations, relevant above 100 kHz, the following two requirements should be applied to the field levels:

$$\sum_{i=100\text{ kHz}}^{1\text{ MHz}} \left(\frac{E_i}{c}\right)^2 + \sum_{i>1\text{ MHz}}^{300\text{ GHz}} \left(\frac{E_i}{E_{L,i}}\right)^2 \leq 1, \qquad (9)$$

and

$$\sum_{j=100\text{ kHz}}^{1\text{ MHz}} \left(\frac{H_j}{d}\right)^2 + \sum_{j>1\text{ MHz}}^{300\text{ GHz}} \left(\frac{H_j}{H_{L,j}}\right)^2 \leq 1, \qquad (10)$$

where

E_i = the electric field strength at frequency I;
$E_{L,i}$ = the electric field reference level from Tables 6 and 7;
H_j = the magnetic field strength at frequency j;
$H_{L,i}$ = the magnetic field reference level from Tables 6 and 7;
c = 610/f V m^{-1} (f in MHz) for occupational exposure and 87/$f^{1/2}$ V m^{-1} for general public exposure; and
d = 1.6/f A m^{-1} (f in MHz) for occupational exposure and 0.73/f for general public exposure.

For limb current and contact current, respectively, the following requirements should be applied:

$$\sum_{k=10\text{ MHz}}^{110\text{ MHz}} \left(\frac{I_k}{I_{L,k}}\right)^2 \leq 1 \qquad \sum_{n=1\text{ Hz}}^{110\text{ MHz}} \frac{I_n}{I_{C,n}} \leq 1, \qquad (11)$$

where

I_k = the limb current component at frequency k;
$I_{L,k}$ = the reference level of limb current (see Table 9);
I_n = the contact current component at frequency n; and
$I_{C,n}$ = the reference level of contact current at frequency n (see Table 8).

The above summation formulae assume worst-case conditions among the fields from the multiple sources. As a result, typical exposure situations may in practice require less restrictive exposure levels than indicated by the above formulae for the reference levels.

PROTECTIVE MEASURES

ICNIRP notes that the industries causing exposure to electric and magnetic fields are responsible for ensuring compliance with all aspects of the guidelines,

Measures for the protection of workers include engineering and administrative controls, personal protection programs, and medical surveillance (IL0 1994). Appropriate protective measures must be implemented when exposure in the workplace results in the basic restrictions being exceeded. As a first step, engineering controls should be undertaken wherever possible to reduce device emissions of fields to acceptable levels. Such controls include good safety design and, where necessary, the use of interlocks or similar health protection mechanisms.

Administrative controls, such as limitations on access and the use of audible and visible warnings, should be used in conjunction with engineering controls. Personal protection measures, such as protective clothing, though useful in certain circumstances, should be regarded as a last resort to ensure the safety of the worker; priority should be given to engineering and administrative controls wherever possible. Furthermore, when such items as insulated gloves are used to protect individuals from high-frequency shock and burns, the basic restrictions must not be exceeded, since the insulation protects only against indirect effects of the fields.

With the exception of protective clothing and other personal protection, the same measures can be applied to the general public whenever there is a possibility that the general public reference levels might be exceeded. It is also essential to establish and implement rules that will prevent:

- interference with medical electronic equipment and devices (including cardiac pacemakers);

- detonation of electro-explosive devices (detonators); and
- fires and explosions resulting from ignition of flammable materials by sparks caused by induced fields, contact currents, or spark discharges.

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APPENDIX

Glossary

Absorption. In radio wave propagation, attenuation of a radio wave due to dissipation of its energy, i.e., conversion of its energy into another form, such as heat.

Athermal effect. Any effect of electromagnetic energy on a body that is not a heat-related effect.

Blood-brain barrier. A functional concept developed to explain why many substances that are transported by blood readily enter other tissues but do not enter the brain; the "barrier" functions as if it were a continuous membrane lining the vasculature of the brain. These brain capillary endothelial cells form a nearly continuous barrier to entry of substances into the brain from the vasculature.

Conductance. The reciprocal of resistance. Expressed in siemens (S).

Conductivity, electrical. The scalar or vector quantity which, when multiplied by the electric field strength, yields the conduction current density; it is the reciprocal of resistivity. Expressed in siemens per meter (S m^{-1}).

Continuous wave. A wave whose successive oscillations are identical under steady-state conditions.

Current density. A vector of which the integral over a given surface is equal to the current flowing through the surface; the mean density in a linear conductor is equal to the current divided by the cross-sectional area of the conductor. Expressed in ampere per square meter (A m^{-2}).

Depth of penetration. For a plane wave electromagnetic field (EMF), incident on the boundary of a good conductor, depth of penetration of the wave is the depth at which the field strength of the wave has been reduced to l/e, or to approximately 37% of its original value.

Dielectric constant. See permittivity.

Dosimetry. Measurement, or determination by calculation, of internal electric field strength or induced current density, of the specific energy absorption, or specific energy absorption rate distribution, in humans or animals exposed to electromagnetic fields.

Electric field strength. The force (E) on a stationary unit positive charge at a point in an electric field; measured in volt per meter (V m^{-1}).

Electromagnetic energy. The energy stored in an electromagnetic field. Expressed in joule (J).

ELF. Extremely low frequency; frequency below 300 Hz.

EMF. Electric, magnetic, and electromagnetic fields.

Far field. The region where the distance from a radiating antenna exceeds the wavelength of the radiated EMF; in the far-field, field components (E and H) and the direction of propagation are mutually perpendicular, and the shape of the field pattern is independent of the distance from the source at which it is taken.

Frequency. The number of sinusoidal cycles completed by electromagnetic waves in 1 s; usually expressed in hertz (Hz).

Impedance, wave. The ratio of the complex number (vector) representing the transverse electric field at a point to that representing the transverse magnetic field at that point. Expressed in ohm (Ω).

Magnetic field strength. An axial vector quantity, H, which, together with magnetic flux density, specifies a magnetic field at any point in space, and is expressed in ampere per meter (A m^{-1}).

Magnetic flux density. A vector field quantity, B, that results in a force that acts on a moving charge or. charges, and is expressed in tesla (T).

Magnetic permeability. The scalar or vector quantity which, when multiplied by the magnetic field strength, yields magnetic flux density; expressed in henry per meter ($H\ m^{-1}$). *Note:* For isotropic media, magnetic permeability is a scalar; for anisotropic media, it is a tensor quantity.

Microwaves. Electromagnetic radiation of sufficiently short wavelength for which practical use can be made of waveguide and associated cavity techniques in its transmission and reception. *Note:* The term is taken to signify radiations or fields having a frequency range of 300 MHz-300 GHz.

Near field. The region where the distance from a radiating antenna is less than the wavelength of the radiated EMF. *Note:* The magnetic field strength (multiplied by the impedance of space) and the electric field strength are unequal and, at distances less than one-tenth of a wavelength from an antenna, vary inversely as the square or cube of the distance if the antenna is small compared with this distance.

Non-ionizing radiation (NIR). Includes all radiations and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter; characterized by energy per photon less than about 12 eV, wavelengths greater than 100 nm, and frequencies lower than 3×10^{15} Hz.

Occupational exposure. All exposure to EMF experienced by individuals in the course of performing their work.

Permittivity. A constant defining the influence of an isotropic medium on the forces of attraction or repulsion between electrified bodies, and expressed in farad per metre ($F\ m^{-1}$); *relative permittivity* is the permittivity of a material or medium divided by the permittivity of vacuum.

Plane wave. An electromagnetic wave in which the electric and magnetic field vectors lie in a plane perpendicular to the direction of wave propagation, and the magnetic field strength (multiplied by the impedance of space) and the electric field strength are equal.

Power density. In radio wave propagation, the power crossing a unit area normal to the direction of wave propagation; expressed in watt per square meter ($W\ m^{-2}$).

Public exposure. All exposure to EMF experienced by members of the general public, excluding occupational exposure and exposure during medical procedures.

Radiofrequency (RF). Any frequency at which electromagnetic radiation is useful for telecommunication. *Note:* In this publication, radiofrequency refers to the frequency range 300 Hz -300 GHz.

Resonance. The change in amplitude occurring as the frequency of the wave approaches or coincides with a natural frequency of the medium; whole-body absorption of electromagnetic waves presents its highest value, i.e., the resonance, for frequencies (in MHz) corresponding approximately to $114/L$, where L is the height of the individual in meters.

Root mean square (rms). Certain electrical effects are proportional to the square root of the mean of the square of a periodic function (over one period). This value is known as the effective, or root-mean-square (rms) value, since it is derived by first squaring the function, determining the mean value of the squares obtained, and taking the square root of that mean value.

Specific energy absorption. The energy absorbed per unit mass of biological tissue, (SA) expressed in joule per kilogram ($J\ kg^{-1}$); specific energy absorption is the time integral of specific energy absorption rate.

Specific energy absorption rate (SAR). The rate at which energy is absorbed in body tissues, in watt per kilogram ($W\ kg^{-1}$); SAR is the dosimetric measure that has been widely adopted at frequencies above about 100 kHz.

Wavelength. The distance between two successive points of a periodic wave in the direction of propagation, at which the oscillation has the same phase.

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