Exposure of humans to electromagnetic fields. Standards and regulations

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Summary. Biological and health effects of electromagnetic fields (EMF) have been investigated for many years. Exposure standards have been developed internationally, that provide adequate protection against all known adverse effects of exposure to EMF. The guidelines developed by the International Commission on Non Ionizing Radiation Protection (ICNIRP) are widely recognized and have formed the basis for national regulations in several countries. The two-level structure, with basic restrictions and reference levels, allows the standards to be adapted to virtually any exposure condition, including complex situations at workplaces. However, concerns for hypothesized, but unproven, long-term effects of chronic exposure to low-level EMF have created a demand for precautionary measures beyond the standards for recognized, acute effects. Such measures, if deemed justified by social considerations, including public anxiety, should be separate from exposure standards, and adopted with special care to avoid undermining the credibility of science-based guidelines, and of health authorities.

Key words: electromagnetic fields, health protection, exposure guidelines, precautionary principle.

Riassunto *(L'esposizione umana ai campi elettromagnetici. Standard e normative)*. Gli effetti sulla salute dei campi elettromagnetici (EMF) sono stati oggetto di ricerche per molti anni. A livello internazionale sono stati sviluppati standard che forniscono una protezione adeguata contro tutti gli effetti avversi da esposizione a EMF noti. Le linee guida sviluppate dalla Commissione Internazionale per la Protezione dalle Radiazioni non Ionizzanti (ICNIRP) sono ampiamente conosciute ed hanno rappresentato la base per regolamenti nazionali in molti Paesi. La struttura a due livelli, con restrizioni base e livelli di riferimento, consente a questi standard di essere adattati virtualmente a ogni condizione di esposizione, incluse situazioni complesse sul posto di lavoro. Tuttavia, la preoccupazione per effetti di lungo periodo, ipotizzati ma non provati, dovuti a esposizione cronica a campi elettromagnetici di bassa intensità, ha creato una domanda di misure precauzionali oltre gli standard per gli effetti acuti accertati. Queste misure, anche se giustificabili da considerazioni di tipo sociale, ivi inclusa la preoccupazione dell'opinione pubblica, devono essere distinte dagli standard di esposizione, e adottate con estrema attenzione al fine di evitare di ledere la credibilità delle linee guida basate su dati scientifici e delle autorità sanitarie.

Parole chiave: campi elettromagnetici, protezione della salute, linee guida all'esposizione, principio cautelativo.

INTRODUCTION

With the rapid development of new technologies, exposure of both workers and the general population to electromagnetic fields (EMF) has enormously increased in recent years. At the same time, concern has been expressed for possible adverse effects of such exposures on human health. Consequently, in several countries national governments and health authorities have been urged to adopt measures to prevent, or to minimize, risks associated to EMF exposure.

Standards on protection against possible health effects of EMF have been developed and updated by various international and national bodies for several decades. Over the years, such standards have evolved from simple recommendations on exposure limits in a limited frequency range to a comprehensive and complex system of protection, covering a large part of the spectrum of non-optical EMF (in general, from 0 Hz to 300 GHz).

At the international level, guidelines for the safe exposure of workers and the general public have been issued by the International Commission on Non Ionizing Radiation Protection (ICNIRP) [1]. A wide consensus exists on these guidelines, that have formed the basis for national regulations in several countries. It should be mentioned however that internationally recognized standards have also been developed by other bodies, in particular the Institute of Electrical and Electronics Engineers in the USA (IEEE) and the National Radiological Protection Board in the UK (NRPB). In spite of few differences of some importance, such as the one- or

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two-tier (workers *vs* general public) structure, or the classification of the environments rather than of the exposed personnel, these standards show close similarities, and are based on the same approach and rationale as ICNIRP guidelines.

A common, basic feature is that all the above standards are firmly based on established science, and aim at protecting against all – and only – the adverse effects that have been clearly indicated by qualified research.

In recent years, however, a culture of precaution has progressively emerged, in all fields of environmental and health protection. Consequently, the demand has increased for policies that go beyond the prevention of established effects, taking in some consideration also partial or preliminary research findings, and health risks not definitely established. This has led to a broader perspective of health protection, in which other factors than scientific findings are taken into consideration, such as socioeconomic implications.

Different systems of protections have been developed, that may be alternative or complementary to one another. Prior to a discussion of the recommendations issued by ICNIRP for the specific case of EMF, a short discussion of these systems is appropriate. More details can be found in a paper that describes the general approach of ICNIRP to the development of exposure guidelines [2].

THE SYSTEMS OF PROTECTION

Different systems of protection are generally adopted for different situations, depending on the nature of the effects and the quality of scientific data. A schematic distinction can be made between:

- *health threshold based systems*, that are adequate when biological effects that might lead to health detriment have been established, and thresholds for such effects have been identified. The protection of physical health is provided through exposure limits (or dose limits, depending on the nature of the agent), in order to assure that exposures are below the thresholds. Such approach allows, in principle, the total prevention of the identified adverse effects;
- *optimization systems*, that may be appropriate in face of a known and accepted hazard, for which a threshold cannot be determined. This is typical of established effects that are stochastic in nature. The knowledge of the hazard includes the identification of a monotonic dose-response relationship, with health risk reducing to zero at zero exposure. Rather than preventing adverse effects, such systems aim at defining – in an objective way – the most acceptable level of risk, *i.e.* the best balance of costs and benefits of measures adopted to reduce the health detriment. A well-known example is the ALARA (as low as reasonably achievable) principle adopted in the area of ionizing radiation;
- *precautionary measures*, that may be adopted in case of uncertainty, *i.e.* to protect against hazards that have been suggested, but not established by scientific research. Most frequently, these measures are implemented – or invoked – in observance of the precautionary principle.

While the two latter systems require economical, social and political considerations to be taken into account, all the three must be based on solid and reliable scientific data. The starting point for the selection, the development, and the implementation of any protection system is therefore an in-depth analysis of the literature, and a scientific assessment of health risks.

SCIENTIFIC ASSESSMENT OF HEALTH EFFECTS

In the evaluation of biological and health effects carried out by ICNIRP, three steps can schematically be identified [2]:

- initially, each study is evaluated in terms of its relevance for the effect being considered, and the quality of methods used. Different weights may be assigned to the studies, depending on the extent to which they meet quality criteria regarding *e.g.,* the experimental techniques used, the assessment of exposure, the control of experimental conditions, possible biases and confounders, the replicability of the experiments and the reproducibility of the results;
- as a second step, all information relevant for each effect is evaluated. This review is normally carried out separately for epidemiological investigations, human laboratory tests, animal studies, and *in vitro* research;
- finally, the outcomes of the above steps are combined in an overall evaluation, taking the consistency of data in proper consideration. ICNIRP recognizes that this process involves some judgements; however, collective participation minimizes bias due to personal attitudes.

Such process of scientific review is at the same time comprehensive and selective. While the totality of science – and not just the most recent research – is taken into consideration, only papers that meet commonly accepted quality standards are retained. Publication in peer reviewed journals is the basic criterion, but further selection may be operated based on crucial aspects such as the quality of the exposure assessment.

In this analysis, a fundamental distinction is made between *biological effects* and *health effects*. EMF exposure may in fact result in different biological responses, with different consequences. Some biological effects have no known consequences, either adverse or beneficial, others may result in diseases, and other still have beneficial health consequences.

When the overall evaluation allows the identification of an effect that is causally related to the exposure, the effect becomes *established*. Leading criteria in the identification of effects are the reproducibility of findings, and the consistency across studies of different nature (*e.g.*, data from laboratory research *in vitro* and *in vivo* that may give biological plausibility to a causal interpretation of statistical correlations indicated by epidemiology).

In general, biological effects without any identified adverse health consequences do not form a basis for limiting exposure. However, effects that might plausibly result in health hazards can be taken into account in the definition of basic restrictions.

The established effects shall be quantitatively related to the exposure. However, the entity of a given effect not only depends on the external field level, but also on the coupling of the field with the exposed body, or selected body organs. The quantitative relationship by which the external exposure affects a biologically effective parameter of the target tissue is unique to a single exposure condition. Therefore, effects are better described by quantities that reflect the efficacy by which the external exposure causes a certain biological effect. These are termed *biologically effective quantities*, or *dosimetric quantities*.

Different dosimetric quantities have been identified as appropriate for different interaction mechanisms and biological effects, and are listed in *Table 1*.

In general – but not always – these quantities are internal to the body and therefore cannot be directly measured. A correspondence shall therefore be established between biologically effective quantities and external fields, taking exposure conditions in due account. This is accomplished through theoretical and experimental modelling techniques that constitute what is called *dosimetry*, in analogy with toxicology and ionizing radiation.

By means of biologically effective quantities, established adverse effects can generally be ranked according to the exposure level at which each effect becomes relevant. The effect that is relevant at the lowest level of exposure is called the *critical effect*, and is the criterion for the definition of exposure limits. The limitation of exposure to levels below the threshold for the critical effect provides, *a fortiori*, protection against any other established adverse effect.

It should be noted that in this process the different sensitivities, and ability to tolerate EMF, of different groups of the population are taken into account. The critical effect is selected with special consideration to categories that might exhibit lower tolerance, including children, the elderly, and some chronically ill people. The guidelines are therefore adequate to protect all the population groups, to the extent to which the corresponding scientific knowledge is adequate.

INTERACTION MECHANISMS

As indicated in *Table 1*, different interaction mechanisms have been established depending on the nature of the field, and on the frequency. These mechanisms are discussed in detail in various scientific reviews, including WHO's Environmental Criteria Documents [3-5], and ICNIRP monographs [6].

Two basic mechanisms are relevant in the low- and the high-frequency region of the spectrum, respectively. Time-varying electric and magnetic fields of frequency up to about 10 MHz induce electric fields and currents inside the body. Such currents and fields

Table 1 | *Relevant mechanisms of interaction, adverse effects, biologically effective physical quantities and reference levels for different parts of the EMF spectrum*

EMF spectral region	Relevant mechanism of interaction	Adverse effect	Biologically effective physical quantity	External exposure, reference level
Time-varying electric fields (up to 10 MHz)	Surface electric charges	Annoyance from surface effects, electric shock and burn	External electric field strength	Electric field strength
	Induction of internal electric fields and currents	Stimulation of nerve and muscle cells; effects on nervous system functions	Tissue electric field strength or current density	Electric field strength
Time-varying magnetic fields (up to 10 MHz)	Induction of internal electric fields and currents	Stimulation of nerve and muscle cells; effects on nervous systems functions	Tissue electric field strength or current density	Magnetic flux density
Electromagnetic fields (100 kHz to 300 GHz)	Induction of internal electric fields and currents; absorption of energy within the body	Excessive heating, electric shock and burn	Specific energy absorption rate	Electric field strength; magnetic field strength; power density
	> 10 GHz: Surface absorption of energy	Excessive surface heating	Power density	Power density
	Pulses < 30 μs, 300 MHz to 3GHz, thermoacoustic wave propagation	Annoyance from microwave hearing effect	Specific energy absorption	Peak power density

Table 2 | *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 m^{-2})(rms)	Whole-body average SAR (W kg^{-1})	Localized SAR (head and trunk) (W kg^{-1})	Localized SAR (limbs) (W kg^{-1})
Occupational exposure	up to 1 Hz	40	—	—	—
	1-4 Hz	40/f	—	—	—
	4 Hz-1 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-1 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

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 √2 (~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-minute 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 2 mJ kg^{-1} for the general public averaged over 10 g tissue.*

cause stimulation of electrically excitable tissues, such as nerves and muscles. The appropriate dosimetric quantities for these phenomena are the induced current density and the internal electric field; while present basic restrictions recommended by ICNIRP are based on the first, it has the recently been suggested that the internally induced electric fields are more closely related to several biological effects.

At frequencies above 100 MHz, a different mechanism becomes increasingly important, namely the absorption of electromagnetic energy and its dissipation in tissues as heating. This absorption results in an increase of body temperature, either general or local. The associated biological effects are related to the temperature increase rather than to EMF *per se,* and for this reason are indicated as *thermal effects.* The appropriate biologically effective quantity is the specific absorption rate (SAR), measured in watts per kilogram (W/kg). However, at frequencies above 10 GHz, the energy absorption is limited to superficial body tissues, and the interaction is better represented by the power density of the electromagnetic wave impinging on the body (measured in watts per square meter).

In the frequency region between 100 kHz and 10 MHz, stimulation and thermal effects co-exist, with their relative importance gradually shifting from the former to the latter as the frequency increases.

In the radio frequency (RF) region, the efficacy of EMF coupling with the human body – and therefore SAR, varies with frequency, showing a typical resonance behaviour. The resonance frequency, where the absorption rate is maximum, basically depends on body size, and posture.

BASIC RESTRICTIONS AND REFERENCE LEVELS

A distinctive feature of the ICNIRP guidelines – as well as of other international standards – is the two-level structure. As already mentioned, the biological and health effects depend on several parameters that characterize exposure. *Basic restrictions* are defined in terms of the appropriate biologically effective quantities, and are set below the threshold for the appropriate critical effects. Due to practical difficulties in measuring or calculating some biologically effective quantities, from basic restrictions *reference levels* are derived, that are expressed in terms of a directly measurable parameter of the external exposure. The correspondence is established through dosimetric techniques, either experimental (based on physical phantoms) or computational (based on numerical models of the whole body or specific organs).

Such procedure makes the guidelines practical and flexible. While the basic restrictions are closely related to the biological mechanisms, the reference levels are easier to evaluate and to relate to the emission levels of different sources.

Table 3 | *Basic restrictions for power density in the frequency range 10-300 GHz*

Exposure characteristics	Power density (W m^{-2})
Occupational exposure	50
General public	10

1. *Power densities are to be averaged over any 20 cm^2 of exposed area and any 68/f$^{1.05}$-minute 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 strategy is also conservative. The use of reference levels assures in fact compliance with the basic restrictions, since the relationships between them have been developed under worst-case hypotheses, *i.e.* for conditions of maximum coupling between the external fields and the exposed person. On the other hand, exceeding the reference levels does not necessarily imply that basic restrictions are exceeded; whether this occurs or not should be ascertained through a more detailed investigation.

Both basic restrictions and reference values are affected by uncertainties, due to the intrinsic variability of biological data, experimental errors, uncertainties in the extrapolation of animal data to humans, limitation in dosimetry, biases and confounders. Reduction factors are therefore conservatively introduced, whose magnitude varies depending on the degree of incertitude.

To avoid possible misunderstandings, it shall be clarified that reduction factors are not intended to compensate for gaps in knowledge. In effect, their use as a precautionary measure to account for uncertainty in science has been criticized as inappropriate by standard-setting bodies and health protection agencies. WHO, for example, notes that *"science-based exposure limits should not be undermined by the adoption of arbitrary cautionary approaches. That would occur, for example, if limit values were lowered to levels that bear no relationship to the established hazards or have inappropriate arbitrary adjustments to the limit values to account for the extent of scientific uncertainty"* [7].

Basic restrictions recommended by ICNIRP are listed in *Table 2* and *Table 3*, for frequencies below and above 10 GHz, respectively.

Reference levels for occupational exposure and for general public exposure are listed in *Table 4* and *Table 5*, respectively. The frequency behaviour reflects the different coupling efficiency at different frequencies.

INDIRECT EFFECTS

Besides direct action on biological tissues and physiological functions, two indirect coupling mechanisms of electromagnetic fields exist, that may have an adverse impact on human health.

If a contact occurs either between an individual electrically connected to ground and an ungrounded metal object that has been charged by the external fields, or between a charged individual and a ground-

Table 4 | *Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values)*

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 x 10^5	2 x 105	—
1-8 Hz	20 000	1.63 x 105/f^2	1.63 x 105/f^2	—
8-25 Hz	20 000	2 x 104/f	2.5 x 104/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
400-2000 MHz	3f1/2	0.008$f^{1/2}$	0.01$f^{1/2}$	f/40
2-300 GHz	137	0.36	0.45	50

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-minute period.*
4. *For peak values at frequencies up to100 kHz see* Table 2, *note* 3.
5. *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 1000 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$^{1.05}$-minute period (f in GHz).*
7. *No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields.*

Table 5 | *Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)*

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 x 104	4 x 104	—
1-8 Hz	10 000	3.2 x 104/f^2	4 x 104/f^2	—
8-25 Hz	10 000	4000/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/f1/2	0.73/f	0.92/f	—
10-400 MHz	28	0.073	0.092	2
400-2000 MHz	1375/f$^{1/2}$	0.0037/f$^{1/2}$	0.0046/f$^{1/2}$	f/200
2-300 GHz	61	0.16	0.20	10

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-minute period.

4. For peak values at frequencies up to100 kHz see Table 2, *note 3.*

5. 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 1000 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 $68/f^{1.05}$-minute period (f in GHz).

7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields.

ed metal object, a contact current flows through the body. The resulting biological response varies from perception to painful shocks and burns. Taking into account the different sensitivities of different population groups (men, women, and children), and conservatively assuming as the criterion the lowest perception thresholds, reference levels on contact currents have also been provided. The reader is referred to the text of guidelines for further details.

The second indirect coupling mechanism is related to electromagnetic interference with medical devices worn by, or implanted in, an individual. Such interference, with possible malfunctioning of the devices, may occur at exposure levels lower that the recommended guidelines. However, ICNIRP considers that this issues can be best dealt with by technical bodies that are responsible for electromagnetic compatibility standards.

PRECAUTIONARY POLICIES

While only acute effects have been scientifically established, the possibility of long-term adverse consequences of chronic exposure below the thresholds for acute effects cannot be dismissed, and extremely low frequency (ELF) magnetic fields have been classified by IARC as "possibly carcinogenic to humans" (group 2B) [8]. In order to prevent or reduce these risks, though hypothetical, some national governments or local authorities have adopted measures that replace or complement science-based exposure limits. In general, the *precautionary principle* is invoked to this purpose.

In spite of its popularity, the principle is not well defined, and is variously interpreted. In addition, a possible conflict between science and the principle has been outlined [9]. An important clarification was provided by the European Commission (EC) [10]; it stressed that a basic condition for the principle to be invoked is that a potentially serious health hazard had been identified and scientifically evaluated. Therefore, science should be the fundamental basis – though not the unique one – for the adoption of precautionary policies.

Other criteria are indicated by EC for the correct application of the principle. The selected measures should be *inter alia*:

- tailored to the chosen level of protection;
- non-discriminatory, *i.e.,* comparable situations should be treated in a similar way;
- comparable to measures already taken in equivalent areas;
- based on an examination of the potential benefits and costs;
- provisional, *i.e.,* subject to review in the light of new scientific data.

Examining in this respect the case of EMF, WHO considers that *"[…] a cautionary policy for EMF should be adopted only with great care and deliberation. The requirements for such a policy as outlined by the European Commission do not appear to be met in the case of either power or radio frequency EMF"* [5].

This position is consistent with the evaluation of both IARC and ICNIRP. The classification of ELF magnetic fields in the Group 2B is in fact based on a limited evidence of carcinogenicity in humans, and an inadequate evidence of carcinogenicity in animals. ICNIRP, on its side, considers that, in the absence of support from laboratory studies, the epidemiological data are insufficient to allow an exposure guideline to be established for these fields.

The evidence of carcinogenicity is even less convincing for RF EMF: though limited, epidemiological studies are largely negative, as are most of laboratory studies. In the scientific rationale of its guidelines of 1998, ICNIRP noted that the studies available at the date had yielded no convincing evidence that typical exposure levels led to adverse reproductive outcomes or to an increased cancer risk in exposed individuals. The epidemiological findings appeared consistent with the results of laboratory research on cellular and animal models, that showed neither teratogenic nor carcinogenic effects of exposure to athermal levels of RF EMF.

Findings published after the guidelines were issued did not change the overall pattern. Thus, there seems not to be a need to modify the present guidelines to account for the risk of cancer or other long-term adverse effects not scientifically established.

The inapplicability of the precautionary principle does not necessarily mean disregarding any precaution. On the contrary, WHO recommends that in the presence of scientific incertitude (that is unavoidable in principle) any political decision be taken in the context of a *precautionary framework*, where besides scientific evidence of risk, also social and economic factors are taken into account, including public sensitivities.

In this context, health risks of EMF should be put in an appropriate perspective, comparing them with other risks. It is worth to note, for example, that EMF have received only limited attention in comprehensive reviews on cancer and on children's health, carried out by IARC [11] and by the European Regional Office of WHO [12], respectively.

FUTURE DEVELOPMENTS OF THE ICNIRP GUIDELINES

The development of safety guidelines is a dynamic process, that evolves with the progress of knowledge. ICNIRP continuously checks the validity of its recommendations by monitoring both the advancement of research on biological and health effects of electromagnetic fields, and the development of emerging technologies that may involve the introduction of new sources and new modalities of exposure. While there seems not to be an urgent need to change basic restrictions and reference levels, an update of the scientific rationale that includes the most recent research findings is appropriate. ICNIRP is in the process of revising its recommendations for the whole frequency range covered by the present guidelines, *i.e.* from 0 Hz to 300 GHz. Such activity is coordinated with other international bodies, in particular with WHO and IARC. The three organizations have established tight links, in order to avoid redundant activities and to create the most effective synergies.

A specific sequence of actions has been established in order to provide to authorities, workers, and the public the best possible advice on all health issues related to EMF. On commitment by WHO, ICNIRP carries out a comprehensive review of the scientific literature concerning exposure assessment and dosimetry, biological effects, and epidemiology. On its side, IARC evaluates the available data regarding a possible role of EMF in the development of cancer, with the final goal of classifying the different types of electromagnetic fields on the basis of their carcinogenic power. Using the conclusions of ICNIRP and IARC as input, WHO globally evaluates any possible health risk of EMF exposure, and publishes its review as an Environmental Health Criteria (EHC) document. Finally, ICNIRP revises and updates its guidelines as appropriate.

For low-frequency fields (up to 100 kHz), the IARC monograph was published in 2002 [8], and ICNIRP published its review in 2003 [6]. The EHC document, presently in press, is available online at WHO's website [13]. A revision of ICNIRP guidelines based on this risk assessment is in progress.

The process is necessarily longer for RF fields (100 kHz-300 GHz). An international epidemiological study on mobile phone users is in fact in progress, that is expected to provide important information on a possible association between RF fields and cancer, in particular brain tumours. Only after completion of this study, IARC will convene the expert group for the classification of RF fields with respect to human carcinogenicity. Further steps of risk assessment by WHO and revision of guidelines by ICNIRP will follow, and the whole process will probably take a few years.

CONCLUSIONS

Comprehensive systems of protection have been developed at the international level, and adopted in a large number of countries. They are conservative, flexible, and based on solid science, so providing adequate protection against all known health effects of EMF.

In response to the concerns of the public, and given some uncertainties that still exist in some areas of scientific knowledge, consideration of precautionary measures could be warranted in some cases. A basic requirement is that these measures are adopted in such a way as not to undermine the credibility of the international standards, and consequently the trust in health authorities and in science.

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