AUSTRALIA

Interim guidelines on limits of exposure to 50/60 Hz electric and magnetic fields (1989)

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NATIONAL HEALTH AND MEDICAL RESEARCH COUNCIL

INTERIM GUIDELINES

ON

LIMITS OF EXPOSURE

TO 50/60 Hz

ELECTRIC AND MAGNETIC

FIELDS (1989)

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Department of Community Services and Health

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PREFACE

These guidelines were developed by the International Non-ionizing Radiation Committee of the International Radiation Protection Association (IRPA/INIRC). Two earlier documents, *Environmental health criteria 35: extremely low frequency (ELF) fields* (UNEP/WHO/IRPA 1984) and *Environmental health criteria 69: magnetic fields* (UNEP/WHO/IRPA 1987) contain a review of the biological effects reported from exposure to ELF electric and magnetic fields and, together with more recent publications, served as the scientific rationale for the interim guidelines developed by IRPA/INIRC.

The interim guidelines were approved by the President of IRPA on behalf of the IRPA Executive Council on 3 May 1989. The text was kindly made available to the National Health and Medical Research Council before its publication in the international scientific literature to enable it to be adopted with the minimum of delay and published as an NHMRC document.

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1 - INTRODUCTION

Just over 100 years ago human exposure to external electric and magnetic fields was limited to those fields arising naturally. Within the past 50 years there has been very significant growth of man-made, extremely low frequency (ELF) electromagnetic fields at frequencies of 50 and 60 Hz predominantly from electric energy generation, transmission, distribution and use. Man-made ELF fields are now many orders of magnitude greater than the natural fields at 50 and 60 Hz.

Within all organisms are endogenous electric fields and currents that play a role in the complex mechanisms of physiological control such as neuromuscular activity, glandular secretion, cell-membrane function, and development, growth and repair of tissue. It is not surprising that, because of the role of electric fields and currents in so many basic physiological processes (Grandolfo et al. 1985), questions arise concerning possible effects of artificially produced fields on biological systems. With advances in technology and the ever greater need for electric energy, human exposure to 50/60 Hz electric and magnetic fields has increased to the point that valid questions are raised concerning safe limits of such exposure.

Public concern is growing and in many countries regulatory and advisory agencies have been requested to evaluate possible adverse effects of ELF electromagnetic fields on human health (Grandolfo and Vecchia, 1989). From a review of the scientific literature it is apparent that gaps exist in our knowledge and more data need to be collected to answer unresolved questions concerning biological effects of exposure to these fields. On the other hand, analysis of the existing literature does not provide evidence that exposure at present day levels has a public health impact which would require corrective action. In several countries there is an ongoing controversy between proponents of restrictive protective measures and advocates of technological growth leading to an increase in exposure levels. It thus appeared that there was a need for guidelines on exposure limits based on an objective analysis of currently available knowledge. A detailed discussion of potential adverse effects can be found in the literature (Ahlbom et al. 1987, UNEP/WHO/IRPA 1984, UNEP/WHO/IRPA 1987), and a summary is presented in sections 7.1-7.4.

A first draft of these interim guidelines was distributed to the Associate Societies of IRPA, and to various institutions and individual scientists for comments. Many helpful comments and criticisms were obtained, and are gratefully acknowledged.

The committee recognizes that when exposure limits are established, various value judgements have to be made. The validity of scientific reports must be considered, and extrapolation from animal experiments to effects on humans has to be made. A cost-benefit analysis taking into account national public health priorities, and consideration of economic impact and social issues, may be necessary to derive limits suited to the conditions prevailing in different countries

The rationale for these interim guidelines is provided in sections 7.1-7.4. Measures used to protect workers and the general public from excessive or unnecessary exposure to 50/60 Hz fields are given in. section 7.6.

2 - PURPOSE AND SCOPE

These guidelines apply to human exposure to electric and magnetic fields at frequencies of 50 or 60 Hz. The guidelines do not apply to deliberate exposure of patients undergoing medical diagnosis or treatment.

3 - QUANTITIES AND UNITS

Transmission lines and electrical devices generate 50/60 Hz electric and magnetic fields in their vicinity. The electric and magnetic fields must be considered separately, because at the very long wavelengths (thousands of kilometres in free space or air) corresponding to these frequencies, measurements are made in the near field of the source. where the electric and magnetic fields are not in a constant relationship. Biological systems are extremely small compared to these wavelengths, so that the electric and magnetic fields interact (couple) separately with the system. The electric field created in the vicinity of a charged conductor is a vector quantified by the electric field strength, E. This vector is the force exerted by an electric field on a unit charge and is measured in volts per metre (V/m). The E-vector either oscillates along a fixed axis (single phase source) or rotates in a plane and describes an ellipse (three-phase source). Because the electric field at or close to the surface of an object in the field is generally strongly perturbed, the value of the 'unperturbed electric field' (i.e. the field that would exist if all objects were removed) is used to characterise exposure conditions.

The magnetic field is a vector quantity. As in the case of electric fields, single-phase and three-phase fields can be defined whose vector properties are the same as those previously described for the E-field. The magnetic field strength, H, is the axial vector whose curl (rotation) equals the current density vector, including the displacement current, and is expressed in amperes per metre (A/m). The magnetic flux density, B, also known as the magnetic induction or simply the B-field, is accepted, however, as the most relevant quantity for expressing magnetic fields associated with biological effects. The magnetic flux density is defined in terms of the force exerted on a charge moving in the field, and has the unit teslas (T). One tesla is equal to 1 $V \cdot s/m^2$ or 1 weber per square metre (Wb/m^2). An important distinction between B- and H-fields becomes apparent only in a medium which has a net polarization of magnetic dipoles. In free space, and for practical purposes in biological tissues, B and H are proportional. The ratio B/H is the magnetic permeability of free space, $\mu_o = 4\pi 10^{-7}$ H/m, and it is expressed in henrys per metre (1 H/m = 1 Wb/A-m).

The E-, B- and H-fields can be described as time-varying sunusoidal components along three orthogonal axes. The effective field strength is the root of the sum of these three mean squared (temporal mean square) mutually orthogonal components.

In this document exposure limits for the magnetic field are given in terms of the rms magnetic flux density. The corresponding values of the rms magnetic field strength can be obtained taking into account that 1 μT corresponds to 0.7958 A/m, and 1 A/m corresponds to 1.257 μ.T.

The quantities described above characterise somewhat idealised exposure conditions (fields impinging upon the surface of the body), because reference is made to the situation in which the exposed body is absent from the field. Thus unperturbed E or H fields may be compared to radiometric quantities.

Biological effects should be related to the field on the surface of the body, as well as to the electric fields, currents and current densities induced inside the body. The unit of electric current is the ampere (A) which is equal to an electric charge of 1 coulomb moving past a given point per second (C/s). The current density is a vector quantity whose magnitude is equal to the charge that crosses a unit surface area perpendicular to the flow of charge per unit of time. The current density is expressed in amperes per square metre (A/m^2). These quantities should be considered dosimetric ones. Considered rigorously these quantities represent dose rates. In order to derive a meaningful dose concept the dependence of biological effects upon the duration of exposure and the distribution of the dose rate in space and time, have to be explored and taken into account.

Well established effects, such as interactions with excitable membranes of nerve and muscle cells, show a dependence upon local E field strength or current density. As is the case with other dose rate dependent phenomena, thresholds for these effects can be demonstrated. These thresholds are best expressed in terms of the current density induced in the body. Thus the criterion used for exposure limits is this induced current density. Because currents induced in the body cannot be easily measured directly, the working limits in terms of unperturbed electric field strength and magnetic flux density have been derived from the criterion value of induced current density. The values obtained were modified taking into account effects due to indirect coupling mechanisms as discussed in the rationale.

A review of quantities, units and terminology for non ionizing radiation protection has been previously published (IRPA/INIRC 1985).

4 – EXPOSURE LIMITS

The basic criterion is to limit current densities induced in the head and trunk by continuous exposure to 50/60 Hz electric and magnetic fields to no more than about 10 mA/m^2.

4.1 – OCCUPATIONAL

4.1.1 - Electric field

Continuous occupational exposure during the working day should be limited to rms unperturbed electric field strengths not greater than 10 kV/m.

Short-term occupational exposure to rms electric field strengths between 10 and 30 kV/m is permitted, provided the rms electric field strength (kV/m) times the duration of exposure (hours) does not exceed 80 for the whole working day.

4.1.2 - Magnetic field

Continuous occupational exposure during the working day should be limited to rms magnetic flux densities not greater than 0.5 mT.

Short-term occupational whole body exposure for up to two hours per workday should not exceed a magnetic flux density of 5 mT. When restricted to the limbs, exposures up to 25 mT can be permitted.

4.2 – GENERAL PUBLIC

4.2.1 - Electric field

Members of the general public should not be exposed on a continuous basis to unperturbed rms electric field strengths exceeding 5 kV/m. This restriction applies to open spaces in which members of the general public might reasonably be expected to spend a substantial part of day, such as recreational areas, meeting grounds and the like. Exposure to fields between 5 and 10 kV/m should be limited to a few hours per day.

When necessary, exposures to fields in excess of 10 kV/m can be allowed for a few minutes per day, provided the induced current density does not exceed 2 mA/m^2 and precautions are taken to prevent hazardous indirect coupling effects.

It should be noted that buildings in a 5 kV/m external field have a field strength lower by more than an order of magnitude inside the building.

4.2.2 - Magnetic field

Members of the general public should not be exposed on a continuous basis to unperturbed rms magnetic flux densitites exceeding 0.1 mT. This restriction applies to areas in which members of the general public might reasonably be expected to spend a substantial part of the day.

Exposures to magnetic flux densities between 0.1 and 1.0 mT (rms) should be limited to a few hours per day. When necessary, exposures to magnetic flux densities in excess of 1 mT should be limited to a few minutes per day.

4.3 - SUMMARY OF EXPOSURE LIMITS

A summary of the limits recommended for occupational and general public exposures to 50/60 Hz electric and magnetic fields is given in table 1.

Table 1. Limits of exposure to 50/60 Hz electric and magnetic fields

Exposure characteristics	Electric field strength kV/m (rms)	Magnetic flux density mT (rms)
OCCUPATIONAL		
Whole working day	10	0.5
Short term	30[a]	5[b]
For limbs	-	25
GENERAL PUBLIC		
Up to 24 hours/day[c]	5	0.1
Few hours/day[d]	10	1

Notes: (a) The duration of exposure to fields between 10 and 30 kV/m may be calculated from the formula $t \leq 80/E$ where t is the duration in hours per work day and E is the electric field strength in kV/m.

(b) Maximum exposure duration is two hours per work-day.

(c) This restriction applies to open spaces in which members of the general public might reasonably be expected to spend a substantial part of the day, such as recreational areas, meeting grounds and the like.

(d) These values can be exceeded for a few minutes per day provided precautions are taken to prevent indirect coupling effects.

5 - MEASUREMENT

Measurements of electric and magnetic fields should be performed according to the IEC and - IEEE standards on measurement of electric and magnetic fields from AC power lines (IEC 1987, IEEE 19.87). For inhomogencous magnetic fields the magnetic flux density should be averaged on a loop surface of 100 cm^2.

6 - CONCLUDING REMARKS

The exposure limits are based on established or predicted effects of exposure to 50/60 Hz fields. Although some epidemiological studies suggest an association between exposure to 50/60 Hz fields and cancer, others do not. Not only is this association not proven, but present data do not provide any basis for health risk assessment useful for the development of exposure limits.

Current laboratory studies are testing the hypothesis that 50/60 Hz fields may act as, or with, a cancer promoter. These studies are still exploratory in nature and have not established any human health risk from exposure to these fields.

These limits have been developed from present knowledge, but there are still areas of research where questions have been raised that need to be addressed. A major research effort to supplement our knowledge on the health consequences, if any, of long-term continuous exposure of humans to low-level 50/60 Hz fields is required.

There is an ever increasing number of people wearing implanted cardiac pacemakers which may be sensitive to interference from electric and magnetic fields. These people may not always be adequately protected against interference at some of the above exposure limits (see section 7.5).

These guidelines will be subjected to periodic revision and amendment with advances in knowledge.

7 – RATIONALE FOR EXPOSURE LIMITS

7.1 - GENERAL CONSIDERATIONS

These guidelines are intended to protect the health of humans from the potentially harmful effects of exposure to electric and magnetic fields at frequencies of 50/60 Hz, and are primarily based on established or predicted effects.

7.1.1 - Population

The first step in establishing exposure limits is to define the population to be protected. Exposure limits may pertain to the general population or to particular groups within it.

A distinction is made between the exposure limits for workers and the general public for the following reasons. The occupationally exposed population consists of adults exposed under controlled conditions in the course of their duties, who should be trained to be aware of potential risks and to take appropriate precautions. Occupational exposure is limited to the duration of the working day or duty shift per 24 hours, and the duration of the working lifetime.

The general public comprises individuals of all ages and different health status. Individuals or groups of particular susceptibility may be included in the general population. In many instances members of the general public are not aware that exposure takes place or may be unwilling to take any risks (however slight) associated with exposure. The general public can be exposed 24 hours per day and over the whole lifetime. Finally the public cannot be expected to accept effects such as annoyance and pain due to transient discharges or hazards due to contact currents. The above considerations were the reason for adopting lower exposure limits for the general public than for the occupationally exposed population.

7.1.2 – Coupling mechanisms

The more important mechanisms of these interactions (Tenforde and Kaune 1987, Bernhardt 1998) are shown below:

- 50/60 Hz electric fields induce a surface charge on an exposed body, which results in currents inside the body, the magnitude of which is related to the surface charge density. Depending on the exposure conditions, 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;

- magnetic fields from 50/60 Hz sources also act on humans by inducing electric fields and currents inside the body;

- electric charges induced in a conducting object (e.g. an automobile) exposed to a 50/60 Hz electric field may cause current to pass through a human in contact with it;

- magnetic field coupling to a conductor, for example a wire fence, causes 50/60 Hz electric currents to pass through the body of a person in contact with it;

- transient discharges (often called sparks) can occur when people and metal objects exposed to a strong electric field come into sufficiently close proximity, and

- 50/60 Hz electric or magnetic fields may interfere. With implanted medical devices (e.g. unipolar cardiac pacemakers), and cause malfunction of the device.

The first two interactions listed above are examples of direct coupling between living organisms and 50/60 Hz fields. The latter four interactions listed above are examples of indirect coupling mechanisms, because they can occur only when the exposed organism is in the vicinity of other bodies. These bodies can include other humans or animals, and objects such as automobiles, fences, or implanted devices.

7.2 - CRITERION FOR LIMITING EXPOSURE

The limits recommended in these guidelines were developed primarily on established or predicted immediate health effects produced by currents induced in the body by external electric and magnetic fields. These limits correspond to induced current densities that are generally at or slightly above those normally occurring in the body (up to about 10 mA/m^2).

An unperturbed electric field strength of 10 kV/m induces rms current densities of less than 4 mA/m^2 when averaged over the head or trunk region (Bernhardt 1985, Kaune and Forsythe 1985). However, peak current densities in the same regions would exceed 4 mA/m^2 (Kaune and Forsythe 1985, Dimbylow 1987) depending on the size, posture or orientation of the person in the electric field.

Assuming a 10 cm radius loop of tissue of conductivity 0.2 S/m, a magnetic flux density of 0.5 mT at 50/60 Hz would induce a rms current density of about 1 mA/m^2 at the periphery of the loop.

The following statements can be made with respect to induced current density ranges and biological effects resulting from whole body exposure to 50/60 Hz fields (UNEP/WHO/IRPA 1987):

- between 1 and 10 mA/m^2 minor biological effects have been reported;

- between 10 and 100 mA/m^2 there are well established effects, including visual and nervous system effects;

- between 100 and 1000 mA/m^2 stimulation of excitable tissue is observed and there are possible health hazards;

- above 1000 mA/m^2 extra systoles and ventricular fibrillation can occur (acute health hazards).

Endogenous currents in the body. are typically up to about 10 mA/m^2, although they can be much higher during certain functions. The committee felt that, to be conservative, current densities induced by external electric or magnetic fields should not significantly exceed this value. Thus, limits for continuous human exposure to electric and magnetic fields were determined using this criterion.

Safety factors in health protection standards do not guarantee safety, but represent an attempt to compensate for unknowns and uncertainties. Readers are referred to the Environmental Protection Agency (EPA 1986) for a description of the use of safety factors in the derivation of exposure limits.

7.3 - RATIONALE FOR LIMITS ON ELECTRIC FIELD EXPOSURES

From a review of laboratory and human studies, the conclusions below were drawn by a joint WHO/ERPA Task Group studying health effects of ELF electric fields (UNEP/WHO/IRPA 1984). The guidelines were essentially based on the following WHO/IRPA conclusions and on more recent reports.

- Animal experimentation indicates that exposure to strong ELF electric fields can alter cellular, physiological and behavioural events. Although it is not possible to extrapolate these findings to human beings at this time, these studies serve as a warning that unnecessary exposure to strong electric fields should be avoided.

- Adverse human health effects from exposure to ELF electric fields at strengths normally encountered in the environment or the workplace have not been established.

- The threshold field strength for some human beings to feel spark discharges in electric fields is about 3 kV/m and to perceive the field between 2-10 kV/m. There are no scientific data at this time that suggest that perception of a field per se produces a pathological effect.

- Although there are limitations in the epidem iological studies that suggest an increased incidence of cancer among children and adults exposed to 50/60 Hz fields, the data cannot be dismissed. Additional study will be required before these data can serve as a basis for risk assessment.

- It is not possible from present knowledge to make a definitive statement about the safety or hazard associated with long-term exposure to sinusoidal electric fields in the range of 1 to 10 kV/m. In the absence of specific evidence of particular risks or disease syndromes associated with such exposure, and in view of experimental findings on the biological effects of exposure, it would be prudent to limit exposure, particularly for members of the general population.

7.3.1 - Basis for extrapolation of experimental results to man

External electric fields induce electric currents within biological systems. The magnitude of the induced currents depends on a number of factors including the size and shape of the object exposed its electric conductivity and proximity to other conducting objects. Man's size and posture make it difficult to simulate in laboratory animals the current densities that occur when man is exposed to strong electric fields. The species differences between man and laboratory animals may result in differences in the threshold for biological responses, the magnitude of physiological responses, and the degree of adaptation.

A physical basis for extrapolations or what is called 'scaling' from animal to human subjects was provided by recent dosimetric studies. Comparing enhancement of fields at body surfaces and internal current densities, comparisons of exposure can be made. According to a study by Kaune et al. (1985), exposure of pigs to an effective electric field strength of 25 kV/m is equivalent to human exposure at 9.3 kV/m if peak electric field strengths at the surface of the body are taken into account, and 13 kV/m if the average electric field strength at the surface is considered. Using average total current densities in the torso as a scaling factor, Kaune and Forsythe (1988) derived approximate values for comparisons of exposure of humans, swine and rats. Electric fields at 60 Hz result in current densities 7.3 times larger in humans than in swine, and 12.5 times larger in humans than in rats at the same unperturbed field strength. Exposure of rats at 100 kV/m is roughly equivalent to human exposure at 8 kV/m, and to exposure of swine at 13.7 kV/m. Thus animal experiments suggest that prolonged exposure to fields in the range of 8 to 15 kV/m does not lead to evident adverse effects in humans (Czerski, 1988).

7.3.2 - Experimental studies

A large body of data has been collected on blood chemistry changes in animals exposed under different conditions; no consistent picture of physiological changes is evident.

Results of behavioural experiments on animals which suggested an effect of exposure were at levels at or above those needed for sensory perception of the field. Most behavioural tests showed no effects with exposure to electric field strengths up to 10 kV/m (UNEP/WHO/IRPA 1994, Ahlbom et al. 1987). Effects on behaviour have been reported in isolated instances from electric field exposure inducing current densities as low as 3 mA/m^2. Health consequences, if any, of these observations require further studies.

Many studies on laboratory animals (rodents) have indicated that there are no significant adverse effects on growth and development. Multigeneration studies in swine and rats exposed to electric fields (30 kV/m and 65 kV/m respectively) revealed developmental defects (Phillips 1981, Phillips 1983). These results were not confirmed in recent, well controlled studies on rats (Rommereim et al. 1988, Sikov et al. 1987).

Evaluation of the evidence from many studies indicates that animal morbidity and mortality are unaffected by long-term exposure. Such studies were carried out on small laboratory animals (rats and mice) at unperturbed 50/60 Hz electric field strengths up to 100 kV/m (Bonnell et al. 1986), and on larger animals, including miniature pigs, at levels near 30 kV/m (Phillips 1981, Phillips 1985).

7.3.3 - Human studies

At 50/60 Hz a field strength of 20 kV/m is the perception threshold of 50% of people for sensations from their head hair or tingling between body and clothes; as shown under laboratory conditions a small percentage of people can perceive a field strength of 2 or 3 kV/m (Cabanes and Gary 1981, IEEE 1978).

Controlled laboratory studies on volunteers exposed for short periods to electric field strengths of up to 20 kV/m have, in general, shown no significant effects (Hauf and Wiesinger 1973, Hauf 1974, Rupilius 1976, Sander et al. 1982). These data do not establish that health effects could not occur from long-term exposure (months or years).

Well-controlled studies on the health status of linemen and switchyard workers have not revealed any statistically significant differences between exposed and control groups (Knave et al. 1979, Stopps and Janischewsky 1979, Baroncelli et al. 1986). These studies are among the more complete and are representative of high levels of occupational exposure. Because of the small populations studied and the resulting low statistical power, these studies cannot exclude the existence of small effects in these highly exposed populations.

Several studies of the incidence of cancer or mortality from cancer among arbitrarily defined occupational groups considered to be exposed to electromagnetic fields (among other factors) suggested an association between 'electrical occupations' and cancer. Because of the inherent uncertainty associated with this type of epidemiological study, and the lack of measurement of exposure, no definitive conclusion can be drawn. However, the questions raised by these reports necessitate further investigation (UNEP/WHO/IRPA 1984, UNEP/WHO/IRPA 1987. Repacholi 1988).

Recent epidemiological studies (Savitz, 1988) provided some support for the findings of a previous study on childhood cancer and exposure to weak magnetic fields (Wertheimer and Leeper 1979). Both studies were carried out in the same geographical area and on a similar population, thus the conclusions drawn from both reports cannot be generalised. A scientific panel (Ahlbom et al. 1987) which evaluated the implications of these epidemiological studies concluded that the association between cancer incidence and 60 Hz field exposure is still not established and remains a hypothesis. The committee concurs with this conclusion. To date, chronic low-level exposure to 50/60 Hz fields has not been established to increase the risk of cancer.

From the experimental data and human studies it was concluded (UNEP/WHO/IRPA 1984) that no adverse health effects resulted from short-term exposure at strengths up to 20 kV/m at frequencies of 50 and 60 Hz.

Steady-state 50/60 Hz current from contact with charged objects can produce biological effects that range from just noticeable perception to ventricular fibrillation and death (UNEP/WHO/IRPA 1984). The severity of an electric shock from touching a charged object depends upon a number of factors including grounding conditions, the magnitude of contact current, the duration of current flow, and body mass. Currents above the 10 mA level represent a serious risk, because the 'let-go' threshold* may be exceeded, and the individual might not be able to release a charged object due to involuntary muscle contractions (IEEE 1978, IEEE 1984). The estimated level of let-go current in small children, is approximately one half of that for an adult man. If the current is increased beyond the let-go value, there is a possibility that ventricular fibrillation can occur Short circuit current resulting from touching charged objects can be related to unpertubed field strengths (Guy 1985).

Typical threshold values resulting from steady-state contact currents of 50/60 Hz from vehicles (IEEE 1978, Zaffanella and Deno 1978, UNEP/WHO/IRPA 1984) include:

10-12 kV/m: median pain. perception for children, finger contact, car;

8-10 kV/m: painful shock for children, finger contact, truck;

4-5 kV/m: median touch perception for men, finger contact, car;

2-2.5 kv/m: median touch perception for children, finger contact, car.

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* The let-go threshold is the current intensity above which a person cannot let go of a gripped conductor as long as the stimulus persists due to uncontrollable muscle contraction.

Transient capacitative discharges can occur between a person and a charged object via a spark through an air gap. The human reaction to transient electric shocks from spark discharges has been shown to depend in a complex manner on the discharge voltage and the capacitance of the discharging object (IEEE 1978). The sensitivity of individuals to transient discharges has a linear dependence on body mass (Larkin et al. 1986). Other factors such as sex, age or skin hardness have no correlation with the threshold sensitivity of an individual to transient electric discharges. Data obtained on adults exposed to spark discharges of various intensities showed that 50% of the subjects perceived spark discharges in a field of 2.7 kV/m and 50% found the spark discharges annoying at 7 kV/m (Zaffanella and Deno 1978). To obtain these data, persons standing in an electric field touched a metallic post with a finger; it is assumed that their capacitance was of the order of 170 pF.

7.3.4 - Derivation of exposure limits

The proposed criterion of induced current density of 10 mA/m^2 in the body is within the range of magnitude of spontaneous endogenous current densities. Our knowledge about the possible effects of long-term exposure to fields inducing currents near the criterion value is still limited and most evidence is based on short-term observations.

In view of these reservations the continuous occupational exposure should be limited to 10 kV/m, inducing a current density of 4 mA/m^2 on average. There is substantial workplace experience in addition to controlled laboratory studies on volunteers which indicate that short-term exposures to fields up to 30 kV/m have no significant adverse health consequences. Exposures to electric fields between 10 and 30 kV/m produce proportionally increasing discomfort and stress and should be limited in duration accordingly. A practical approach to limiting the duration of exposure to fields between 10 and 30 kV/m is to use the formula $t < 80/E$ over the whole working day, where t is the duration of exposure in hours to a field strength of E kV/m.

For the reasons given in section 7.1.1, a further safety factor was incorporated for exposure of the general public.

A safety factor of 5 with respect to the criterion of 10 mA/m^2 was introduced leading to a limit of 2 mA/m^2 which corresponds to an electric field strength of 5 kV/m.

The limit of 5 W/m for continuous exposure of the general public also provides substantial protection from annoyance caused by steady-state contact currents or transient discharges. This limit, however, cannot completely eliminate perception of the electric field effects since the perception threshold for some people is below 5 kV/m. In such cases additional technical measures (e.g. grounding) may be instituted to avoid indirect coupling effects arising from touching charged, ungrounded objects. It should be noted that continuous exposures of the general public outdoors rarely exceed 1-2 kV/m (Tenforde and Kaune 1987).

7.4 - RATIONALE FOR LIMITS ON MAGNETIC FIELD EXPOSURES

In terms of a health risk assessment, it is difficult to correlate precisely the internal tissue current densities with the external magnetic flux density. Assuming a 10 cm radius loop in tissue of activity 0.2 S/m, it is possible to calculate the magnetic flux density that would produce potentially hazardous current densities in tissues. The following statements can be made for induced current density ranges and magnetic flux densities of sinusoidal homogeneous fields that produce biological effects from whole-body exposure (UNEP/WHO/IRPA 1987):

- between 1 and 10 mA/m^2 (induced by magnetic flux densities above 0.5 and up to 5 mT at 50/60 Hz) minor biological effects have been reported;
- between 10 and 100 mA/m^2 (above 5 and up to 50 mT at 50/60 Hz) there are well established effects, including visual and nervous system effects;
- between 100 and 1000 mA/m^2 (above 50 and up to 500 mT at 50/60 Hz) stimulation of excitable tissue is observed and there are possible health hazards;
- above 1000 mA/m^2 (greater than 500 mT at 50/60 Hz) extra systoles and ventricular fibrillation can occur (acute health hazards).

Several laboratory studies have been conducted on human subjects exposed to sinusoidally time-varying magnetic fields with frequencies of 50/60 Hz. None of these investigations has revealed adverse clinical or physiological changes. The strongest magnetic flux density used in these studies with human volunteers was a 5 mT, 50 Hz field to which subjects were exposed for four hours. Some epidemiological reports present data indicative of an increase in the incidence of cancer among children, adults, and occupational groups (as mentioned in section 7.3). The studies suggest an association with exposure to weak 50 or 60 Hz magnetic fields. These associations cannot -be satisfactorily explained by the available theoretical basis for the interaction of 50/60 Hz electromagnetic fields with living systems. The magnetic flux densities in some epidemiological studies suggesting an increased cancer incidence are at values near 0.25 μT. This magnetic flux density would induce a current density that is well below those levels normally occurring in the body. The epidemiological studies are not yet conclusive. Although these epidemiological data cannot be dismissed, there must be additional studies before they can serve as a basis for health hazard assessment. Furthermore, scant laboratory evidence is available to support the hypothesis that there is an association between 50/60 Hz fields and increased cancer risk.

The total number of direct observations of the effect of magnetic flux densities in humans is limited. Controlled laboratory studies on human volunteers exposed for four to six hours per day for several days to magnetic flux densities up to 5 mT (together with electric fields up to 20 kV/m) did not demonstrate significant effects (UNEP/WHO/IRPA 1987, Sander et al. 1982). Therefore the short term occupational exposure should not exceed 5 mT (inducing current densities of 10 mA/m^2, the criterion value) and 25 mT for the extremities. The latter value takes into account the loop diameters in the limb which are about one fifth of those in the trunk. Because of the sparseness of data on long-term exposures to magnetic fields the magnetic flux density for continuous exposure in the occupational environment is limited to 0.5 mT, a limitation which can be accepted without great difficulty in most occupational .environments.

For reasons developed in section 7.1.1 the limit for continuous exposure of the general public was set at 0.1 mT, a factor of 5 below the limit for continuous occupational exposure, while the short-term exposure limit was set at 1 mT.

Typical office and household average levels are 0.01-1 μT (Gauger 1984). Values of up to 12 μT may occur intermittently in rooms heated using electric/oil heaters (Krause 1986) as well as peak levels of 1-30 μT at 30 cm distance from various appliances; magnetic flux densities from power transmission systems are somewhat higher and can typically approach levels of about 10-30 μT (Bernhardt 1988, Tenforde and Kaune 1987, UNEP/WHO/IRPA 1987). However, near (3.0 cm) some appliances like electric blankets, hair dryers, shavers and magnetic mains voltage stabilizers, the magnetic flux density can approach levels of 0.1-1 mT. Because of the strong inhomogeneity of magnetic fields near most appliances, the magnetic flux density should be averaged on a loop surface of 100 cm^2 to simulate a realistic current loop in the human body.

7.5 - CARDIAC PACEMAKERS

Interference of electric fields with implanted cardiac pacemakers can lead to reversion to a fixed rate; cessation of stimulation is possible. Such direct interference has not been reported in fields below 2.5 kV/m (UNEP/WHO/IRPA 1984, Moss and Carstensen 1985). Although body currents produced by contact with a vehicle in a weaker field may cause interference, the risk of pacemaker reversion is believed to be slight (UNEP/WHO/IRPA 1984).

The probability that a malfunction will occur in the presence of an external magnetic field is strongly dependent on the pacemaker model, on the value of the programmed sensing voltage and on the area of the pacemaker loop which is determined during implantation. Assuming sensitivities of 0.5 to 2 mV for 50/60 Hz worst case conditions (600 cm^2 for the area of the pacemaker electrode, homogeneous field perpendicular to this area), interference magnetic flux densities of 15 to 60 μT may be calculated. Similar results were obtained by other authors (Bridges and Frazier 1979). For more realistic conditions, due to the inhomogeneity of magnetic field, smaller effective loop areas, and smaller sensitivities of the signal sensing circuit, there is only a small probability of the occurrence of a pacemaker malfunction at magnetic flux densities below about 100-200 μT (UNEP/WHO/IRPA 1987).

Increased sophistication of pacemakers has made the question of possible electromagnetic interference more difficult. Physicians implanting (and/or programming) very sensitive unipolar demand pacemakers should be informed by the manufacturer that malfunction of the pacemaker can occur in a strong electric field, so that the patient can receive a detailed warning, e.g. avoiding areas with strong electric fields. A reduction of the susceptibility of pacemakers to electromagnetic interference is recommended.

7.6 - PROTECTIVE MEASURES

The responsibilities for the protection of workers and the general public against the potentially adverse effects of exposure to 50/60 Hz electric and magnetic fields should be clearly assigned. It is recommended that the competent authorities consider the following steps:

- development and adoption of exposure limits and the implementation of a compliance program;
- development of technical standards to reduce the susceptibility to electromagnetic interference, e.g. for pacemakers;
- development of standards defining zones with limited access around sources of strong electric and magnetic fields because of electromagnetic interference (e.g. for pacemakers, and other implanted devices). The use of appropriate warning signs should be considered;
- requirement of specific assignment of responsibility for the safety of workers and the public to a person at each site with high exposure potentials;
- drafting of guidelines or codes of practice for worker safety in 50/60 Hz electromagnetic fields;
- development of standardized measurement procedures and survey techniques;
- requirements for the education of workers on the effects of exposure to 50/60 Hz fields and the measures and rules which are designed to protect them.

General rules on medical surveillance have been established by the ILO in the ILO Convention 161 concerning Occupational Health Services (ILO 1985).

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