Exposure to electromagnetic fields (0 Hz - 10 MHz)

The Minister of Housing, Spatial Planning and the Environment

Subject : report electromagnetic fields
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Dear Sir,

Regularly, questions are being asked about the safety of living near power lines. That was one of the reasons that the Health Council issued an advisory report on that subject in 1992.

In that report the Council proposed exposure limits for 50 Hz fields. These were based on recommendations of the International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA). In 1998, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), that originated from that committee, published guidelines for exposure limits for the entire frequency range of 0 Hz through 300 GHz. Therefore the proposals from the Health Council's 1992 report had to be revised. Also, the report called for a re-evaluation after five years of the research on long-term effects, because new data were to be expected within that period.

In the present advisory report, an *ad hoc* Expert Committee set up by me gives an updated review of the state of science. It was charged with reconsidering the exposure limits and expand them to the frequency range of 0 Hz (static fields) through 300 Hz and with re-analysing all available data on long-term effects.

After consultation of the Standing Committee on Radiation Hygiene, I hereby present you the final report of the Committee. I have also presented it today to the Minister of Health, Welfare and Sport, the Minister of Economic Affairs, the State Secretary of Social Affairs and Employment and the State Secretary of Transport, Public Works and Water Management.

The exposure limits proposed in this advisory report differ in part from the most recent guidelines of the ICNIRP. Despite the fact that the ICNIRP guidelines for exposure of the general population have been adopted in 1999 in a recommendation of the Council

of the European Communities, several parts of them are still under scientific discussoin. To my opinion, the present recommendations have been scientifically better founded than the ICNIRP guidelines. I would therefore make a plea that the policy of the Netherlands Government on this matter be based on the recommendations of the Health Council.

With regard to the long-term effects the report concludes that, also on the basis of the most recent data, a causal relationship between exposure to the electromagnetic fields associated with the electricity supply and certain types of cancer cannot be scientifically established. Nevertheless it remains advisable to continue following the scientific developments in this field. This will be one of the tasks of the semi-permanent Electromagnetic Fields Committee that will be set up shortly at the Health Council.

Yours sincerely,

(signed)

Prof JA Knottnerus

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Report of a Committee of the Health Council of the Netherlands

To:

the Minister of Housing, Spatial Planning and the Environment

the Minister of Health, Welfare and Sport

the Minister of Economic Affairs

the State Secretary of Social Affairs and Employment

the State Secretary of Transport, Public Works and Water Management

No. 2000/06E, The Hague, 7 March 2000

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Executive summary

Extremely low frequency electromagnetic fields can influence the human body. In 1992 the Health Council therefore issued an advisory report containing proposals designed to limit exposure to fields of this type. The limits of exposure proposed in that report related only to the 50 Hz fields associated with the electricity supply and were based on short-term effects. According to the report, there was insufficient scientific evidence of the existence of long-term effects, and in particular the induction of certain forms of cancer. Due to continuing public discussions and advances in scientific understanding, a revision of the 1992 advisory report is now desirable.

In the present advisory report, a committee of the Health Council of the Netherlands has tested the scientific data against a number of criteria. Depending on the type of research involved, if one or more of these criteria is not fulfilled then the respective data is not included in the subsequent analysis. This applies both to the data on short-term effects and that on long-term effects. With the available data and based on these considerations, the committee is only able to base its recommendations for exposure limits on short-term effects.

Short-term effects

The Committee draws a distinction between those subjected to occupational exposure and the general population. The limits for the former group are higher than those for the population as a whole. This results from the application of safety factors to the exposure levels above which health impairment could occur. Those safety factors are five times higher for the general population than for those subjected to occupational exposure. However, the committee does not include everybody who might be exposed in the course of their work in the latter category. The higher levels of exposure apply only to workers who are familiar with the risks and with steps that can be taken to limit them.

The actual exposure limits are called 'basic restrictions'. These are maximum values for electromagnetic phenomena which in the body can have negative effects on health. Precisely which phenomenon is involved depends on the frequency of the electromagnetic field. In the case of static fields, what matters is the strength of the electric or magnetic field. It should be noted that there is no sharp boundary between static and alternating fields. For this purpose, the committee chooses the frequency of 1 Hz. For alternating fields with frequencies up to around 10 MHz, the density of the current that is induced in the body is important. For frequencies upwards of around 100 kHz, the key factor is the conversion of electromagnetic energy into heat (between 100 kHz and 10 MHz, both current density and heat absorption are important). This advisory report relates mainly to frequencies at which the basic restrictions are expressed as current density. In establishing the basic restrictions, the committee applies certain safety limits. This is done, among other things, because of uncertainties in and incompleteness of scientific knowledge and a possible higher sensitivity of certain populations groups, e.g., diseased people, elderly and young children.

Because the current density in the body cannot in practice be measured, the committee has derived values from the basic restrictions for parameters which are, in fact, easy to measure, namely the strength of the undisturbed electric and magnetic field at the exposure site. It calls these derived values 'reference levels'. They can be considered as tools in establishing compliance with the basic restrictions. If the field strengths are not higher than these reference levels, the basic restrictions are not being exceeded. If, on the other hand, the field strengths are higher than the reference levels, then it is necessary to investigate whether the basic restrictions are being exceeded. It should be noted that, partly because of the applied safety margins, the basic restrictions (and therefore also the reference levels) cannot be regarded as representing a sharp boundary between high, potentially dangerous and low, intrinsically safe field strengths. What they do tend to indicate is that, if they are not exceeded, the risk for adverse health effects is negligible, but if they are exceeded, it is necessary to investigate whether the resultant exposure could give rise to health problems.

The influence of current that is induced in the body is to be regarded as a direct effect of the interaction between electric and magnetic fields and the body. In formulating the exposure limits, the committee has also taken into account the possible occurrence of indirect effects. These can occur if, as a result of exposure to an electric field, a potential difference arises between an organism and a (large) object. This might be the case, for example, if such an object is not earthed. If it is being touched by an organism that is in contact with the earth, a discharge current will be generated. In the case of high potential differences, it is even possible for spark discharges to occur.

The committee is not issuing any exposure limits for static electric fields. Even in the case of extremely high field strengths, no negative health effects have been discovered. For static magnetic fields it is not possible to indicate a distinct biological effect on which limitation of exposure can be based. As a maximum for short peaks in exposure the committee proposes a magnetic field strength above which biological effects have been demonstrated, as well as unpleasant effects such as nausea and dizziness in individuals who move within the field. In the case of exposure of extremities only, a higher maximum field strength is permissible. For continuous exposure, the committee uses safety factors on account of the relatively scarce and sometimes contradictory scientific data. The committee's recommendations are summarized in Table 1.

Table 1 Basic restrictions for exposure to static magnetic fields.

	magnetic field strength (mT)	
	workers	general population
continuous exposure	200	40
peak exposure	2 000	
peak exposure, extremities only	5 000	

The basic restrictions for exposure to alternating fields have been based on the prevention of two distinct biological effects. For the frequency range up to around 200 Hz, phosphenes are important. These are spots or flashes of light which are perceived via direct stimulation of the retina by electrical current. They are, in themselves, harmless phenomena which disappear of their own accord a short time (generally within an hour) after the removal of the causative factor. The occurrence of phosphenes can, however, be disturbing and cause startling reactions. At frequencies ranging from a few Hz to around 10 MHz, stimulation of nerves can occur. In the case of high current density in the heart region, this can lead to ventricular fibrillation.

Taking these two phenomena into account and applying the safety factors, the committee arrives at the basic restrictions for alternating fields as given in Table 2.

Table 2 Basic restrictions for the frequency range of 1 Hz to 10 MHz.

frequency	current density (mA/m^2)				
	workers		general population		
	body, head [a]	body, partly [b]	body, head [a]	body, partly [b]	
1 - 20 Hz	10	100	2	20	
20 - 200 Hz	$0.5 \times f$	100	$0.1 \times f$	20	frequency *f* in Hz
200 Hz - 4 kHz	100	100	20	20	
4 kHz - 10 MHz	$25\,000 \times f$	$25\,000 \times f$	$5\,000 \times f$	$5\,000 \times f$	frequency *f* in MHz

[a] body, head: body completely or partly exposed, with head included
[b] body, partly: body partly exposed, head not included

From these basic restrictions, and taking into account the possible occurrence of indirect effects, the committee has calculated reference levels. These are given in Table 3 and 4 for situations in which the entire body is exposed.

Table 3 Reference levels for the external electric field (V/m).

frequency	Workers			general population	
	indirect effects not possible		indirect effects possible		
	body, head [a]	body, partly [b]			
1 Hz - 20 Hz	$125 \times 10^4 / f$	$12.5 \times 10^6 / f$	$125 \times 10^4 / f$	$25 \times 10^4 / f$	*f* in Hz
20 Hz - 32 Hz	62 500	$12.5 \times 10^6 / f$	62 500	12 500	*f* in Hz
32 Hz - 200 Hz	62 500	$12.5 \times 10^6 / f$	$200 \times 10^4 / f$	$40 \times 10^4 / f$	*f* in Hz
0,2 kHz - 4 kHz	$1.25 \times 10^4 / f$	$1.25 \times 10^4 / f$	$2\,000 / f$	$400 / f$	*f* in kHz
4 kHz - 1 MHz	3 125	3 125	500	100	
1 MHz - 10 MHz	$3\,125 \times f^{-1.71}$	$3\,125 \times f^{-1.71}$	$500 \times f^{-0.91}$	$100 \times f^{-0.55}$	*f* in MHz

[a] body, head: body completely or partly exposed, with head included
[b] body, partly: body partly exposed, head not included

Table 4 Reference levels for the external magnetic field strength.

frequency	magnetic fluxdensity (μT)		magnetic field strength (A/m)		
	workers	general population	workers	general population	
< 1 Hz	200 000	40 000			
1 - 20 Hz	$12\,000 / f$	$2\,400 / f$	$9\,550 / f$	$1\,910 / f$	*f* in Hz
20 - 200 Hz	600	120	477	95.5	
0,2 - 4 kHz	$120 / f$	$24 / f$	$95.5 / f$	$19.1 / f$	*f* in kHz
4 - 67 kHz	30	6	23.9	4.8	
67 - 153 kHz	$2\,000 / f$	6	$1\,590 / f$	4.8	*f* in kHz
0,153 - 10 MHz	$2.0 / f$	$0.92 / f$	$1.6 / f$	$0.73 / f$	*f* in MHz

If the exposure is limited to parts of the body, higher reference levels can usually be calculated for the magnetic field. Separate proposals are given for such situations. Finally, the committee provides formulas with which, in the case of simultaneous exposure to multiple frequencies, it is possible to calculate whether or not the basic restrictions are being exceeded.

Long-term effects

With regard to long-term effects, the committee limits its discussion to the data concerning the frequencies used in the electricity supply, 50 and 60 Hz. These fall within the range of the extremely low frequencies (ELF).

In recent years the basic *in vitro* and *in vivo* research has afforded few new insights into a possible mechanism which could form the basis for long-term biological effects of exposure to ELF electromagnetic fields. Several mechanisms have been proposed, but none is deemed plausible.

The concerns that are regularly voiced with regard to possible dangers of exposure to ELF electromagnetic fields are, in virtually every case, based on results of epidemiological research. The committee thinks that the quality of the relevant epidemiological research has improved considerably since the publication of the advisory report in 1992. Even so, this research has not resulted in unequivocal, scientifically reliable conclusions.

For the majority of the diseases and health problems that have been investigated, epidemiological research has not resulted in any evidence of a connection with environmental exposure to ELF electromagnetic fields. However, some epidemiological data points to a reasonably consistent association, that is, a statistically significant relation, between residence in the vicinity of overhead power lines and an, otherwise slight, increase in the incidence of childhood leukemia. According to the committee, a fairly consistent association has likewise been found between occupations in which exposure to ELF electromagnetic fields takes place and the incidence of chronic lymphatic leukemia and, to a lesser extent, leukemia in general and brain tumours in adults. However, the consistency of these associations is even less than that observed with childhood leukemia. The results of these epidemiological studies, both in children and adults, do not allow the establishment of a causal relationship between the observed effects and exposure to ELF EM fields or any other factor.

Also the large body of experimental research has failed to produce any evidence of a causal relationship between exposure to ELF EM fields and the occurrence of any form of cancer. Moreover, experimental research has not identified any plausible biological mechanism that might explain a causal link in humans. The question of how to explain the associations that have been identified in epidemiological research therefore remains open. It is possible that one or more factors other than EMF EM field exposure are responsible for the observed associations. The nature of such factors and whether in this context they also play a role in the Netherlands is not known.

The committee arrives at the conclusion that it has not been demonstrated that exposure to electric or magnetic fields originating from the electricity transmission and distribution system at field strengths below the limits of exposure that have been established for short-term effects, induces any kind of disease or abnormality. It feels that, on the basis of the current scientific understanding described in this report, there is no reason to recommend measures to limit living near overhead power lines or working under conditions involving ELF EM field exposure that is increased, but not exceeding the exposure limits. The committee does recommend to continue following the scientific developments in this field.

Chapter **1**

Introduction

1.1 Background

In 1992 the Health Council issued the advisory report entitled Extremely low frequency electromagnetic fields and health (GR92). In that advisory report a Council Committee made recommendations regarding maximum values for exposure to electric and magnetic fields with a frequency of 50 Hz (the frequency of the electricity supply in Europe). These recommendations were adopted from the International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA), which since 1992 has been operating as an independent organization under the name of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Their aim is to prevent health impairment due to electrical currents that are induced in the body upon exposure to electric or magnetic fields and which result in acute effects. Such electrical currents can, for example, influence the transmission of stimuli in the nervous system, possibly leading to the occurrence of such undesirable effects as involuntary muscle movements or muscle cramps.

The biological effects on which the above-mentioned exposure limits have been based are short-term effects. They occur during or shortly after exposure. In general, it is therefore quite possible to establish a causal link between exposure and effect. Long-term effects are a different matter. In this case, because of the longer period of time (months or even decades) between the exposure and the manifestation of a possible health effect, it is extremely difficult to demonstrate a causal link. This is particularly the case if the biological mechanism which might be responsible for the effect is also not known. Moreover, for every long-term health effect there are, of course, one or more underlying short-term biological effects. During the exposure, a physiological reaction will need to occur. This also indicates that a biological effect and a health effect are not necessarily identical.

Since the beginning of the 1980s, researchers and others have been suggesting, particularly based on results from several of a series of epidemiological studies, that prolonged exposure to extremely low frequency electromagnetic (ELF EM) fields with a low field strength (such as those occurring in residential and working environments) has adverse effects on health. These are long-term effects, such as an influence on the development of certain forms of cancer.

The development of cancer is nowadays regarded as a process that consists of various stages. A number of changes are required in a cell's DNA before it begins to behave like a cancer cell. Those changes do not need to occur in swift succession. Sometimes a period of many years may elapse between successive stages and in theory, electromagnetic fields could exert an influence on each different stage.

In the 1992 Health Council advisory report it was concluded that there was insufficient scientific evidence to assume the existence of such an influence. However, the Council advised a re-evaluation of the literature in five years time, due to this scientific uncertainty and the fact that research programmes were being (or had already been) set up in various countries. Other organizations have also conducted such evaluations in recent years. This advisory report considers the most important of these.

On 28 May 1997 the Vice-President of the Health Council installed the Provisional Committee on ELF Electromagnetic Fields, whose task was to make proposals on how the Council might manage the subject of health effects from exposure to ELF EM fields. The Provisional Committee was of the opinion that a succinct report, on the state of affairs with regard to possible effects of chronic exposure to ELF EM fields with a low field strength, would be sufficient.

In April 1998 the ICNIRP published new guidelines for exposure to electromagnetic fields for the frequency range 0 Hz to 300 GHz. These are a modified version of previously issued guidelines, including the 50/60 Hz guideline issued by the IRPA/INIRC in 1990, to which reference was made in the Health Council's 1992 advisory report. The need to review that advisory report was therefore increasing. To this end, the above-mentioned Provisional Committee was installed on 28 September 1998 as the ELF Electromagnetic Fields Committee. The present advisory report is the result Committee’s deliberations. Membership of the Committee is detailed in Annex A.

1.2 Scope of this advisory report

In this advisory report the Committee makes recommendations regarding exposure limits for the frequency range 0 Hz to 10 MHz. Whilst the 1997 advisory report on radiofrequency electromagnetic fields (GR97) did, indeed, discuss the frequency range 300 Hz to 300 GHz, the present advisory report contains new recommendations for the frequency range 300 Hz to 10 MHz since the present recommendations for the frequencies up to 300 Hz do not correspond to those from 1997.

The recommendations in this advisory report, like those from 1992, relate exclusively to sinusoidal fields. At the frequencies discussed in this advisory report, it is not inconceivable that for other forms - such as pulsed, square-wave or sawtooth fields - other relationships with possible effects may exist than with sinusoidal fields.

1.3 Method

In Chapter 2 of the advisory report the Committee discusses direct and indirect short-term effects and in Chapter 3, long-term effects.

For each type of effect, the Committee ascertains whether it has been demonstrated that exposure leads to adverse effects on health. It considers an adverse effect on health to be scientifically demonstrated if the following objective scientific requirements, which include the criteria formulated by Hill for epidemiological research (Hil71), have been satisfied:

1. The research has been published in international peer reviewed journals of a quality that is generally regarded as adequate by the scientific community.
2. The research is of adequate quality according to the standards currently applied by the scientific community.
3. The research results have been demonstrated to be reproducible (for laboratory research) or consistent (for epidemiological research), based on research as referred to under (1) and (2) which has been performed by other, independent researchers.
4. The research outcome has been supported by means of quantitative analysis, leading to the conclusion that there is a statistically significant relationship between exposure and effect; in the case of epidemiological research, this implies that the probability of a causal link increases as the association becomes stronger.
5. The strength of the effect is proportional to that of the stimulus (i.e. there is a dose-response relationship).
6. A hypothesis exists, that experts find acceptable, which explains how the stimulus can cause the effect (i.e. there is a biological mechanism).

If one or more of these requirements has not been satisfied, the Committee concludes that it has not been demonstrated that the relevant exposure modality causes health impairment. Otherwise, the Committee uses the data as a basis for the establishment of exposure limits.

A glossary of terms and concepts is appended to the advisory report in Annex B and a graphical comparison between the present recommendations and those of the ICNIRP in Annex C.

Chapter **2**

Short-term effects

2.1 Conceptual framework

2.1.1 Workers versus general population

Following the example of earlier Health Council advisory reports (GR92, GR97), the Committee draws a distinction in its recommendations for exposure limits between those subjected to occupational exposure and the general population. This is due to differences in the level and duration of exposure and (possibly) sensitivity. An overview can be found in table 5.

The Committee considers workers to be those adults who may be exposed to EM fields in the course of their work and who have been given information about the risks associated with that exposure and about the precautionary or protective measures that can be taken. For the purposes of this advisory report, this means that not all people who might, in principle, be exposed to EM fields in the course of their duties are considered workers. An essential proviso is that the worker must have received the information mentioned. As far as exposure outside the working situation is concerned, the recommendations for the general population are always applicable to workers.

Table 5 Differences between occupational exposure and the general population.

working population	general population
exposure levels higher	exposure levels lower
exposure only during working time	continuous, lifelong exposure
(on average) relatively healthy adults; no children and elderly people	varying states of health; all ages
usually controlled conditions: - supervision of exposure - special (occupational) health care	uncontrolled conditions: - exposure unknown - no special medical supervision
precautionary measures against burns and shocks	no precautionary measures against burns and shocks
aware of possible risks; voluntary risk	generally not aware of risks; involuntary risk

2.1.2 *Direct versus indirect effects*

As in the advisory report on radiofrequency electromagnetic fields (GR97), the Committee draws a distinction between direct and indirect effects. Direct effects are caused by the action of electric, magnetic or electromagnetic fields on the exposed organism. Indirect effects, on the other hand, can occur if, as a result of exposure to an electric field, a potential difference arises between an organism and a (large) object. This might, for example, be the case if such an object is not earthed. The object in question then acts as a capacitor and, if it is being touched by an organism that is in contact with the earth, a discharge current will be generated. In the case of high potential differences, it is even possible for spark discharges to occur. In formulating its recommended exposure limits, the Committee has taken into account the possible occurrence of such indirect effects.

2.1.3 *Exposure limits*

As in other advisory reports and recommendations (GR92, GR97, ICN98, NRPB93), the Committee draws a distinction between ‘basic restrictions’ and values derived from

Basic restrictions

In principle, certain electromagnetic phenomena can, if they are induced in the human body at a sufficient intensity, lead to health impairment. As far as the frequency range considered in this advisory report is concerned, these will be the electric and magnetic field strength in the case of static fields, and for alternating fields, the electric current that is induced in the body. At higher frequencies (> 100 kHz) the most important effect is the conversion, in the body, of electromagnetic energy into heat. To prevent health impairment, the intensity of these electromagnetic phenomena needs to be restricted. The maximum permissible values for the physical quantities which determine this intensity are called ‘basic restrictions’. Basic restrictions can therefore be regarded as health-based exposure limits.

Reference levels

A problem with both electrical current and heat that are generated in the body, is that these phenomena are not easy to measure in a non-invasive manner. With the aid of mathematical models, it is possible to *calculate* both of these quantities based on the strength of the electric or magnetic field that is present at the location of the exposed organism, using a number of electromagnetic parameters from body tissues. The strength of the electric or magnetic field is relatively easy to measure. Because an electromagnetic field is disturbed by the presence of an object in that field, measurement must take place in the absence of the organism in question. The calculations are therefore based on undisturbed fields.

The strength of the undisturbed electric or magnetic field can thus serve as an indicator of the current density or heat generation in the body. This is why limit values are derived from the basic restrictions for those field strengths. These are called ‘reference levels’. If the field strength at the exposure site remains below the proposed reference levels, the basic restrictions are not exceeded. If the field strength is higher, then it is not necessarily the case that the base restrictions have been exceeded but verification should take place for the relevant exposure scenario.

The exposure must always be tested against the basic restrictions. The reference levels serve merely as an aid in this regard.

Safety factors

Just as in previous Health Council advisory reports on possible health effects of exposure to electromagnetic fields, the Committee takes certain safety factors into consideration when formulating the exposure limits. The advisory report entitled

Radiofrequency electromagnetic fields (300 Hz - 300 GHz) (GR97) contains a detailed description of the background to these safety factors. The Committee confines itself here to indicating the most important reasons for the use of safety factors, which are: uncertainties and gaps in scientific knowledge and the possible existence of differences in sensitivity between different population groups (see also section 2.1.1).

For workers, the Committee always applies a safety factor of 10 and for the general population, an extra factor of 5 (giving a total safety factor of 50 for this group). The maximum permissible values for the basic restrictions are therefore lower by factors of 10 or 50 than the levels above which health impairment could occur.

Due to these safety margins, neither the basic restrictions nor the reference levels should be regarded as a sharp boundary between high, potentially harmful and low, intrinsically harmless field strengths. It can, in certain situations, be acceptable to exceed the reference levels — or even the basic restrictions — for short periods and to a limited extent. This will need to be examined on a case-by-case basis.

2.1.4 Static versus alternating fields

In this advisory report the Committee makes recommendations regarding exposure limits for static electric and magnetic fields and for alternating fields. In principle, only fields with a frequency of 0 Hz are static fields. In practice, fields with an extremely low frequency also behave like static fields. For these fields, the peak value is more important than the mean (r.m.s.) value. There is no distinct frequency boundary between static and alternating fields. The Committee has chosen the frequency of 1 Hz for this purpose.

2.2 Basic restrictions

2.2.1 Static fields: background

Effects of static electric fields

The most important effect of static electric fields on the body is the generation of an electric charge on the body surface. This can lead to the movement of hairs. The threshold for this charge lies at a field strength of approximately 20 kV/m (Cla89).

If the potential difference between the (electrically insulated) body and the surrounding area is large enough, a (spark) discharge may occur when it is approached or touched by a conducting object. This happens, for example, when walking over a synthetic carpet in a dry environment. Depending on the conditions, the field strength generated in this situation can range around 10 kV/m to more than 1200 kV/m (Kow91). This does not result in negative health effects. However, discomfort may be caused, for example as a result of startle responses to spark discharges.

No effect on the circadian rhythm has been found in volunteers following prolonged exposure to static electric fields up to 600 V/m (Wev70). Exposure of experimental animals to field strengths up to 12 kV/m did not lead to changes in their behaviour (Bai86). Nor have animal studies, with an exposure to electric fields of up to 340 kV/m, identified any effect on total blood count, reproduction and perinatal mortality (Fam81).

Effects of static magnetic fields

There are three different mechanisms whereby static magnetic fields can interact with organisms (ICN94).

By a process of magnetic induction, charged particles moving in a static field can give rise to electric fields and currents. This can result in the generation of small electric currents in the blood. Induction of this kind also occurs when an organism moves through a static field. According to Faraday's Law, small electric currents will then be generated in the body.

Magnetomechanical effects are a second mechanism. These can result in molecules and larger structures being oriented in a static field (similar to the working of a compass). The biological effects of this type of interaction are (at least in human beings) negligible, since the number of natural magnetic substances present in the body is extremely low (ICN94).

The third type of effect relates to interactions between molecules. A static magnetic field can exert an influence on certain intermediate products of chemical reactions whereby the rate of those reactions can change. For reactions involving the formation of radicals as intermediate products, it has been suggested that an influence would be detectable even at field strengths of 10 mT (Rep99). However, biological effects have never been discovered at such low field strengths.

In the most recent review, Repacholi and Greenbaum, building on earlier summaries (EC96, ICN94, Kow91, NRPB93, Sim92), state that biological effects have not been unequivocally demonstrated at field strengths below about 2 T (Rep99). People moving quickly in a strong magnetic field sometimes experience effects such as dizziness, nausea and headache (Sch92). At field strengths below 2 T, such effects have not been observed.

It appears from calculations (ICN94) that an electrical current with a density of 10-100 mA/m^2 is generated in the body of someone moving in a 200 mT field. The

ICNIRP likewise calculated the effect of the blood’s current velocity on its electric current density upon exposure to a 200 mT field. For the worst-case situation in the largest blood vessel, the aorta, this produces a maximum current density of 44 mA/m^2. This value is lower than the levels that can be expected to exert adverse effects on blood flow or the cardiovascular system (Ten85).

In particular situations, static magnetic fields can indirectly influence health, notably when they disturb the operation of a pacemaker. Such electromagnetic interference problems will not be discussed in this advisory report.

2.2.2 *ELF fields: background*

Influence of ELF fields on muscles and nerve fibres

In a recently published book, Reilly provides a detailed overview of all of the potential effects of electrical current in the body on nerves, skeletal muscles and the heart (Rei98a). The Committee is of the opinion that this publication provides the most complete insight into the current knowledge level in this area and has therefore derived the majority of the following data from this source.

As current density in the body rises, increasingly serious reactions can be discerned. The current density that results in a given effect depends on the frequency, with maximum sensitivity lying approximately in the frequency range between 10 and 100 Hz (Rei98a, Figs. 6.4, 6.8). The exposure period is also important: the minimum current density that is required in order to elicit an effect increases where stimulation is shorter than around 1 - 2 seconds (Rei98a, Figs. 6.9 - 6.12).

The most serious effects, which can be life-threatening, are cardiac arrhythmias. At 60 Hz - i.e. within the range in which sensitivity is greatest - the minimum current density that is required for ventricular fibrillation (the uncontrolled contraction of the muscle fibres of the ventricle, resulting in drastic reduction of the heart's pumping action) is around 2.5 A/m^2 (Rei98a, Fig. 6.21). This value can be regarded as the 1st percentile for this effect - *i.e.* upon exposure to this current density, the effect will occur in around 1% of cases (Rei98a, p. 233). Reilly states that this value, which was obtained using experimental animals, can be regarded as the conservative limit value for stimulation of the heart in human beings (Rei98a, p. 234).

The current-density values which result in excitation of the heart lie at around 40% of the levels that cause fibrillation. This means that the 1st percentile for a measurable effect on the heart is approximately 1 A/m^2. This value, which can be regarded as the estimated value of a ‘lowest observed adverse effect level’, corresponds closely to that of the minimum current density required for stimulation of nerve fibres: 1.2 A/m^2 (Rei98a, p. 235).

Phosphenes

The most significant effect at lower current densities is the occurrence of phosphenes. These are spots or flashes of light which are perceived in response to direct stimulation of the retina by electrical current. They can, for example, result from an external electric or magnetic field. However, phosphenes can also be induced by pressure on the eyeball. These phenomena generally disappear of their own accord within an hour of the causative factor being removed.

In research with trial subjects, the minimum field strength required for the induction of phosphenes was found to be clearly frequency-dependent. This minimum field strength is located in the frequency range 20-30 Hz. As the current density in the retina cannot be determined directly, it has to be derived from the strength of the external electric or magnetic field. With respect to this, one problem is the path taken by the current through the tissues of the head. Although unknown, it is of crucial importance in determining the surface over which the current density needs to be calculated.

Adrian has measured the perception of phosphenes by causing a current to flow between two electrodes attached to the head (Adr77). He found a minimum value of 0.014 mA at 20 Hz. The surface area of the electrodes was 2.4 cm^2. This means a current density across this surface area of 58 mA/m^2. Adrian states, however, that the effective surface area lies somewhere between that of the electrode and the cross-section of the head (100-200 cm2). He assumes a value of 10 cm^2, which gives a minimum current density of 14 mA/m^2.

Lövsund exposed the heads of volunteers to electric and magnetic fields and determined the relationship between the frequency and the field strength with regard to the occurrence of phosphenes (Löv80a, Löv80b). He arrives at a rough estimate of 1 mA/m^2 for the minimum current density required (also at 20 Hz). For the same data, Reilly calculates a minimum current density of 8 mA/m^2 (Rei98a, p. 389). The Committee regards Lövsund's estimate (Löv80b), which is unsupported, as too low, and Reilly's as more realistic (although also on the low side).

By using an eyebath filled with saline as an electrode, Carstensen caused a current to flow through the retina and thus determined the current intensity at which phosphenes were observed (Car85). The minimum current was 0.04 mA (at 25 Hz). Given an eyeball 4 cm in diameter, this corresponds to a current density of 32 mA/m^2. In the Committee’s opinion, this outcome is a more reliable estimate of the current density because the current was applied directly to the eye. Nevertheless, the Committee believes - partly in the light of the data from the experiments of Lövsund and Adrian -

that a value of 10 mA/m^2 can be regarded as a reasonable lower limit for the occurrence of phosphenes. With both an increase and a decrease in frequency, the current density required for the perception of phosphenes increases rapidly (see, for example, Figs. 1 and 2 from Adr77), and therefore the frequency range within which this phenomenon actually plays a role is limited from a few Hz to around 200 Hz.

2.2.3 *Limits*

Based on the above data, the Committee has established the following maximum permissible levels for the current density in the body.

Static fields

For static fields, the relevant quantity for the establishment of exposure limits is not the current density, but the magnetic field strength. In section 2.2.1 it is stated that, even at extremely high field strengths, static electric fields do not have any adverse effects on health. These fields will not, therefore, be considered further.

The Committee proposes a magnetic field strength of 2 T as the upper limit, because biological effects have not been unequivocally demonstrated below this level, not even in the form of unpleasant effects such as nausea and dizziness in human beings moving in the field in question. Following the example of the NRPB (NRPB93) and the ICNIRP (ICN94), it considers 2 T to be the maximum permissible field strength for short peaks in exposure. If only the extremities are exposed, a field strength of up to 5 T is permissible. For continuous exposure, a safety factor of 10 is applied on account of the relatively scarce and sometimes contradictory scientific data. The resultant value of 200 mT applies to the working population. For the general population, the Committee allows an extra safety factor of 5, giving a maximum permissible field strength for continuous exposure for this group of 40 mT.

The basic restrictions thus determined for static fields are summarized in Table 1 (see the Executive Summary).

Extremely low frequency fields

In the frequency range between the arbitrarily chosen lower limit for alternating fields of 1 Hz (see section 2.1.4) and 10 MHz, the Committee regards the need to prevent the occurrence of two different phenomena as the determining factor as far as the setting of limits is concerned.

The first of these effects is the perception of phosphenes in response to direct stimulation of the retina by electrical current. The Committee selects a current density of 10 mA/m^2 as the lower limit for the occurrence of this phenomenon between 1 and 20 Hz, opting for 0.5 x f mA/m^2 (frequency f in Hz) above 20 Hz. The transition frequency of 20 Hz is derived from Reilly (Rei98a, pp. 490-491). The frequency dependency above 20 Hz corresponds to that determined by Adrian (Adr77). The resultant curve is shown in Figure 1 as the 'phosphenes' curve.

The second phenomenon is stimulation of the cardiac muscle and nerve fibres. In this case, the Committee applies a lower limit of 1000 mA/m^2 at frequencies up to 4000 Hz and 0.25 x f mA/m^2 (f in Hz) at higher frequencies. The resultant curve is shown in Figure 1 as the 'heart, nerve' curve.

The perception of phosphenes, even in connection with prolonged exposure, is at most disturbing, but not detrimental to health. Startle effects may well occur when individuals are suddenly confronted with this phenomenon. The Committee is therefore of the opinion that the occurrence of phosphenes should be prevented wherever possible. For the working population, which according to the definition must be familiar with the effects that may occur, there is no need for limit values below the lower limit that has been specified for the occurrence of phosphenes. For the general population, a safety factor would seem to be appropriate. The Committee employs the factor of 5 that is specified in section 2.1.3 for this purpose.

Influences on nerve tissue can, in principle, be detrimental to health. The Committee therefore finds it appropriate to apply a general safety factor of 10 with regard to the aforementioned lower limit for these phenomena and, in addition, an extra safety factor of 5 for the general population. The limit-value curve applying to the working population for the occurrence of phosphenes intersects with that for stimulation of nerve fibres at 200 Hz and 100 mA/m^2. The corresponding curves for the general population intersect at 200 Hz and 20 mA/m^2. The resultant curves are plotted in Figure 1. The limit values are given numerically in Table 2 (see the Executive Summary). They apply to exposure of the head (due to the restrictions on the occurrence of phosphenes) and thus also to exposure of the entire body.

Where solely body parts other than the head are exposed, only the limit values that have been derived for effects on nerve fibres are important. The maximum permissible current density in the frequency range 1 Hz to 4 kHz is then 100 mA/m^2 for the working population and 20 mA/m^2 for the general population. The resultant curves are plotted in Figure 1. The values are given in Table 2 (see the Executive Summary).

At 300 Hz, the lower limit of the frequency range that is considered in the 1997 Health Council advisory report 1997 (GR97), these recommendations are not compatible with the proposals made in that advisory report. The Committee is therefore making new recommendations for the frequency range 300 Hz to 10 MHz.

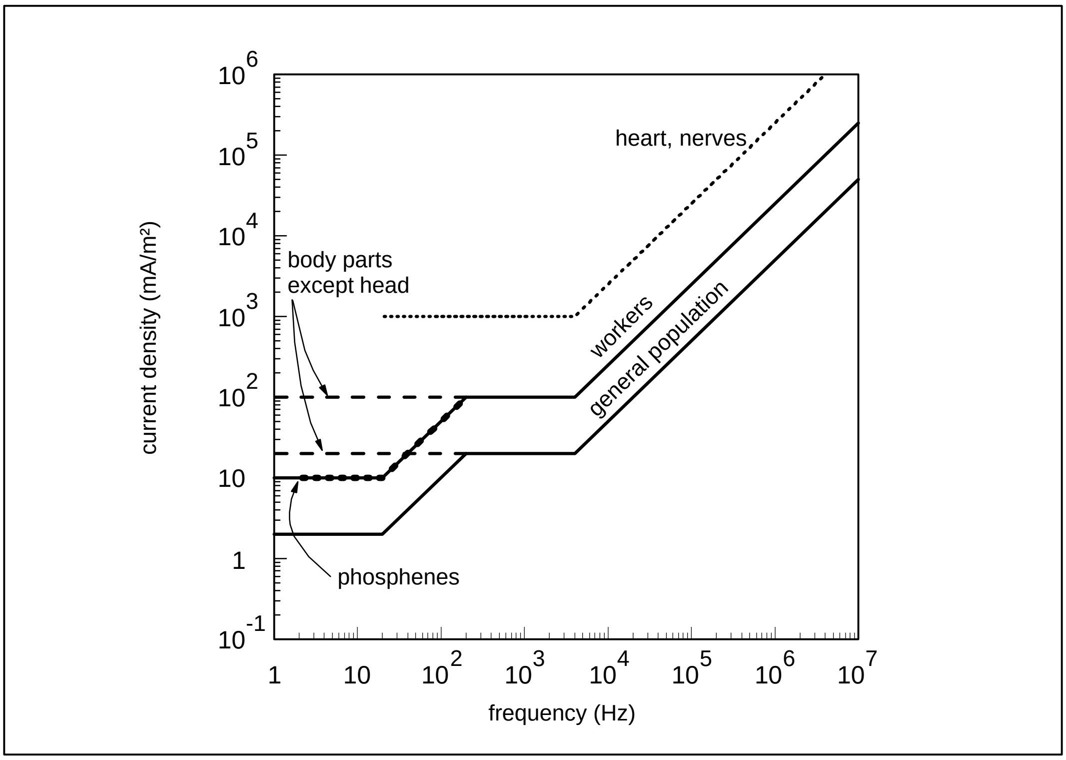

Figure 1 Basic restrictions for the frequency range 1 Hz to 10 MHz. The ‘heart, nerve’ and ‘phosphenes’ curves indicate the lower limit described in the text for effects on the heart and nerve fibres and for the perception of phosphenes, respectively. The continuous lines are the basic restrictions for situations that involve exposure of the head. As described in the text, they have been derived from both the ‘heart-nerve’ and the ‘phosphenes’ curves. The dashed curves pertain to exposures that do not involve the head and have -nerve’ curve.

The guidelines given here differ from those issued by the ICNIRP (ICN98). The difference arises from the ICNIRP's approach of adopting a fixed value of 10 mA/m^2 for the maximum current density for the frequency range 4 Hz to 1 kHz. The rationale for this is not clear, but it is probably based on the prevention of phosphenes. The ICNIRP thus opts for a more conservative approach than the Committee. In Annex C a comparison is made between the recommendations given in this report and those of the ICNIRP.

The maximum current densities applying to 50 Hz are given in Table 6.

Table 6 Basic restrictions for 50 Hz.

frequency	current density (mA/m^2)			
	workers		general population	
	body, head [a]	body, partly [b]	body, head [a]	body, partly [b]
50 Hz	25	100	5	20

[a] body, head: body completely or partly exposed, with head included
[b] body, partly: body partly exposed, head not included

The basic restrictions apply to an exposure to sinusoidal electromagnetic fields greater than 1 second in duration. Depending on the duration of exposure and the shape of the pulse, higher current densities may be acceptable in the case of shorter exposures or exposure to pulsed fields (Rei98a, pp. 490-491). The Committee does not pursue this point further, partly because the number of possibilities is, in principle, unlimited. Nor is it making recommendations for other field shapes, such as square-wave or sawtooth fields. In many cases, however, the effects of such fields can be considered similar to those of sinusoidal fields.

2.3 Reference levels

2.3.1 Continuous exposure of the entire body

Electric field strength

During exposure under the most unfavourable circumstances – with the direction of the electric field parallel to the body axis – a current density of approximately 2 mA/m^2 is generated in the neck and in the trunk by a 50 Hz electric field of 5 kV/m (NRC97, Ten87)[a]. The Committee uses this value as a reference point in deriving the values for the undisturbed external electric field from the basic restrictions. The relationship between the current density (J) and the external electric field strength (E) and the frequency (f) is given by the formula

$$J = \mathrm{k}\, f\, E$$

[a] With a 60 Hz electric field of 10 kV/m, a current density of 5.5 mA/m^2 has been measured in the neck of an earthed adult human being, and in the ankles, a current density of 20 mA/m^2 (Ten87). For an insulated individual, these readings were 4.1 and 9.4 mA/m^2, respectively. Conversion into an external 50 Hz E-field of 5 kV/m gives values for the neck of 1.7 (insulated) and 2.3 mA/m^2 (earthed) and for the ankles, 3.9 (insulated) and 8.3 mA/m^2 (earthed).

where k is a constant. The maximum values for the current density according to Table 2 (see the Executive Summary) can thus be converted into values for the electric field strength. However, the resultant field strengths are at a level where indirect effects can occur in such cases. The Committee has already indicated in section 2.1.2 the need to avoid indirect effects. In the frequency range 20 Hz to 1 MHz it is therefore lowering the maximum values for the external electric field to the extent that such effects will not occur.

In determining the indirect effects, the Committee has assumed a difference in sensitivity between men, women and children. Measurements show that in women the threshold values for electrical stimuli are around 2/3 of those detected in men (Guy85). The sensitivity of children has not been measured. Guy estimates the threshold value for electrical stimuli to be around 50% of that encountered in men (Guy85).

The most likely situation in which indirect effects might occur (which, however, rarely arises in practice) is when a car, bus or truck stands lengthways beneath a high-voltage power line. To prevent undesirable indirect effects in such situations, the Committee proposes that the electric field should have a maximum strength of 8 kV/m at a frequency of 50 Hz. Upon contact with a large truck or bus, the discharge current will then be 3.5 - 4.5 mA. This remains below the let-go threshold for the 0.5% most sensitive children, assuming a normal distribution of sensitivity. Only in exceptional cases (e.g. an articulated truck in an 8 kV/m field) will the discharge current be higher (approx. 5 mA); it may then possibly cause a painful sensation in a small percentage of children, but will not give rise to a health risk[a].

The various recommendations are visualized in Figure 2. Several measuring points for indirect effects are also indicated. The legend explains how the curves are constructed.

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[a] The basis for this assumption is as follows. When it is touched, a large articulated truck standing in a 50/60 Hz electric field of 10 kV/m produces a discharge current of 6.3 mA (Lee86); at 8 kV/m this current is approx. 5 mA. For a truck 12 m in length, the discharge current is 4.2 mA (WHO89). A discharge current of 5 mA also arises on contact with a passenger car in a 50 kV/m electric field and on contact with a truck or bus in an 11 kV/m field (For91).
Extrapolation of the values calculated for adult males gives a *let-go* threshold of 8 mA for 50% of the children; for 0.5% of the children, Guy gives 5 mA as a conservative value (Guy85). For a severe shock involving respiratory problems, the threshold for 50% of the children stands at 12 mA. These values apply to a current that flows through the body for 10 seconds or more (Ber88). Higher threshold values will apply in the case of shorter exposure periods.
For the purposes of comparison: an electric fence produces a discharge every 1.3 s with a voltage of 5-9 kV and a duration of approx. 0.1 ms. The discharge current is approx. 10 A. In the most unfavourable situation (a child with bare feet in wet grass), such a shock is experienced as being extremely painful, but is not life-threatening. This situation is comparable to touching a large truck standing lengthways beneath a 380 kV high-voltage power line. Moreover, the chances of touching an electric fence are much greater than those of contact with a truck in the situation mentioned above.

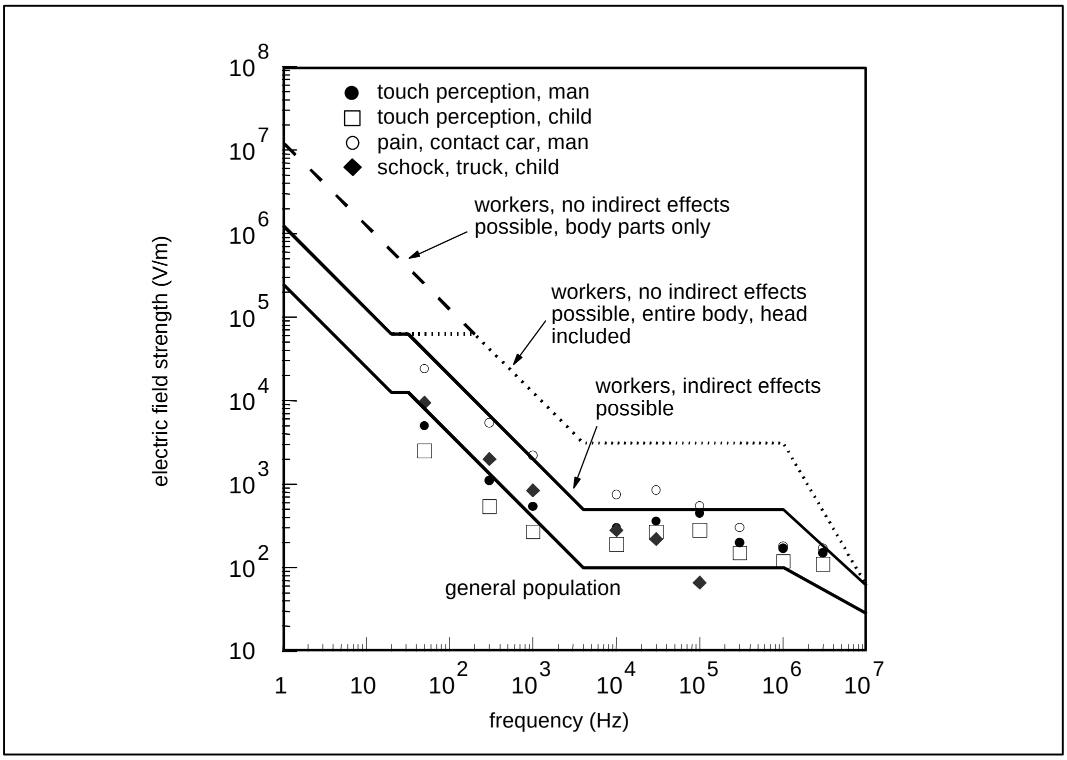

Figure 2 Reference levels for the external electric field for situations where indirect effects may or may not occur. The curves for the working population (indirect effects not possible) are a direct conversion of the current-density curves for the working population that are shown in Figure 1. The curve for the general population is also based on the corresponding current-density curve, but a maximum of 8 kV/m was set at 50 Hz to prevent indirect effects (see text). The sloping portion of the curve between approx. 100 Hz and 2.5 kHz and the adjacent horizontal portion between 2.5 kHz and 1 MHz were then moved downwards, so that at 50 Hz the value is 8 kV/m. The intersection with the left-most portion of the original curve was re-calculated (32 Hz, 62.5 kV/m). For the general population, it is not possible give a separate curve for exposure of parts of the body only, since this would not satisfy the need to prevent indirect effects. The curve for the working population (indirect effects possible) exceeds the one for the general population by a factor of 5. The right-most portion of all three curves was determined in relation the values given in GR97 at 10 MHz.

Due to the above-mentioned changes in the understanding of the maximum permissible current density, the reference levels that have now been set by the Committee differ from those in the advisory report entitled *Radiofrequency electromagnetic fields (300 Hz - 300 GHz)* (GR97), in the frequency range 300 Hz to 10 MHz. The numerical values for the electric field in the frequency range 1 Hz to 10 MHz are given in Table 3 (see the Executive Summary).

Magnetic field strength

Section 2.2.1 gives the maximum values for static magnetic fields.

When deriving the magnetic field strengths that correspond to the maximum current densities in the body for alternating fields (such as given in Table 2), the approach, that was also followed by the ICNIRP in its recent recommendations (ICN98), was to use highly simplified models, whereby the body was regarded as a sphere or an ellipsoid with an electrically homogeneous or multilayered composition. However, the reference levels for the magnetic field produced from calculations with these models are probably higher than the true levels.

In recent years, more advanced models have been developed, which take into account the anatomical structure of the body and the different electrical properties exhibited by the various body tissues. In a recent article, Dawson et al. describe the calculation of average and maximum current densities in the entire body and in a large number of organs upon exposure to a 60 Hz magnetic field of 1 µT in various orientations (from left to right, from top to bottom, from back to front) (Daw97). The maximum current density in the body occurred in the cerebrospinal fluid upon exposure to a field with a left-to-right orientation, and totalled 77.3 $\mu A/m^2$. Because the Committee regards heart and nerve fibres as critical tissues for the determination of current density, it views an examination of innervated tissues and organs as meaningful. The highest current density is then found in muscle tissue: 50.7 $\mu A/m^2$ upon exposure to a field with a back-to-front orientation. (The current density in brain tissue is substantially lower: a maximum of 7.3 $\mu A/m^2$ (Daw97).) The Committee has used the value of 50.7 $\mu A/m^2$ as a reference point in calculating the reference levels for the external magnetic field. For sinusoidal electromagnetic fields, the magnetic flux density *B* is related to the current density *J* according to the following formula:

$$J = \pi \, r \, f \, \sigma \, B$$

where r is the radius of the exposed object, π the electrical conductivity and *f* the frequency. As the calculations make use of the above-mentioned reference value, the values of r and σ do not necessarily need to be known.

The reference levels calculated with this formula for the strength of the magnetic field, expressed in terms of the magnetic flux density, are represented in Figure 3. It is not possible in this case, as with the current density, to draw a distinction between exposure of the head or entire body and parts of the body only, since the derivation relates to muscle tissue. Exposure of just the extremities will, however, be considered separately in section 2.3.2.

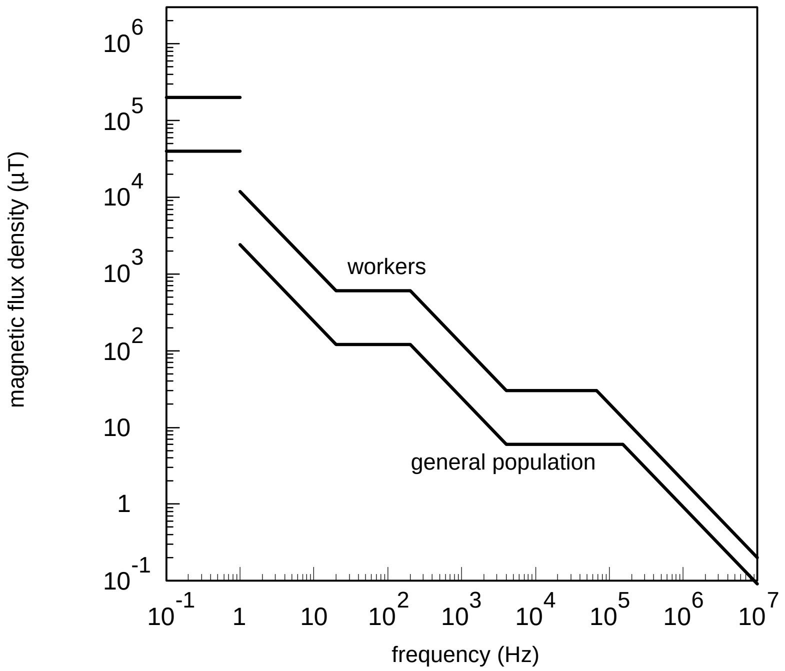

Figure 3 Reference levels for the external magnetic field, expressed in terms of the magnetic flux density. The lines between 0.1 and 1 Hz give the values for static fields. The remaining curves have been calculated from the basic restrictions for the current density as given in Figure 1. The current density of 50.7 µA/m^2 (as described in the text) with an external B-field of 1 µT at 60 Hz serves as a reference point.

The right-most, sloping portions of both curves are equal to the values that were proposed in the advisory report entitled *Radiofrequency electromagnetic fields (300 Hz - 300 GHz)* (GR97). From the intersection with the horizontal portion (at 67 and 153 kHz for the working and general population, respectively) to the lowest frequencies on the left of the figure, they deviate from this. The Committee believes it is incorrect to give a continuous transition between alternating fields and static fields, because the position of the curve then relies heavily on the (arbitrarily chosen) boundary between static and alternating fields. At the specifically selected frequency of 1 Hz it therefore gives a transition of the curve for alternating fields to the fixed value for static fields.

The numerical values of the reference levels calculated by the Committee for the magnetic field strengths are given in Table 4 (see the Executive Summary).

The large variety of studies that have been conducted under clearly defined conditions have failed to demonstrate that health effects occur upon exposure to electromagnetic fields with strengths below the maximums that have been calculated here. It is true that in a number of these studies, biological effects have been identified, such as an influence on aspects of sleeping patterns and on certain cognitive functions (Gra99, Por98, pp. 301-25). However, the effects were, without exception, reversible and too slight to be give rise to health problems.

2.3.2 *Exposure of extremities*

It appears from the article by Dawson (Daw97) that the maximum current density in extremities upon exposure to an external magnetic field is about one-third of that in the entire body - approximately 15 µA/m2 at a field strength of 1 µT and a frequency of 60 Hz. This means that the field strength upon exposure of extremities only may be three times higher than if the entire body is exposed. As a result, the situation upon exposure of extremities only is as outlined in Table 7. The values have been determined such that at 10 MHz there is no longer any difference between this situation and exposure of the entire body, since that is also not the case at higher frequencies.

Table 7 Reference levels for the strength of the external magnetic field upon continuous exposure of extremities only.

	magnetic flux density (µT)		magnetic field strength (A/m)		
	workers	general population	workers	general population	
1 - 20 Hz	36 000 / *f*	7 200 / *f*	28 640 / *f*	5 728 / *f*	*f* in Hz
20 - 200 Hz	1 800	360	1 432	286	
0.2 - 4 kHz	360 / *f*	72 / *f*	286 / *f*	57.3 / *f*	*f* in kHz
4 - 67 kHz	90	18	71.6	14.3	
67 - 153 kHz	6 000 / *f*	18	4 773 / *f*	14.3	*f* in kHz
0.153 -10 MHz	$3.65 \times f^{-1.26}$	$1.68 \times f^{-1.26}$	$2.90 \times f^{-1.26}$	$1.34 \times f^{-1.26}$	*f* in MHz

2.3.3 Reference levels for 50 Hz

The reference levels for 50 Hz are given in Table 8.

Table 8 Reference levels for 50 Hz.

		electric field strength (kV/m)	magnetic flux density (μT)	magnetic field strength (A/m)
workers	indirect effects not possible, head, entire body	62.5		
	indirect effects not possible, parts of the body except for the head	250		
	indirect effects possible	40		
	body		600	477
	extremities		1800	1432
general population	indirect effects may or may not be possible	8		
	body		120	95.5
	extremities		360	286

2.4 Exposure to multiple frequencies

In practice, exposure is usually to electromagnetic fields of varying frequency. This needs to be taken into consideration when determining whether the exposure limits are being satisfied. The advisory report entitled Radiofrequency electromagnetic fields (300 Hz - 300 GHz) (GR97) provides formulas for this purpose. The Committee reproduces these below in an adapted form, as proposed by the ICNIRP (ICN98).

For the basic restriction the current density in the body is given as:

$$\sum_{i=1\,\mathrm{MHz}}^{10\,\mathrm{MHz}} \frac{J_i}{J_{L,i}} \leq 1$$

whereby

J_i = the current density at frequency *i*
$J_{L,i}$ = the current-density limit at frequency *i*, as given in Table 2.

For the reference levels of the electric field the formula is

$$\sum_{i=1\text{Hz}}^{1\text{MHz}} \frac{E_i}{E_{L,i}} + \sum_{i>1\text{MHz}}^{10\text{MHz}} \frac{E_i}{a} \leq 1$$

whereby

E_i = the electric field strength at frequency i

$E_{L,i}$ = the field-strength limit at frequency i, as given in Table 3.

a = 3125 V/m upon occupational exposure under circumstances in which no indirect effects are possible

= 500 V/m upon occupational exposure where such effects are possible

= 100 V/m upon exposure of the general population.

At frequencies above 1 MHz, the field strength has no longer been calculated directly from the current density, but is given such that at 10 MHz it corresponds to the values given in GR97 for higher frequencies. These reference levels thus tend to be determined more by the heat absorption, which is the limiting factor at higher frequencies (GR97). In the above calculation, a fixed limit value of between 1 MHz and 10 MHz is therefore applied for the current density, namely the value calculated for 1 MHz (the factor *a*).

For magnetic fields, the comparable formula applies

$$\sum_{i=1\text{Hz}}^{x\,\text{kHz}} \frac{H_i}{H_{L,i}} + \sum_{i>x\,\text{kHz}}^{10\text{MHz}} \frac{H_i}{b} \leq 1$$

whereby

H_i = the magnetic flux density or field strength at frequency i

$H_{L,i}$ = the magnetic flux-density or field-strength limit at frequency i, as given in Table 5

b = 30 µT or 23.9 A/m upon occupational exposure

= 6 µT or 4.8 A/m upon exposure of the general population

x = 67 kHz upon occupational exposure

= 153 kHz upon exposure of the general population.

Chapter **3**

Long-term effects

The Committee limits its discussion on long-term effects to the information on exposure to 50 and 60 Hz fields. The reason for this is the omnipresence of exposure to these frequencies, which are associated with the electricity supply. Moreover, almost no data is available on long-term effects of exposure to other frequencies.

The Committee bases its conclusions regarding long-term effects principally on the most recent data from the literature. Due to time constraints, it has not consulted all of the original sources itself, but relied in part on the recently published reports of the US National Research Council (NRC97) and the US National Institute for Environmental Health Services (NIEHS) (Por98). Both give a thorough overview of the subject matter. From the latter report, the critical abstracts of the literature, in particular, have been used as a basis for the following overview.

The Committee endorses the conclusion advanced by NIEHS Director Dr Kenneth Olden in the letter of presentation accompanying the NIEHS's final report to the US Congress (NIE99):

> The scientific evidence suggesting that ELF-EM exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed adults. While the support from individual studies is weak, the epidemiological studies demonstrate, for certain exposure characteristics, a fairly consistent pattern of a small, increased risk with increasing exposure that is somewhat weaker for chronic lymphocytic leukemia than for childhood leukemia. In contrast, the mechanistic studies

and the animal toxicology literature fail to demonstrate any consistent pattern across studies although sporadic findings of biological effects have been reported. No indication of increased leukemias in experimental animals has been observed.

[.......]

Virtually all of the laboratory evidence in animals and humans and most of the mechanistic work done in cells fail to support a causal relationship between exposure to ELF-EMF at environmental levels and changes in biological functions or disease status.

A number of significant publications that have appeared since the publication of the NRC and NIEHS reports have also been evaluated by the Committee. This has not led to any change in the above-mentioned views.

3.1 Experimental research

Fundamental *in vitro* and *in vivo* research has, in recent years, produced few new insights with regard to a possible mechanism that might underlie long-term biological effects of ELF EM fields. The most significant development in this regard relates to the possible influence of such fields on the transmission of signals in the cell. There is evidence to suggest that the structure of certain membrane proteins may undergo changes under the influence of ELF EM fields. Such changes could result (*inter alia*) in a change in the transport of calcium ions through the cell membrane. Whether this non-specific signal can lead to a change in cellular functions and therefore to health impairment (and if so, then how) has not, however, been demonstrated.

In animal studies, ELF EM fields have only been shown, in some experiments, to have a growth-promoting influence on breast tumours that had been induced in rats by means of certain chemical agents (Bau95, Lös93, Mev93, Mev98). In other experiments this effect has not been discovered (Eks98, Mev96a, Mev96b, NTP98). However, the field strengths involved in these studies are 10 to 100 times the levels generally encountered in residential or working environments. Furthermore, doubt has been expressed over the relevance of the model for breast cancer in humans (Por98, App. B). The breed of rat used has a naturally high sensitivity to chemical carcinogens.

In a recently completed study with nearly 2800 mice, the influence of lifelong (i.e. approx. 2.5 years), continuous exposure to a 60 Hz field on the life-span and the development of leukemia was investigated. The provisional results indicate that there is no effect (EPRI99). However, this study has not yet been published in the scientific literature.

Some researchers regard an effect of ELF EM fields on the production of the hormone melatonin as a possible mechanism whereby health might be influenced (Bal98, Ste97). Melatonin is produced by the pineal gland in the brain, in quantities that fluctuate considerably during the course of the day. Production is greater at night than in the daytime (Rei91). Melatonin is actually used (especially in the United States) as a remedy for jetlag and sleeping disorders, though its sale for this indication is no longer permitted in the Netherlands. In the context of the effects of ELF EM fields, however, its action as a free-radical scavenger is more significant (Rei97). Radicals are highly reactive molecules which can damage other molecules. Damage to DNA can lead to the development of cancer. A reduction of the melatonin level in the blood could therefore increase the risk of cancer. In rodents it has been shown that exposure to ELF EM fields inhibits the nocturnal increase in melatonin levels (Por98, Rei98b). Less is therefore released into the blood, which could lead to an increase in the risk of cancer. In sheep and baboons, no effect has been identified from exposure to ELF EM fields (Por98). Nor have studies with human volunteers revealed any influence of ELF EM fields on the amount of melatonin in the blood (Ake97, Gra96, Gra97, Sel96, Woo98). This means it is unlikely that ELF EM fields have an effect on the development of cancer in humans by influencing melatonin levels.

The above is a brief summary of the relevant literature on experimental research. A detailed summary can be found in the NRC and NIEHS reports (NRC97, Por98).

3.2 Epidemiological research

The concern that is regularly voiced over supposed dangers of exposure to ELF EM fields is, in virtually every case, based on outcomes of epidemiological research. The Committee finds that the quality of that research has improved substantially in recent years. However, it has not yet led to unequivocal, scientifically reliable conclusions.

The greatest shortcoming of the studies is the fact that it is not possible to establish what the exposure has been during the period in which the disease has been developing. Various surrogate measures are therefore used in order to characterize that exposure. The ‘wire code’, that is to say the configuration of the overhead power lines, is a measure which was used in the initial studies. The weighting of the configuration is divided into various categories and it is presumed that the strength of the magnetic field in connection with a ‘heavy’ configuration is greater than for a ‘light’ one. The wire code is thus regarded as a measure of the intensity of the exposure in the past. There are, however, a number of factors that need to be taken into consideration when using such an indirect measure of exposure.

In the NRC report (NRC97) a conceptual framework is indicated for evaluating the relationship between wire code, magnetic fields and cancer in children. The Committee presents this conceptual framework in a more general form in Figure 4.

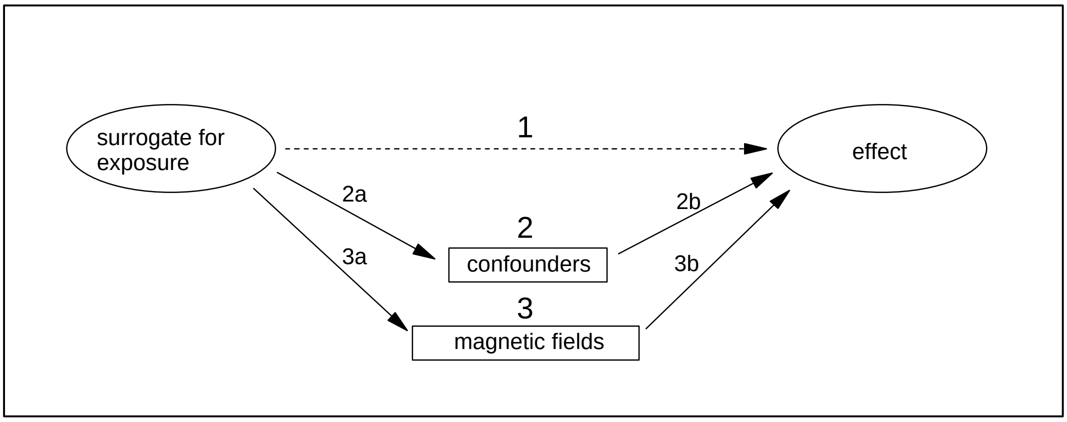

Figure 4 Model for the evaluation of the relationship between a surrogate measure of exposure to magnetic fields and an effect. The broken arrow 1 indicates the association between a surrogate for exposure and the effect. In routes 2 and 3, various steps (2a and 2b, and 3a and 3b, respectively) can be distinguished. When investigating the cause of the identified association, it is necessary to examine all of these steps. (Source: NRC97, modified)

The arrows indicate associations, not causal relationships. If, as indicated with broken arrow number 1, an association exists between a (surrogate) measure of exposure (such as the wire code or a job title) and a particular effect (such as cancer), various factors may be responsible for that association. The magnetic fields may be the cause of the effect. This is indicated as route number 3. The surrogate measure is then presumed to be an indication of the magnetic field strength. It is also possible that the effect may be caused by another factor which is (also) connected with the surrogate measure, but which has not yet been identified. Possible causes might, for example, be exposure to carcinogens in the environment or in working situations. This is represented as route 2. Such a factor confounds the actual relationship between magnetic fields and the effect; that is to say, a statistical relationship is observed although there is no causal link. In analyzing the epidemiological data, it is necessary to examine all of the relationships that are designated with arrows in order to be able to make an unequivocal statement about a possible causal link between exposure to magnetic fields and the intended effect.

Besides establishing the wire code, measurements in residences or in the workplace are also regularly performed during the studies. The results of these measurements have the disadvantage that they are not, as a rule, a good reflection of exposure in the past, because the exposure can vary considerably over time. In several (especially Scandinavian) studies, the historical magnetic field strengths around high-voltage power lines have been calculated on the basis of available data about the loading of the lines at the time. Although these calculations also have their limitations, these studies provide the most direct data about a relationship between exposure and health effects.

According to the NIEHS report, no unequivocal, reproducible evidence has been found for the majority of the supposed relations between exposure to ELF EM fields in the residential or working environment and the occurrence of diseases, with the diseases considered being principally leukemia and brain tumours in children, and leukemia, brain and chest tumours and Alzheimer's disease in adults (Por98). According to that report, an association (i.e. a statistically significant relation) with an indirect measure of exposure (namely the proximity of power lines for children and the job title for adults) has only been sufficiently convincingly demonstrated for leukemia in children and chronic lymphatic leukemia in connection with occupational exposure. The NIEHS report also notes an association between occupational exposure (in this case, the job title) and the occurrence of brain tumours. That association is considered to be less convincing than the association with chronic lymphatic leukemia. The Committee examines these associations in more detail below.

The Committee would also like to draw attention to the results of a very recent study which has appeared since the publication of the NIEHS and NRC reports. This study reveals a possible association between occupational exposure to ELF EM fields and slight changes in cardiac rhythm (Sav99). However, this is merely one study, the design and execution of which may well still raise a few questions. It is also still too early to draw a conclusion about a possible causal link and an influence on health. Nevertheless, the Committee feels that the results justify further research.

3.2.1 Leukemia in children

Based on the totality of the results from epidemiological research, and taking into consideration the strengths and weaknesses of the different studies, the Committee believes that there is a reasonably consistent association between the occurrence of leukemia in children and residence near overhead power lines (both high-voltage and distribution lines). As has already been indicated, however, the data does not point directly to a causal link with exposure to ELF EM fields.

This conclusion, which corresponds to the one that was reached in both the NRC and the NIEHS reports (NRC97, Por98), is based primarily on the results of research in the US and in Scandinavian countries. It makes no difference to the conclusion whether all of the studies into leukemia in children are included in the analysis, or only a selection which satisfied certain (quality-related) criteria, as has been done in the NRC and NIEHS reports.

In the US research, the association in question is principally with the configuration of the electricity network's distribution lines (i.e. the wire code), which for the most part run overhead. It appears that there is a comparatively higher incidence of childhood leukemia close to lines that carry greater current - and where ELF EM field strengths are therefore higher - than elsewhere. In the NIEHS report, four studies are considered in which the wire code has been used as a measure of exposure. In three of the four, a slightly positive association has been found (Lon91, Sav88, Wer79), whereas no relationship came out of the fourth study (Lin97). Possible distortion of the results due to shortcomings in the design of the study did not, in itself, explain the positive results. The impact of confounding factors such as traffic density and socio-economic factors was also not conclusive. A meta-analysis reveals a slight - but statistically significant - increase in the risk (relative risk 1.4; 95% confidence interval 1.0-2.0) (War98).

In two recent publications about research in Canada, no statistically significant associations have been found with the wire code (Gre99, McB99). However, the numbers of people involved in these two studies are certainly not sufficient to negate the outcome of the meta-analysis that has just been mentioned (see also War98).

In several Scandinavian studies, the strength of the magnetic field from nearby high-voltage power lines has been calculated retrospectively in the houses in which the subjects of the studies had been living for a relevant period in the past. This field strength has been used as an exposure criterion. The results of these studies appear to support the indications of slightly increased risk that emerged from the study with wire codes. In three of the four studies that were judged to be of sufficiently high quality by the authors of the NIEHS report, a weak exposure-response relationship has been detected (Fey93, Ols93, Ver93). In a fourth study, this was absent (Tyn97). Confounding factors such as traffic density and socio-economic status had no significant impact on the outcome. It is true that the numbers of subjects investigated in these population studies were small, which detracts from the reliability of the results. Additionally, the period of time spent away from the residences was not taken into consideration, nor has any allowance been made for this. A meta-analysis of these four studies shows a slight, but statistically just significant increase in the risk (relative risk 1.6; 95% confidence interval 1.0-2.7) (War98).

The NIEHS report also discusses three studies in which point measurements of the present strength of the electromagnetic field in the residences have been made (Lon91, Mic98, Sav88). The results are inconclusive: in only one of the three studies (Sav88) has a connection been found, but the value of that study is limited due to the extremely low percentage of patient participation. A meta-analysis of these studies does not reveal a significantly increased risk (relative risk 1.2; 95% confidence interval 0.7-2.1) (War98).

In three studies in which the present magnetic field strength was measured over 24 hours, an increase in the risk was found for patients in the higher exposure classes (Lin97, Lon91, Mic98). In only one study a dose-response relationship was found (Lin97). However, the number of patients was low in all of the studies, partly due to a low participation rate. Moreover, various methodological objections can be made against each of the studies. A meta-analysis reveals an increase in risk that is slight, but statistically just significant (relative risk 1.5; 95% confidence interval 1.0-2.3) (War98).

In one of the above-mentioned recent studies from Canada, no relationship has been found with the measured magnetic field strength (McB99). In the other (Gre99), an increased risk with the field strength that was measured in or outside the residence was only apparent for a few subgroups, but comparison of these subgroups fails to present a consistent picture. In a recently published, large-scale study from Great Britain, no connection emerged between 48-hour measurements and the risk of leukemia in children (Day99). The same applies in the case of a smaller study in New Zealand (Doc99). Further meta-analysis will need to demonstrate whether these recent studies have any impact on the provisional conclusion that a slight, but statistically significant association exists.

When analyzing epidemiological studies, it is important to take into consideration a number of criteria that are used in epidemiology when drawing conclusions about a causal link. The Committee has taken account of the considerations that were noted in section 1.3.

At this point, the Committee would like to emphasize once again the fact that the significance of the above-mentioned weak associations is strictly statistical. A causal relationship has certainly not been demonstrated. Other research - for example, experimental research into a biological mechanism of action - has produced no evidence of a causal link (see section 3.1). One cannot, therefore, rule out the possibility that other, as yet unknown, risk factors that more frequently play a role in individuals living near overhead power lines are responsible for the increased incidence of leukemia that has been found in some studies. It is precisely because very little is still known about the causes of leukemia in children that a currently unknown risk factor - such as a carcinogen in the environment - could explain the association between leukemia and residence close to power lines. Furthermore, the question then arises as to whether those risk factors also come into play in the Netherlands.

If the association mentioned above should also be present in the Netherlands, that would mean, on the basis of a global estimate, that only less than 0.5% of the approximately 110 annual new cases of childhood leukemia could be explained in this way.

3.2.2 *Epidemiological research in workers*

The relationship between occupational exposure to ELF EM fields and the occurrence of cancer has been investigated in a large number of epidemiological studies. These are case-control studies, research into patterns of mortality and cohort research. The case-control studies were principally directed at leukemia, brain tumours and (to a lesser extent) at lung cancer and breast cancer in men. The cohort studies have mainly been conducted in employees of electricity companies.

Kheifets (Khe95) combined the results from 29 studies into the possible association between occupational exposure to ELF EM fields and the occurrence of brain tumours in a meta-analysis. The outcome was a small, but statistically significant increase in risk (relative risk 1.2; 95% confidence interval 1.1-1.3). Several studies produced sufficient information for a dose-effect analysis, but a dose-effect relationship has not been found.

A meta-analysis of studies into a possible link between occupational exposure to ELF EM fields and the occurrence of leukemia reveals the same picture (Khe97). In this case also, combining the results from 42 available studies of sufficient quality produced evidence of the existence of a slight, but statistically significant increase in risk (relative risk 1.2; 95% confidence interval 1.1-1.3). When the data was broken down into different forms of leukemia, the relative risk for chronic lymphatic leukemia proved to be the greatest (relative risk 1.6; 95% confidence interval 1.1-2.2). However, no evidence was found of the existence of a dose-effect relationship.

A significant limitation that applies to both meta-analyses is the fact that the different studies have usually categorized exposure in different ways.

Other factors also came to light which could explain the association that has been identified between exposure to ELF EM fields and the occurrence of cancer (Khe97). Examples are exposure to carcinogenic substances in the workplace, publication bias (the tendency not to publish results from studies in which no link is found) and the fact that different studies were not *a priori* directed at the relationship between exposure to ELF EM fields and cancer.

The Committee concludes that there is fairly consistent epidemiological evidence of a weak association between certain indicators of occupational exposure to ELF EM fields and the occurrence of several forms of cancer. In relative terms, the association is strongest for chronic lymphatic leukemia but it has also been identified, to a lesser extent, for leukemia in general and for brain tumours in adults. According to the NIEHS report (Por98), an association is probable only for chronic lymphatic leukemia. The consistency of the epidemiological research on occupational exposure is, however, in all cases less than with that on childhood leukemia. This observation, in connection with the fact that a dose-effect relationship has not been identified in a single study, coupled with the absence of any evidence of a biological mechanism, makes it improbable that there is a causal link, according to the Committee, between occupational exposure to ELF EM fields and the indicated types of cancer.

3.3 Conclusions

The Committee has reached the conclusion that for the majority of the diseases and disorders that have been investigated, epidemiological research has failed to produce any evidence of a relationship with exposure to ELF EM fields at the relatively low field strengths that occur in the residential or working environment. There are, however, a number of exceptions.

In the first place, the data obtained from epidemiological research points to a reasonably consistent association between residence near overhead power lines and a slight increase in the risk of leukemia in children. However, it is not possible to establish on the basis of these data a causal relationship between ELF EM field exposure and any risk factor. Were this association also present in the Netherlands, this would mean that roughly estimated only less than 0.5% of the approximately 110 annual new cases of childhood leukemia in the Netherlands could be explained by it.

In the view of the Committee, a reasonably consistent association has also been found between occupational activities in which exposure to ELF EM fields takes place and the occurrence of chronic lymphatic leukemia and (to a lesser extent) leukemia in general and brain tumours in adults. The consistency of these associations, however, is even less strong than that between residence near power lines and childhood leukemia and a causal relationship with ELF EM field exposure cannot be established with these data.

Experimental research has also produced no evidence of a causal link between exposure to ELF EM fields and the occurrence of any form of cancer, nor has it shed any light as to a possible biological mechanism that could explain a causal link in humans. The question of what the explanation is for the associations that have been found in the epidemiological studies, therefore, remains open. It is conceivable that one or several factors other than ELF EM field exposure are responsible. There are no indications as to the nature of these factors.

The Committee feels that on the basis of the present scientific views described in this advisory report there is no reason to recommend to take measures in order to limit residence near overhead power lines or working under circumstances involving increased ELF EM field exposure. It does recommend, however, to continue following the scientific developments in this field.

The Hague, 7 March 2000,
on behalf of the Committee
(signed)

Dr E van Rongen	Prof EW Roubos
Secretary	Chairman

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A	The Committee
B	Terms and concepts
C	Comparison with the ICNIRP guidelines

Annexes

Annex **A**

The Committee

- Dr EW Roubos, *Chairman*
  Professor of Veterinary Medicine, neurophysiologist; Catholic University of Nijmegen
- FBJ Koops
  biologist; KEMA, Arnhem
- Dr FE van Leeuwen
  Professor of Cancer Epidemiology; Free University of Amsterdam
  epidemiologist; Dutch Cancer Institute, Amsterdam
- Dr GC van Rhoon
  physicist; AZR (University Hospital of Rotterdam)-Daniel den Hoed Clinic, Rotterdam
- Dr GMH Swaen
  epidemiologist; University of Maastricht
- DHJ van de Weerdt, physician
  specialist in environmental medicine; Zwolle Municipal Health Authority (GGD)
- Dr APM Zwamborn
  Professor of Electromagnetic Effects; Technical University of Eindhoven
  physicist; Netherlands Organization for Applied Scientific Research (TNO), The Hague
- Dr E van Rongen, *Secretary*
  radiobiologist; Health Council of the Netherlands, The Hague

Annex **B**

Terms and concepts

1 Quantities and units

A	ampere, unit of electrical current
mA	milliampere = 10^{-3} A
V	volt: unit of electric potential
mV	millivolt = 10^{-3} V
kV	kilovolt = 10^{3} V
E	electric field strength, expressed in V/m
H	magnetic field strength, expressed in A/m
T	tesla: unit of magnetic flux density
mT	millitesla = 10^{-3} T
µT	microtesla = 10^{-6} T
B	magnetic flux density, expressed in T
A/m	ampere per metre: unit of magnetic field strength
V/m	volt per metre: unit of electric field strength
σ	electrical conductivity, expressed in S/m
f	frequency, expressed in Hz
H	henry: unit of self-induction
H/m	henry per metre: unit of magnetic permeability
Hz	hertz: unit of frequency; 1 Hz equals 1 cycle per second
kHz	kilohertz = 10^{3} Hz

MHz	megahertz = 10^6 Hz
GHz	gigahertz = 10^9 Hz
J	current density, expressed in A/m^2
mA/m^2	milliampere per m^2 = 10^{-3} A/m^2
m	metre: unit of length
cm	centimetre = 10^{-2} m
km	kilometre = 10^3 m
m/s	metre per second: unit of speed
S	siemens: unit of conductance
S/m	siemens per metre: unit of conductivity
s	second: unit of time

2 Electromagnetic concepts

Alternating field

An electromagnetic field with alternating positive and negative polarity.

Discharge current

Electrical current which flows when a charged body comes into contact with the earth and is discharged.

Electric field strength (E)

A quantity of the electric field which represents the force (F) exerted on a positive charge (q) at a given point, divided by the charge.

$E = F / q$

The unit is volts per metre (V/m).

Electrical current

Transport of electrical charge.

Electrical current density (J)

The density of the electrical current which flows through a surface perpendicular to the direction of current. The unit is amperes per square metre (A/m^2).

The current density is related to the electric field strength E by $J = k f E$, where f is the frequency and k is a constant.

The current density in a circle in a surface perpendicular to the direction of the magnetic field is related to the magnetic flux density B by $J = \pi r f \sigma B$, where r is the radius of the circle, f the frequency and σ the electrical conductivity of the medium.

ELF EM fields

Extremely low frequency electromagnetic fields, with frequencies between 0 and 300 Hz.

Faraday's law

If a closed circuit with resistance R contains a time-varying magnetic flux Φ, then an induction current J is induced in that circuit, the magnitude of which is proportional to the velocity of the change in the flux.

$J = -(d\Phi/dt) / R$

Frequency

The number of oscillations per second. The unit is hertz (Hz).

Magnetic field strength (H)

A quantity which is equal to the magnetic flux density divided by the permeability of the medium. The unit is amperes per metre (A/m).

Magnetic flux density (B)

A quantity which results in a force (F) being exerted on a moving charge. The vector product of B and the velocity (v) at which an infinitely small charge (q) moves in B is equal to the force which is exerted on the charge divided by q.

$F / q = (v \times B)$

Permeability

The magnetic density of a medium. The unit is henrys per metre (H/m).

Pulsed field

Electromagnetic field whose polarity is not changed according to a harmonic pattern (unlike that of a sinusoidal field), but via abrupt alterations.

R.m.s., root mean square

The calculated mean or effective value of a periodically varying function. The r.m.s. value for an electric field with a field strength $E(t)$ and an oscillation period T (=1/frequency) is calculated as follows:

$E_{r.m.s.} = [(1/T) \int_t^{t+T} E^2(t)\, dt]^{0.5}$

Sinusoidal field

An alternating field which is described as a harmonic oscillation through a sinusoid, in which the deviation x is described as a function of the time by $x = a \sin(2\pi f t + \phi)$, where a is the amplitude, f the frequency and ϕ the starting phase angle.

Static field

An electric or magnetic field whose polarity remains constant in time.

3 Other concepts

Alzheimer's disease

A specific form of presenile dementia which commonly occurs before the age of sixty and rapidly takes a serious course.

Association

In epidemiology, a connection established on the basis of statistical calculations in the sense that, in individuals exhibiting a certain clinical picture, certain environmental factors occur more frequently than in individuals without that clinical picture. The existence of an association does not constitute proof of a causal link, but may well prompt further research.

Basic restrictions

Health-based exposure limits that relate to certain electromagnetic phenomena which can lead to health impairment in the human body. For static fields, these limits are the electric and magnetic field strength, for alternating fields up to around 10 MHz, they are the electrical current that is induced in the body, and for alternating fields upwards of around 100 kHz they are the conversion that takes place in the body from electromagnetic energy into heat. Between 100 kHz and 10 MHz, both the current density and the generation of heat are important.

Carcinogens

Substances that cause cancer.

Cardiovascular system

The heart and blood vessels.

Case-control study

Epidemiological research which takes the disease as its starting point. Using a group of patients selected according to certain criteria (‘cases’), a control group is formed comprising individuals who correspond as closely as possible to the study group with regard to a number of relevant characteristics. Researchers then investigate which factors the ‘cases’ and the controls have been exposed to in the past. A higher incidence of a given exposure factor in the ‘cases’ than in the controls can be indicative of a possible causal factor.

Chronic lymphatic leukemia

Non-acute form of leukemia of the blood lymphocytes.

Cognitive functions

Processes that take place in the brain during perception, information-processing, learning, thinking and problem-solving.

Cohort study

Epidemiological research which takes exposure as its starting point. For a given exposure factor, a group of exposed individuals and an equivalent control group of non-exposed individuals are formed. In both groups, the occurrence of diseases is observed over a period of time. More frequent occurrence of a specific disease in the exposed group can be an indication of a causal link with the selected exposure factor.

Direct effects

Effects caused by the action of electric, magnetic or electromagnetic fields on an exposed organism.

Distribution lines

Overhead network of electricity lines located within residential areas, which transport electricity to the end-users at a lower voltage than high-voltage power lines.

Dose-response relationship

An increase in effect upon increasing exposure to a given factor.

Epidemiological research

Investigation of the occurrence of diseases in connection with the occurrence of factors suspected of having a certain relationship with those diseases. The aim is to obtain evidence regarding the possible causes of the diseases. Epidemiology is an observational, and not an experimental, science. It is not possible to draw definite conclusions about a causal link based on the data from epidemiological research.

General population

Everyone who is not included in the working population.

High-voltage power lines

Long-distance, overhead transport system for electricity.

Indirect effects

Effects that can occur where a potential difference arises between an organism and an unearthed object as a result of exposure to an electric field. The object then acts as a capacitor and, if it is being touched by an organism that is in contact with the earth, a discharge current will be generated.

In vitro research

Experimental research in cultured cells or tissues.

In vivo research

Experimental research in intact organisms, such as experimental animals.

Long-term effect

Biological effect that only manifests itself some time after exposure.

Leukemia

Cancer of the blood cells, uncontrolled growth of early-stage white blood cells.

Melatonin

A hormone produced by the pineal gland in the brain, which plays a role in the circadian rhythm. It can also function as a free-radical scavenger.

Meta-analysis

An epidemiological method whereby the results of different studies are combined in a single, composite analysis. Such an approach has limitations if the design of the studies was different and the risk factors have not been measured in the same way. However, for more or less equivalent studies, in which a weak connection (a relative risk of less than 2) is sometimes identified and sometimes not, a meta-analysis can be a useful way of obtaining an overall picture.

Phosphenes

Spots or flashes of light which are perceived in response to direct stimulation of the retina by electrical current or direct pressure on the eyeball.

Radicals

Highly reactive molecules which can damage other molecules.

Reference levels

Values for the strength of the undisturbed electric and magnetic field which are derived from the basic restrictions and which serve to establish whether the basic restrictions are being satisfied. Measurement of the quantities that underlie the basic restrictions is not easy (whereas the electric and magnetic field strength is easily measured).

Short-term effect

Biological effect that occurs during exposure.

Socio-economic factors

Specific factors which relate to living conditions – for example: income, family situation and education – and which can have a bearing on the interpretation of the outcome of epidemiological research.

Statistically significant effect

An effect which, based on scientific calculation, is unlikely to be wholly attributable to chance.

Safety factor

A factor by which the maximum value of a quantity which underlies a basic restriction but which does not yet give rise to health effects is reduced in order to arrive at the final basic restriction. For example: in a particular frequency range, no effect has yet been identified on nerve fibres at a current density of 1000 mA/m^2. The application of a safety factor of 10 results in the basic restriction of 100 mA/m^2. Safety factors are applied because of uncertainties and gaps in scientific knowledge and possible differences in sensitivity between different population groups.

Wire code

The division of all of the components of an overhead electricity distribution system into a limited number of categories - the number of lines with high and low voltage, their respective locations and the positioning of the transformers - with all of these factors being related to the distance from a residence. There is a certain correlation between the categories and the strength of the electromagnetic field at the residence.

Workers

Adults who may be exposed to EM fields in the course of their work and who have been given information about the risks associated with that exposure and about the precautionary or protective measures that can be taken.

Annex **C**

Comparison with the ICNIRP guidelines

This Annex contains a comparison of the recommendations from this advisory report and those of the ICNIRP (ICN98).

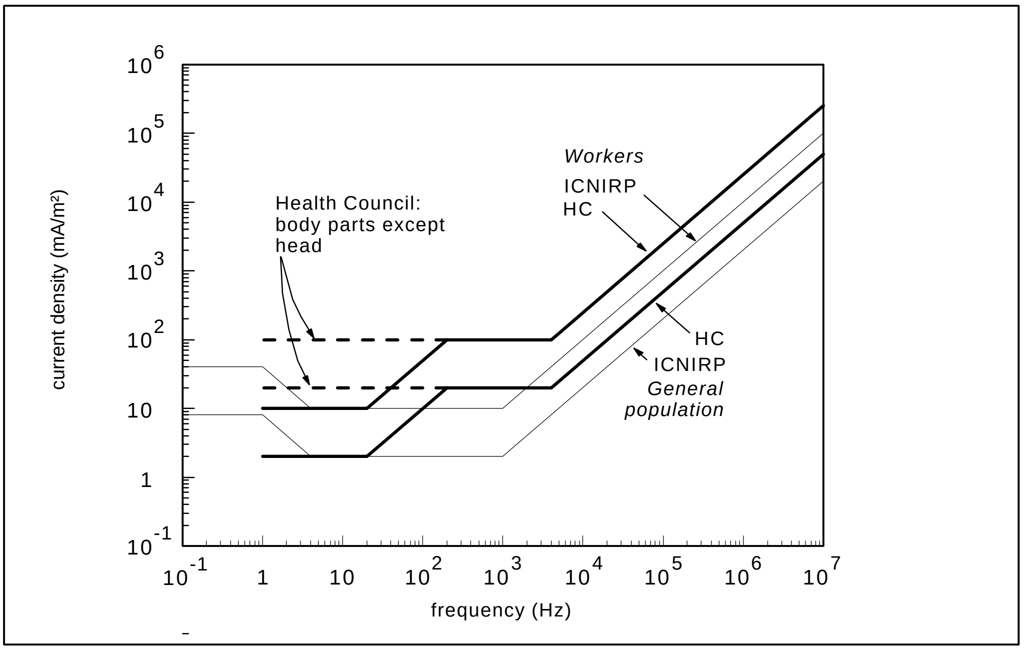

Figure 5 Basic restrictions: the current density.

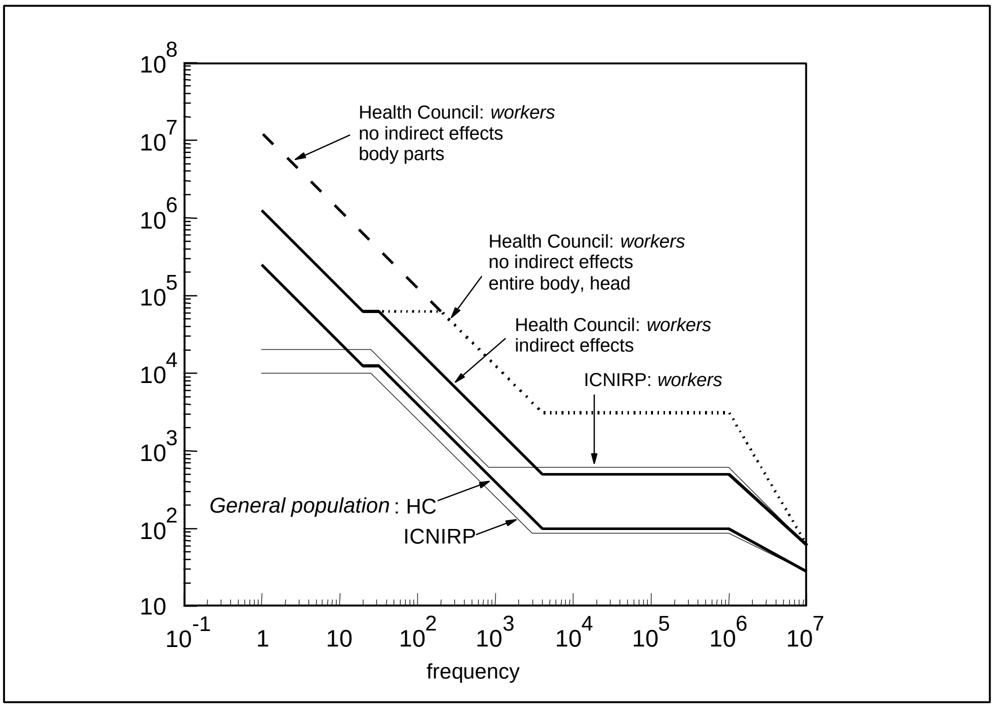

Figure 6 Reference levels for the electric field strength.

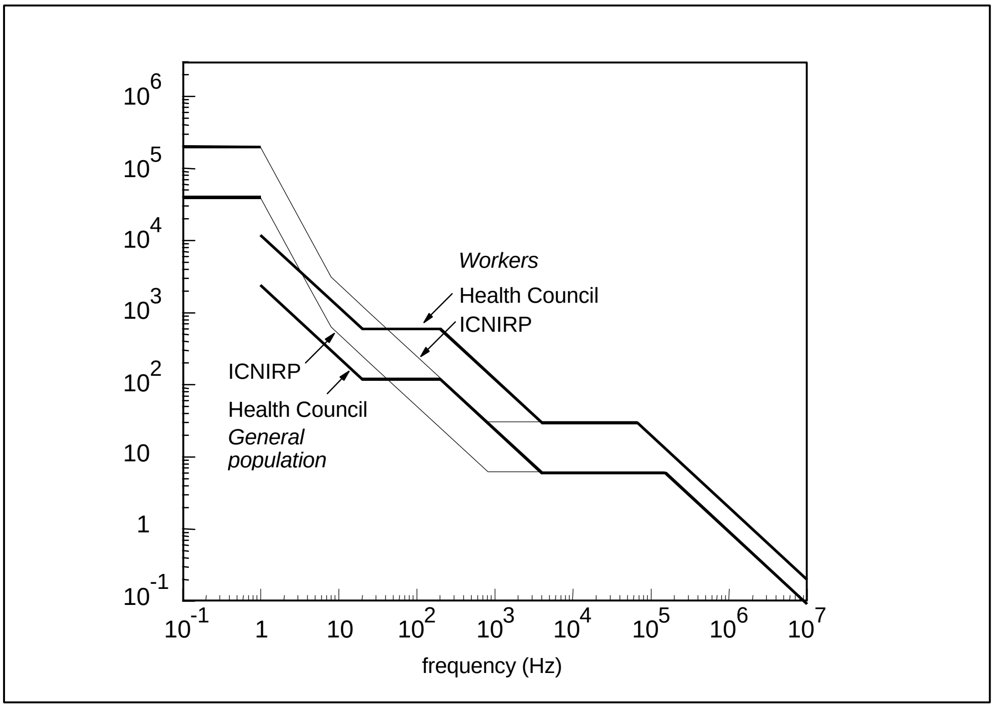

Figure 7 Reference levels for the magnetic flux density.