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Protection against electromagnetic radiation from mobile wireless sets

Recommendation of the German Commission on Radiological Protection

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Schutz vor elektromagnetischer Strahlung beim Mobilfunk

Empfehlung der Strahlenschutzkommission

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1 Introduction

Within the next few years there will be a considerable increase in the number of mobile wireless sets (mobile telephones) worldwide, especially in the Federal Republic of Germany. This will result in a strong increase of high frequency radiation in everyday's life.

If mobile wireless sets do involve health risks, these will affect very large sections of the population. Additionally there would be potential effects of the increased number of fixed wireless stations.

This recommendation reflects the present state of knowledge about the potential effects of high frequency radiation in modern mobile wireless set technology and leads to an assessment of risks to users and population as a whole on the basis of which limits are proposed, whereby the D-network presently being established is emphasized.

2 Mobile wireless set systems

The history of wireless communications in Germany began in 1918 with experiments conducted in Berlin. The first largely area-covering A-network was installed in 1958. It was substituted in 1972 by the technically improved B-network which still comprises about 17,000 participants today. The more recent C- network has experienced such a steep upturn in the Federal Republic of Germany that the maximum capacity of 800,000 participants presumably will be exhausted in the beginning of 1993.

All usual networks are run with a national standard which excludes the use of terminals abroad. This does not apply anymore to the D-network introduced in 1991 which can be used worldwide.

In the mobile wireless set for the D-network the transmission output is automatically adjusted to the lowest possible level, in accordance with the local conditions. This advantage can, however, be offset if the radiation characteristics are impaired due to body-near operation so that the output is adjusted to the maximum value.

In addition to the networks of mobile wireless sets, there are also some unidirectional area-covering "Personenrufsysteme" (paging systems) and locally limited mobile wireless set systems such as "Bündelfunk" ("Betriebsfunk") or the "schnurlose Telefon" (cordless telephone), a summary of the different systems and devices is given in Table 1.

The operation of the networks requires fixed wireless stations the number of which depends upon the planned cell volume of the network considered. Several thousands of fixed stations, each with a maximum output of 50 W have been planned for the D-network.

Tab. 1: Examples for different mobile wireless set systems

Radio service	Frequency	Effective radiated power (max.)	System
Car telephone	450 MHz approx.	Device classes: < 15 W 3.5 up to 8 W < 1 W	C-Network, analogous control
	890 MHz to 960 MHz	< 20 W inherent < 8 W portable < 2 W handheld apparatus each effective 1:8	D-Network, digital pulsed rate (217 Hz)
Cordless Telephone	800 MHz to 1 GHz	typically 10 mW	CT1, CT2, CT3
	1.88 GHz to 1,90 GHz	typically 10 mW	DECT, digital
Paging systems		Receiving devices	Eurosignal, Citycall, PEP, ERMES
"Bündelfunk"	410 MHz to 430 MHz	typically < 10 W	CHEKKER e.g.
"Betriebs-funk"	different frequencies from about 30 MHz	Device classes < 10 W < 1 W	analogous
CB-radios	approx. 27 MHz	< 4 W	Frequency or amplitude modulation analogous
Mobile satellite communications	approx. 1.6 GHz	typically 100 W pulse, 10 W effective	

3 Effects of high frequency radiation

The aerials of the mobile wireless sets presently operated or designed are transmitters of high frequency radiation part of which occurs near the body or, in cases of hand held devices, near the head. In addition, fixed wireless stations or other transmitting units might cause whole-body exposure. Assessment of the health risks conceivable in this respect requires both knowledge of the physical exposure conditions and consideration of the characteristics specific to each organ. The frequency range of interest for mobile wireless communications is that between about 30 MHz (short wave) and some GHz.

3.1 Physical effects

Exposure to high frequency radiation usually is expressed in terms of power flux density in the unit Watt per square meter (W/m^2). Within the near field range of aerials (normally distances of less than one wave length), the indication of the high frequency field requires data on both the electric field strength in Volt per meter (V/m) and the magnetic field strength in Ampere per meter (A/m).

The exposure conditions are strongly modified by the electrical properties and by the size, shape and orientation of the objects exposed to the high frequency field. Consequently, very complex field distributions may occur within and outside the body and its organs. Non-uniform field or energy distributions are also caused by frequency-dependent refraction or dispersion effects. The latter also include the possibility of energy focussing.

The energy fraction of the high frequency absorbed by the body is relevant for the biological effect. Especially in the mostly aqueous biological systems, the major part of the energy absorbed is transferred into heat by dipole effects. However, not all effects of the high frequency radiation may be explained by energy transfer into heat. So, even direct effects on macromolecules, cell membranes or cell organells may be induced under special conditions e.g. via amplitude-modulated HF-fields.

3.2 Biological effects

Since thermal effects must be assumed to predominate on the whole, the induction of biological effects usually preconditions that certain thresholds of energy absorption are exceeded. Effects such as disturbances of the metabolism, the nervous system, or the behaviour, as well as degenerative effects (e.g. cataract) can be largely correlated with the specific energy absorption (in Joule per kg body mass, J/kg) or the specific absorption rate (SAR-value in Watt per kg body mass).

Thermally mediated effects of HF-radiation have been studied extensively by animal experiments. Detectable effects occurred very often following a rise in temperature of the whole body or individual tissues by 1 °C and more. This corresponds to SAR-values of more than 2 W/kg approximately (averaged over the whole body) for permanent action. With an SAR-value of about 0.5 W/kg the temperature rise usually is tolerable. This is also the range of results obtained regarding the occurrence of developmental disorders in utero: teratogenic effects following a rise in temperature by less than 1 °C in the dams are improbable. A further rise in temperature, however, as a result of the high thermosensibility and the low heat dissipation in the embryos, leads to a precipitous rise in both malformations and the embryonic mortality rate.

Data from animal experiments concerning chronic exposures to low intensities are hardly available. The results obtained up to now suggest that there are no late effects as long as the exposures are below thermally significant SAR-values (0.4 to 2 W/kg). Chronic exposure of mice to 2 - 8 W/kg caused an increased progression of spontaneous tumours. The same applies for skin tumours in mice after skin treatment with chemical cancerogenic agents.

The data obtained in animal experiments (including those from primates) are indicative of effects which possibly also occur in man at a comparable high frequency absorption. However these findings can be extrapolated to man only to a limited extent due to species-related differences in thermotolerance and thermoregulation (blood flow, transpiration, hairiness).

Special effects which are not due to rises in temperature have been reported in the literature for about 15 years. If a high frequency radiation is amplitude modulated with another frequency, then field effects may occur which do not exist in cases of non-modulated radiation. These are mostly changes in the permeability of cell membranes. For example it has been found that in the case of a HF-radiation with a frequency of 147 MHz which was modulated with frequencies between 6 and 20 Hertz, the calcium efflux from cell cultures at certain frequencies was significantly increased (by about 10 to 20 %).

On the whole, these effects have been found to complexly depend upon intensity and frequency whereby special frequency ranges are particularly effective. The membrane effects have been confirmed in many cases, so that their existence is taken as granted today. It must be pointed out that the SAR-values in this case are partly below 0.01 W/kg and thus are considerably below thermally relevant intensities.

Except for the effects on the membran permeability of calcium ions observed in vivo and in vitro, changes in the EEG and the phagocytosis activity of lymphocytes have been found in cats and rabbits. Some of these observations were found to be not reproducible. The physiological importance of amplitude modulated effects is unclear up to now.

Relatively few studies have been conducted into the effects of acute or chronic exposure to HF-fields in man. Thresholds for skin heat-up in the frequency range of 2 to 10 GHz are above 200 W/m^2, depending upon the size of the area exposed and the duration of exposure. Whole body exposure of volunteers to SAR-values of 4 W/kg resulted in temperature rises by up to 0.5 °C after 15 to 20 minutes. This might be considered as acceptable for healthy individuals. However, the resulting rise in temperature also depends upon the physical activity of the exposed individual and her or his ability for thermoregulation. In individuals with fever, diabetics, elder individuals, and following the administration of certain drugs, the range of thermoregulation may be restricted.

In the frequency range of 300 MHz up to 2,000 MHz, exposure of the human head, as a result of resonance effects or quasi-optical focussing, might give rise to locally excessive energy absorptions, so-called "hot spots". Due to pulsed or modulated high frequency radiation there may be thermal expansion of the "hot spots" in the acoustic frequency range, leading to audible perceptions. In examinations with single pulses of less than 30 microseconds duration the threshold of effects for the specific energy absorbed during this time was found to be 10 mJ/kg.

4 Evaluation of health risks and generating limits

The effects of the high frequency radiation from mobile wireless sets or from fixed wireless stations on man and environment must be evaluated in order to assess the potential risks. The most important effects in this context are those from the high frequency energy absorbed by the human body. In addition there are technical aspects of electromagnetic compatibility, e.g. in the case of pacemakers.

4.1 Evaluation of thermal effects accounting for whole body exposure

The knowledge of an impairment or hazard to health due to high frequency electromagnetic radiation fields has induced many countries, including the Federal Republic of Germany, to set up limits of field strength.

The evaluation of the findings obtained in animal experiments from the viewpoint of radiation hygiene led to the conclusion that damage may occur with an SAR-value exceeding 4 W/kg (averaged over the whole body with prolonged exposure). The uncertainties in the extrapolation of animal experimental data to man are accounted for by the introduction of safety factors.

As already shown the absorption of high frequency energy primarily acts to rise the body temperature also in man. Under normal conditions SAR-values from 1 to 4 W/kg produce an average rise in temperature of less than 1 °C in man after the thermal equilibrium has been achieved. As a result of physical activities the additional heat production inside the body may amount to 3 to 5 W/kg.

According to a more recent evaluation of a WHO-working group (EHC-document 1992 "Radiofrequency Fields – 300 Hz - 300 GHz") the basic limit of 0.4 W/kg which has been introduced for many years is considered to be sufficient for occupational exposure (e.g. technical personnel in the range of transmitting sets)[1], whereby an additional safety factor is accounted for with regard to potential complications in cases of unfavourable thermal conditions in the surroundings.

For the general public, which comprises sensitive populations as well, an SAR-value of 0.08 W/kg is considered as sufficient for the protection against thermal effects from high frequency radiation. Both these basic limits have been internationally accepted in the meantime. They are in agreement with the IRPA basic limits from 1988. The values have also been adopted for the new DIN VDE Draft 0848, Part 2 (1991) meanwhile which contains additional requirements for practice.

The SAR-values indicated are based upon an average over the whole body and over 6-minutes' intervals. These latter result of the thermal time constants, i.e. after 6 to 10 minutes a local temperature distribution develops within the body.

The limitation of the whole body SAR-values is also important in the operation of fixed wireless stations and other HF-transmitters. However they are hard to be measured directly. Measurement quantities recordable by dosimeters which are derived from the basic limits are frequency-dependent values for the electric or magnetic field strength, or for the power flux density. Further requirements must be fulfilled in such cases as simultaneous action of HF-radiations from different sources by including them in the basic limits. In the Draft Standard DIN VDE 0848, Part 2 (1991) this is regulated by summation equations.

4.2 Evaluation of thermal effects accounting for partial body exposure

In the near range of the transmitting aerial of a mobile wireless set there are very inhomogeneous energy absorptions, depending on a great number of factors. The amount and distribution of SAR-values, e.g. in the human head, depends not only upon the power output and frequency of the device but also on the type of aerial, distance and position of the aerial to the head, and on the mode of operation (e.g. time period of receiving and sending). The power emitted by a device alone, therefore, is not an appropriate measure from which the potential health risks associated with high-frequency radiation could be concluded.

A series of examples shows that very high local SAR-values may lead to locally circumscribed rises in temperature in cases of special exposure conditions within the occupational field (e.g. in cases of dielectric or inductive warm-up or exposures within the

[1] In accordance with the recommendation of the IRPA from 1988, "basic limit" here is referred to as indicating an SAR-value in terms of W/kg. For the requirements of practice, the derived limits are used such as the power flux density in terms of W/m^2

near field range of aerials). It is therefore necessary that a limitation by a local SAR-value is introduced in addition to the whole body SAR-value.

In this context, special consideration must be given to the eye as a critical organ. A good heat dissipation by the blood stream can only be expected to occur near the choroid surrounding the eye, whereas the interior part of the eye, above all the lense, is relatively good isolated against temperature. Therefore, the SAR-values should be averaged over any 10 g in the case of the eye.

If values are averaged over greater tissue sections, local hyperthermia cannot be excluded in cases of greater temperature gradients. Local SAR-values must ensure that no part of the body, or no organ will be subject to a rise in temperature exceeding 1 °C as a result of high frequency absorption. With a limitation of the partial body SAR-value to 10 W/kg (averaged over 10 g of body tissue) the warming up at high frequency radiation will remain below this limit at any location even under unfavourable conditions.

The so-called "7-Watt-concept" which has been valid up to now in the Federal Republic of Germany, assuming that the operation of devices with a power of less than 7 Watt will not affect well-being or health, is not consistent with the basic limits. Experimental studies in tissue-equivalent phantoms have revealed that the basic limits may be significantly exceeded when using a mobile wireless set emitting 7 Watt. In the range between 900 MHz and 2,000 MHz, local SAR-values ranging from 15 to 35 W/kg have been assessed for the eye as well as for the brain, muscle and fat tissue.

The observation of the partial body SAR-value of 10 W/kg (averaged over any 10 g) is essential to ensure that health risks are excluded when mobile wireless sets are used. A value of 2 W/kg (averaged over any 10 g) has to be assumed for the general public as set out in the Draft Standard DIN VDE 0848, Part 2 (1991). The values can be calculated accounting for the conditions of operation or experimentally determined.

4.3 Special effects

In addition to the effects of high frequency radiation considered up to now, special effects may occur particularly when the radiation is pulsed or amplitude-modulated in the low frequency range. An effect which has been studied well is the hearing effect due to pulsed high frequency radiation or high frequency radiation modulated with hearing frequency. This effect may occur when the absorbed specific energy in the frequency range of 300 MHz to 9 GHz exceeds 10 mJ/kg approximately in cases of some short pulses. According to present knowledge, however, the hearing effect needs not be accounted for with regard to uses in the technology of mobile wireless sets.

Besides the hearing effect, effects of amplitude-modulated high frequency radiation on the permeability of cell membranes have been discussed for a long time (see 3.2). The SAR-values for these effects are only very small; they are lower by a factor of about 10 than the present basic limits for the public. It cannot be estimated up to now whether such effects are significant for the risk assessment. Further research should be conducted into this field, also with regard to mobile wireless communications, since some systems do emit a high frequency radiation pulsed with 100 Hz or 217 Hz.

In cases of pulsed radiation, the IRPA (1988) and DIN (1991) recommend to have the peak value of electric or magnetic field strength for frequencies exceeding 30 MHz limited to the

32 fold of the limit for the field strength averaged over time. This corresponds to 1,000 times the limit for the power flux density.

4.4 Problems of electromagnetic compatibility (EMC)

EMC-problems include interference of high frequency radiation with other radio services, functional impairment of electric or electronic systems in the proximity of transmitters (data processing, car electronics, or modern airplane control) as well as impairments of electric or electronic implants (e.g. pacemakers). The EMC-problem has been known for some years and is accounted for already during manufacturing if possible. Testing rules jointly set out by European Committees for Standardization will also help to improve the electromagnetic compatibility of the devices. Due to the frequencies and outputs applied it can be assumed that impairments of implanted pacemakers by mobile wireless sets are improbable, if the SAR-limits given in Section 5 are observed.

5 Recommendations of the Commission on Radiological Protection

A. The Commission on Radiological Protection recommends to refrain from the so-called "7-W-concept" (see Section 4.2.), which is still applied in the Federal Republic of Germany. This concept must be substituted by basic limits based upon SAR-values which are in accordance with the present international values from the American National Standardization Institute (ANSI) and the IRPA as well as DIN VDE 0848, Part 2, Draft 1991. Correspondingly, the Commission on Radiological Protection recommends a whole body SAR-value of 0.08 W/kg averaged over 6-minutes' intervals and over the whole body, and a partial body SAR-value of 2 W/kg, averaged over 6-minutes' intervals and 10 g of tissue for the general public.

   The values applicable for occupational exposure are higher by a factor of 5. They must be checked by appropriate measurements.

   The Commission on Radiological Protection, based on the present state of knowledge, is convinced that a sufficient protection of the whole population is ensured when the given limits are observed.

   For the mobile wireless sets that are commercially available or will be offered in the future, it must be ensured that the quoted partial body SAR-values are not exceeded under all conditions of operations that might occur. If necessary, the operator's manuals must be supplemented by additional instructions for correct use of the devices.

B. When freely accessible fixed wireless stations are installed, too, a whole body SAR-value of 0.08 W/kg must not be exceeded, whereby also potentially occurring high frequency immissions from other sources must be accounted for. If necessary, additional conditions must be observed to avoid burns due to indirect action (limitation of body currents).

C. The Commission on Radiological Protection points out that adherence to the basic limits, accounting for the exposure conditions, can be demonstrated by calculation. Use of appropriate body phantoms also enables an assessment to be made by technical measurement.

D. Unless there is evidence that no basic limit is exceeded during the operation of the mobile wireless sets commercially available, the Commission on Radiological Protection recommends to observe safety distances between the devices and the body. With power outputs of up to 0.5 W, a minimum distance of the body or head to the aerial is not necessary from the point of view of radiation hygiene. For higher outputs, values of orientation for the minimum distances to be observed are given in Table 2 by way of example.

Tab. 2: Examples for minimum distances between the aerial of a mobile wireless set and the body for members of the general public.
Conditions required to observe the partial body SAR-value of 2 W/kg (values averaged over any 10 g of tissue and any 6-minutes intervals).

Frequency	Peak radiated power	Minimum distance
450 MHz analogous	up to 0.5 W up to 1 W up to 5 W up to 20 W	no minimum distance 4 cm approx. 20 cm approx. 40 cm approx.
900 MHz analogous	up to 0.5 W up to 1 W up to 5 W up to 20 W	no minimum distance 5 cm approx. 25 cm approx. 50 cm approx.
900 MHz (GSM) digital	up to 2 W up to 4 W up to 8 W up to 20 W	no minimum distance 3 cm approx. 5 cm approx. 8 cm approx.
1800 MHz (DCS 1800) digital	up to 1 W up to 2 W up to 8 W up to 20 W	no minimum distance 3 cm approx. 7 cm approx. 12 cm approx.

In cases of digital cellular systems (GSM, DCS 1800 etc.) the pulsed radiation (pluse/pause = 1/8) is accounted for.
For occupational exposure the permissible minimum distances may be lower by a factor of 2.

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