Strahlenschutzkommission

Geschäftsstelle der
Strahlenschutzkommission
Postfach 12 06 29
D-53048 Bonn

http://www.ssk.de

German Mobile Telecommunication Research Programme (DMF)

Statement by the German Commission on Radiological Protection
(Strahlenschutzkommission – SSK)

Adopted at the 223rd session of the Commission on Radiological Protection, 13 May 2008

The German original of this English translation was published in 2008 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety under the title:

Deutsches Mobilfunk-Forschungsprogramm

Stellungnahme der Strahlenschutzkommission

Verabschiedet in der 223. Sitzung der Strahlenschutzkommission
am 13.05.2008

In the event of any doubts about the meaning, the German original as published shall prevail.

Table of contents

1 Introduction

In view of the general debate on health effects of high-frequency electromagnetic fields below existing limit values, and in the context of the increasing spread and comprehensive penetration of mobile phone usage among the public, the German federal government requested the German Commission on Radiological Protection (Strahlenschutzkommission, SSK) in the year 2000 to evaluate the current state of knowledge. The SSK subsequently issued its recommendation on "Limit values and precautionary measures to protect the general public against electromagnetic fields" (SSK 2001), in which one precautionary measure proposed was to intensify research activities in order to clarify unresolved issues. The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU) then commissioned the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) to carry out the German Mobile Telecommunication Research Programme (Deutsches Mobilfunk-Forschungsprogramm, DMF). A total of 17 million euros was assigned for the research programme, to be provided in equal parts by the mobile phone network operators and the BMU. The BfS assumed the task of administering the funds, deciding research themes and providing organizational management of the research programme, in order to exclude any influence exerted by mobile phone operators upon research contractors and hence to safeguard independent research. Over the period from 2002 to 2008, 54 research projects (including some awarded as supplements to main studies) were performed on issues in the thematic areas of biology, epidemiology, dosimetry and risk communication.

In its recommendation (SSK 2001) the SSK had identified unresolved scientific issues and had made recommendations on research themes. In its capacity as one of the groups invited to take part in the discussion process on selecting projects and setting research priorities for the DMF, the SSK has taken part in the public debate on the planned research projects and has participated in several BfS-organized scientific workshops convened to present interim reports on DMF projects. The SSK has also played an active role in roundtable meetings which have accompanied the DMF.

In the present statement, the SSK provides a scientific evaluation, on the basis of the available final reports, of the 36 research projects that had been concluded at the time of the consultations. This evaluation covers the suitability of the selected research themes, the scientific quality of the work performed, and the advancement in knowledge relating to the assessment of health aspects of mobile telecommunications that the work has provided. The evaluation also examines questions that have remained unresolved or that may have newly arisen due to the further progress of international knowledge that has taken place in the meantime.

In preparing this statement, the available final reports of individual research projects were analysed and evaluated by at least two independent experts of the SSK's Non-Ionizing Radiation Committee. To ensure objectivity and impartiality, only those members of the SSK

or its committee were appointed to review a project who were neither directly nor indirectly involved in the performance of the project in question. In addition, independent external consultants were also requested to evaluate the projects.

Based on the project reviews thus generated, the results of the DMF were critically debated in the SSK's Non-Ionizing Radiation Committee and a draft statement produced. The draft was submitted to the SSK where, following in-depth debate, it was completed and adopted.

In the following, the SSK states its view on the 4 thematic areas of the DMF.

2 Thematic area: Biology

2.1. Introduction

In the DMF area of Biology, 22 research contracts have been awarded. Of these, 13 have been completed; the remaining 9 are still in progress or nearing completion.

Although there is some overlap between the issues covered by the projects, they can be categorized under the following headings:

- Electromagnetic hypersensitivity (B5, B13, B14, R3),
- EEG and sleep quality (B5, B19, B20),
- Influences on sense organs (B11, B12, B18),
- Blood and blood-brain barrier (B10, B15, B16, B21),
- Cellular processes and mechanisms (B1, B6, B7)
- Carcinogenicity (B3, B4).
- Long-term effects (B9, B22),
- Age-dependent effects, especially in children (B2, B17),
- Overall metabolism (B8).

The close inter-disciplinary cooperation between the experimenters and technicians working in the biological arena who were responsible for the high-frequency technology involved must be regarded as a particularly positive aspect of the overall programme. This cooperation led to the development of improved exposure apparatus and more precise dosimetry, which have contributed to a significant increase in the quality of the laboratory studies. Exposure to high-frequency electromagnetic fields were chosen both below and above the specific absorption rate (SAR) restrictions. These restrictions are set at 0.08 W/kg for whole-body exposure for the general population, and at 2 W/kg for partial body exposure, per each 10g of body tissue. For occupational exposure the whole-body limit is 0.4 W/kg, while the partial body limit is 10 W/kg (for further information, see the Appendix).

The different headings will now be explored more fully on the basis of the final reports that have been received, and the evaluations by the reviewers.

2.2. Electromagnetic hypersensitivity

Some people who suffer from non-specific symptoms of illness attribute these symptoms to adverse effects of "electrosmog". They explain the fact that the majority of the population develops no symptoms, despite the same exposure, by declaring that they are "electromagnetic hypersensitive" – that is, they have significantly increased sensitivity in comparison to the general population. Provocation experiments have so far been unable to confirm this hypothesis. Moreover, outside the subjective convictions it was not possible either to find criteria by means of which "electro-sensitive" people could be objectively identified, or to prove that the cause of their health problems was linked with exposures to electric, magnetic or electromagnetic fields. In the context of the DMF, the results of three projects are available that deal directly or indirectly with these issues, albeit without a standardized definition of "electromagnetic hypersensitivity" and with various selection criteria for "electromagnetic hapersensitive" subjects. In Project B14[1] epidemiological and clinical techniques were combined. Using a case-control study, 89 subjectively "electro-sensitive" individuals and 109 controls were compared. "Electromagnetic hypersensitives" (EHS) complained of a significantly larger number of health problems. Using transcranial magnetic stimulation (TMS) it was shown that EHS more frequently believed that they detected a stimulus, even under sham exposure conditions. Because of the increased false positive rates, they were less good than the controls at identifying exposure. Functional magnetic resonance tomography was used to record cortical activity in response to real and sham external stimuli. In the case of heat signals there were no differences between the groups, but EHS reacted clearly to mobile communications signals, even if these signals were only announced (but not applied). The data indicate that cortical processing is altered in EHS. Overall, no objective criteria for "electromagnetic hypersensitivity" were found.

Project B5[2] adopted a new approach; working with 43 subjects living near base stations who suffered from sleep disorders and described themselves as "electro-sensitive", it investigated the effect on sleep quality of shielding the high-frequency electromagnetic fields that were present. The quality of sleep was assessed both subjectively and by means of polysomnographic recordings. The results were unable to confirm the subjects' entrenched personal convictions.

---

1 *Research project B14: Frick, U., Hauser, S., Landgrebe, M., Eichhammer P.: Investigation of the phenomenon of "electromagnetic hypersensitivity" using an epidemiological study on 'electrosensitive' patients including the determination of clinical parameters*

2 *Research project B5: Leitgeb, N.: Investigation of sleep quality of electrohypersensitive persons living near base stations under residential conditions*

Project R3[3] set out to describe the personality characteristics of EHS people. Individuals were classed as EHS if they had ascribed to electromagnetic fields (EMF) their health problems which had arisen on more than one occasion. 2,406 people were surveyed by means of representative telephone interviewing. The prevalence of EHS in the survey was 6%. Of these 144 EHS, only around 28 individuals described themselves as electro-sensitive and thus met the criteria on which the majority of published studies are based. The prevalence of self-defined "electro-sensitives" was 1.1%. Except with regard to educational level, there were no sociodemographic differences between the 144 identified EHS and the general population. "Electro-sensitivity" as defined for this project emerged as an issue that takes many forms and about which those surveyed are ambivalent, rather than as a consistent and isolated fact.

All in all the DMF studies have not confirmed the assumption of a causal relationship between electromagnetic fields and health problems. Despite varying target group definitions and subject recruitment methods, the conclusion drawn from the synopsis including the international literature is that it is highly likely that "electromagnetic hypersensitivity" does not exist. Further research should therefore take place in thematic areas outside EMF research.

2.3. Sleep quality

The question of whether electromagnetic fields might have a negative impact on sleep quality was investigated in three studies (B5, B19, B20). Research project B5 used a new study design which enabled subjects to remain in their domestic environment. The high-frequency fields which the subjects associated with their sleep disturbances were either shielded by Faraday cages of electrically conductive fabric or, through the use of outwardly identical but ineffective fabrics, a sham-shield was applied. This approach has particular experimental advantages, since it avoids any influence of the laboratory environment – which is often experienced as artificial – on the results. The sleep of 43 subjects was assessed by means of subjective and objective parameters for 10 nights (1 habituation night, 3 randomly distributed nights under each of the 3 conditions of unscreened control, sham-shielding and true-shielding). In general it was found that for the greater proportion of subjects the evidence did not support the subjective conviction that "electrosmog" was the cause of their sleep disturbances. For a majority of 26 subjects (59%) there were no statistically significant differences in sleep parameters under the different conditions. For some subjects (32%) there were statistically significant improvements in subjectively experienced sleep quality even under conditions of non-effective shielding (placebo effect). For 9% of subjects the shielding led to a statistically significant increase in sleep latency times, rather than to an improvement in sleep that they had hoped for.

---

3 *Research project R3: Ulmer, S., Bruse, M.: Supplementary information about electromagnetic hypersensitive persons*

Project B19[4] set out to clarify whether electromagnetic fields from mobile telephones can influence brain activity. Rather than shielding electromagnetic fields, reactions to additional exposure were studied. Thirty healthy male subjects were exposed to either real or simulated electromagnetic fields via antennae attached to the head; both GSM and UMTS mobile phone signals were used. During the day the spontaneous EEG, evoked and event-correlated EEG potentials and cognitive functions were measured. The sleep EEG was also recorded. Of the 361 parameters investigated, only 5 (under UMTS exposure) showed statistically significant changes. This number is lower than the 18 significances which would be expected by chance due to the selected significance level for paired testing ($p<0.05$). It was consistently found that time of day had a significant impact on cognitive abilities; this was far more marked than the sporadic fluctuations that appeared under exposure conditions. This carefully conducted study was unable to confirm the positive findings which have sometimes been reported in the literature.

A further study (B20[5]) of the potential influence of the emissions of mobile phone transmitters on sleep quality has not yet been concluded.

All in all the DMF studies failed to confirm previous reports of health-relevant impacts on sleep quality, impairment of cognitive abilities or changes in the EEG as a result of mobile phone fields. However, a final assessment on the DMF projects dealing with these issues cannot be reached until still ongoing research work will be completed.

2.4. Influences on sense organs

2.4.1 Ear

Two studies dealt with the possible influence of mobile phone fields on the hearing organ Using an experimental approach, Project B11[6] investigated whether mobile phone fields could be associated with the occurrence of phantom noises (tinnitus). The experiment used three groups of rats that were conditioned to indicate tinnitus through an objectively measurable change in behaviour. The three groups consisted of exposed and sham-exposed animals and positive controls. In the positive controls tinnitus was evoked by means of drugs. After extensive testing of the experimental method on the positive controls, the group of exposed animals was subjected to GSM mobile phone signals of up to 20 W/kg – i.e. ten times the basic restriction for partial body exposure – via a specially developed antenna system. Over

4 *Research project B19: Danker-Hopfe, H., Dorn, H., Sauter, C., Bahr, A., Bolz, Th.: Studies of the effects of exposure to electromagnetic fields emitted from mobile phones on volunteers*

5 *Research project B20: Danker-Hopfe, H., Dorn, H.: Investigation of sleep quality in persons living near a mobile base station. Experimental study on the evaluation of possible psychological and physiological effects under residential conditions (unfinished)*

6 *Research project B11: Knipper, M.: Possible influence of high frequency electromagnetic fields of mobile communication systems on the induction and course of phantom auditory experience (tinnitus)*

an exposure period of 4 weeks no significant differences could be found between the actually exposed and sham-exposed groups, even at the highest exposure level.

These experiments were supplemented by molecular biology tests which involved measuring the activity of a number of genes that play a role in hearing. This was done immediately after the four-week exposure period and after a further two-week recovery phase. Here again no significant differences between true-exposed and sham-exposed animals could be found.

Project B18[7] investigated the activity of sense cells and the ion channels of the cell membrane in cochlea isolated from mice, using the experimentally demanding patch clamp technique. The signals applied were GSM 900, GSM 1800 and UMTS mobile phone signals with SAR values of 0.02, 0.2, 2 and 20 W/kg, i.e. up to 10 times the local basic restriction. The temperature of the cell samples fluctuated by a maximum of ±0.2°C. Of 36 statistical tests, 31 were not significant. Of the 5 significant results, one was caused by a single statistical outlier. The remaining 4 significant results were spread over different target parameters and exposure strengths and do not exhibit any systematic pattern. All in all it can be concluded that below basic restrictions the activity of neurones in the aural system of rodents is not affected by mobile phone fields.

2.4.2 Eye

Potential effects of mobile phone use on the eye were investigated in Project B12[8]. The studies were conducted in-vitro on retinas isolated from mice. The retinas were in a temperature-controlled nutrient solution. The experimental conditions involved exposure of the specimens to GSM 900, GSM 1800 and UMTS mobile phone signals with specific absorption rates of 0.02, 0.2 and 20 W/kg, as well as sham exposure. By means of extra-cellular derivations taken with glass electrodes the researchers measured the electrical activity (nerve impulses) of the ganglion cells of the retina in response to light stimuli of varying intensity. 1,344 statistical tests were carried out for each frequency band, yielding 8 significant results for each type of GSM exposure and 13 significant results for UMTS exposure ($p < 0.05$). However, no systematic correlation with exposure strength was found. All the effects observed lay within the normal physiological range. The multivariate statistical analysis revealed a significant thermally explainable influence of the combined parameters of mobile phone exposure and light intensity; this could not be avoided because of the technical limits of temperature regulation in the samples.

---

7 *Research project B18: Münkner, S., Vonthein, R., Engel, J.: Influence of high-frequency electromagnetic fields of mobile telecommunications on sensory organs. A. The auditory system*

8 *Research project B12: Ammermüller, J.: Influence of high-frequency electromagnetic fields of mobile telecommunications on sensory organs. B. The visual system*

2.5. Cellular interaction mechanisms

Three research projects have attempted to examine cellular mechanisms for potential effects of mobile phone fields. Project B1[9] investigated whether high-frequency electromagnetic fields lead to a reduction in melatonin synthesis in the pineal gland, which is responsible for melatonin production, and hence to a lowering of the melatonin level in the body ("melatonin hypothesis"). It is known that visible light produces this effect; the receptors responsible have been identified. If electromagnetic fields had the same effect, this could impact on sleep behaviour (since this is regulated by melatonin), and on carcinogenesis (since melatonin is a radical capture molecule). Therefore, reduction in melatonin concentration could increase the carcinogenic effect of the body's radical molecules. The project studied the influencing of melatonin production in stimulated isolated pineal glands of hamsters using unpulsed electromagnetic waves and pulsed GSM mobile phone signals at exposures with SAR values of 0.008, 0.08, 0.8 and 2.7 W/kg. In comparison to controls, unpulsed fields resulted in higher melatonin levels as SAR values increased; above 0.8 and 2.7 W/kg these became statistically significant. In the case of exposure to pulsed fields, no change was observed below 0.08 W/kg; at 0.8 W/kg there was a statistically significant increase ($p < 0.05$) and at 2.7 W/kg a statistically significant decrease in melatonin production. On account of the experimental conditions the possibility cannot be excluded that the effects at higher SAR values were caused by temperature rises. It is not clear to what extent the results obtained from isolated hamster organs can be transferred to humans, since in humans systemic differences could play a part. In hamsters, however, these differences have been excluded (Lerchl et al. 2007). Overall, these results have not confirmed the melatonin hypothesis.

The research project B6[10] was intended to find out whether it is possible for cell membranes to demodulate low-frequency pulsed microwaves, so that pulsation might cause particular effects. This necessitated modelling and experimental testing of the sub-cellular field distribution, taking account of the molecular structure on and in the cell membrane. In addition, the possible impacts on neuronal communication of effects observed at sub-cellular level were to be investigated by means of electrophysiological measurements taken from cortical nerve cells in an interesting new experimental approach. The method has involved the development of what are known as "neuron sensor chips" in which cells grow on electronic circuits, enabling electrophysiological signals to be processed directly and to be recorded even during exposure. However, on account of technical difficulties in implementing the methodology it was not possible to obtain robust results. Local field absorption by cell membranes was also investigated numerically with the aid of high-resolution numerical models. More than 10-fold local increases were observed.

---

9 *Research project B1: Lerchl, A.: Investigation of mechanisms of action in cells exposed to the high-frequency electromagnetic fields of mobile telephone technology. B. Pineal gland*

10 *Research project B6: Gimsa, J.: Investigation of mechanisms of action in cells exposed to the high-frequency electromagnetic fields of mobile telephone technology. A. Demodulation/communication*

Research project B7[11] investigated potential effects on the immune system: immune-relevant cells (primary human monocytes and primary human lymphocytes) were exposed to unmodulated high-frequency fields and GSM mobile phone signals in various modulation forms (217 Hz – pulsed, with and without DTX) with SAR values of 0.5, 1, 1.5, 2 and in some cases 5 and 10 W/kg and tested for changes in cytological parameters such as apoptosis frequency, changes in cell cycle progression and the production of reactive oxygen species (ROS). No significant changes in these cellular parameters in comparison with sham-exposed samples were found in any of the cell types studied – even for exposures above the limit value. There were, however, differences between sham-exposed samples and non-exposed incubator controls. This unexpected finding needs to be examined thoroughly. It puts into question not only the results of this research project but also the work of other research groups which have used the same experimental design, and justifies it to investigate these works critically.

Even though the majority of previously published studies have not demonstrated adequately verified significant effects below basic restrictions, and independent confirmation of positive results has not been possible, further assessment cannot be performed until the reports of the DMF-projects that have not yet been concluded become available.

2.6. Carcinogenicity

A study published in 1997 (Repacholi et al. 1997) of mice genetically modified to yield high spontaneous lymphoma rates gave rise to the suspicion that high-frequency fields might favour tumour promotion. Two projects have addressed this issue (B3[12] and B4[13]). The very complex experiments under carefully controlled exposure conditions involved large collectives of animals (160 animals in each experimental group) which received uninterrupted constant exposure to 900 MHz GSM signals (Project B3) and UMTS signals (Project B4) (in both cases at 0.4 W/kg). There were no significant differences between sham-exposed and true exposed animals with regard to either the leukaemia rate or the time course of the appearance of the disease. Other studies carried out for the purpose of independently replicating the findings of Repacholi et al. have also been unable to confirm the hypothesis that chronic exposure to mobile phone fields could promote cancers of the blood-forming system (leukaemia). This hypothesis is therefore further weakened by the present DMF studies.

---

11 *Research project B7: Simkó, M.: Investigation of mechanisms of action in cells exposed to the high-frequency electromagnetic fields of mobile telephone technology. C. Functions*

12 *Research project B3: Lerchl, A.: Influence of low- and high-frequency electromagnetic fields on spontaneous leukaemia in AKR/J mice*

13 *Research project B4: Lerchl, A.: In-vivo experiments on exposure to the high-frequency fields of mobile telecommunication*
B. Carcinogenesis

2.7. Long-term effects

2.7.1 Multi-generation study

In experimentally complex studies of Project B22[14], four generations of mice were exposed throughout their livetimes to UMTS signals at SAR values 0.08, 0.4 and 1.3 W/kg. The animals were examined for general health, weight and growth, reproductive ability, teratogenous effects and development parameters. There was no evidence that the high-frequency exposure had negative effects on reproductive processes and development in four successive generations of animals that were exposed continuously throughout the period of the study.

2.7.2 Age-dependent effects, especially in children

Studies B2[15] and B22 looked at particular sensitivities in children. In the laboratory study B22, experimental animals were exposed continuously to UMTS fields over several generations (thus including their foetal stage). Even under life-long exposure there was no evidence of negative effects on reproduction or on embryonic and infant development. This study was therefore unable to confirm that particular sensitivities exists in the early years of life. This is particularly important in regard to the discussion of possible particular sensitivity in children.

In a feasibility study (B2) the literature review showed that the question of a possible age-dependent effect of high-frequency fields and particular vulnerability in children is still open. The study concludes that dosimetry projects should be given priority, although biological and epidemiological studies are also regarded as feasible. The study, which was completed in 2004, was an important aid in setting future priorities of the DMF. Since then some new dosimetric studies have been published (Christ and Kuster 2005, Conil et al. 2008); mention must also be made of the SSK report on mobile phones and children (“Mobilfunk und Kinder”, SSK 2006).

3 Thematic area: Epidemiology

So far five out of 9 studies in the area of Epidemiology have been completed. The following topics have been addressed:

- Feasibility of a cohort study on highly exposed occupational groups (E1)
- Participation in the RIFA case-control study of melanomas of the choroid membrane (E2)

---

14 *Research project B22: Lerchl, A.: Long-term study on the effects of UMTS signals on laboratory rodents*

15 *Research project B2: Schmid, G., Pipal, L., Widhalm, K., Tschabitscher, M.: Feasibility study on age-dependent effects of RF electromagnetic fields on the basis of relevant biophysical and biological parameters*

- Prospective cohort study of mobile phone use (E3)
- Extension of the German part of the INTERPHONE study (E4)
- Cross-sectional study of health problems associated with mobile phone base stations (E5)

The feasibility study E1 [16] set out to investigate whether studies of highly exposed (occupational) groups could clarify whether exposure to high-frequency electromagnetic fields might be associated with an increased risk of illness. The finding was that no suitable group could be identified that would form a sufficiently large cohort for a prospective or retrospective study. This was because, for example, increased exposure as such was questionable or insufficiently defined, too many uncontrollable influences were present and the extent to which the findings could be transferred to mobile phone exposure was questionable.

Project E3[17] set out to investigate the feasibility of carrying out a prospective cohort study in Germany of potential long-term health effects of mobile phone use, in line with the guidelines of the COSMOS study (cohort study on mobile phone use and health). The finding was that, while this was possible in principle, the very low level of willingness to participate in such a study would require an unrealistically large number of mobile phone users to be contacted to achieve an adequate number of participants. The feasibility study nevertheless yielded useful information on the limits of epidemiological methods and has played an important part in clarifying the way forwards.

Project E2[18] addresses the reproducibility of the findings of an international case-control study of melanomas of the choroid membrane (uveal melanomas) and radio-frequency radiation which has been extended nationally. The RIFA study financed by the German Research Foundation (‚Deutsche Forschungsgemeinschaft DFG) was relevantly extended due to support by the DMF. The aim of the overall study was to investigate whether the suggestion, published in 2001, of an increased risk of eye tumours as a result of high-frequency radiation could be substantiated. 458 cases and 1,210 controls took part and were surveyed by means of questionnaires, making this currently the largest case-control study of uveal melanomas in the world. The statistical analysis was not part of the project and is not yet available. The study of risk factors for melanomas of the choroid membrane (RIFA study) demonstrates that national extension in the form of a comprehensive follow-up study can serve to confirm or refute an initial suspicion arising from a relatively small population. Studies conducted on relatively small populations are not convincing. The more broadly

---

16 *Research project E1: Blettner, M. et al., Wahrendorf, J., Schüz, J. et al., Schroeder, E. et al.: Feasibility study for a cohort study: the cohort study should investigate highly exposed (occupational) groups to estimate the risk associated with high frequency electromagnetic fields*

17 *Research project E3: Blettner, M., Schüz, J., Böhler, E., Budinger, M., Brömmel, M.: Feasibility study for a prospective cohort study on mobile phone users*

18 *Research project E2: Stang, A., Schmidt-Pokrzywniak, A., Jöckel, K-H.: Addendum to a case control study on uveal melanoma and radio frequency radiation (RIFA Study)*

based data on melanomas of the choroid membrane now provides a better basis for conclusions.

Project E4 [19] represents the extension of the original German involvement in the INTERPHONE study. Compared with the other 16 participating countries, Germany was able to contribute to the overall study with the largest number of tumour cases and controls. In addition, the German contribution included exposure to cordless telephones and their base units (DECT). For durations of use over a period of less than 10 years, project E4 did not yield any evidence of increased risk for the brain tumour types studied. For use over more than 10 years there were no definite indications of increased risk, but the smaller number of cases does not allow to exclude this possibility. The national findings of earlier studies (Hardell group) from Sweden (with smaller numbers of cases) were therefore not confirmed. There was also no evidence of increased risk in individuals who had a DECT base unit located near their bed, and no evidence of a mutually synergistic effect of exposure to electromagnetic waves from mobile phones and ionizing radiation. A more definitive assessment must await the review of all national findings in the INTERPHONE study.

Project E8[20] aimed at investigating potential health problems associated with the fields of mobile phone base stations. Of the 51,444 individuals who were contacted by letter, 58.4% (30,047) took part in a survey of attitudes to mobile phones and their potential health risks such as sleep disorders, headaches, other physical complaints and quality of life. The interim analysis so far available reveals a north/south gradient within Germany, with concern increasing towards the south. More frequent concerns and/or health problems are experienced mainly by people aged between 30 and 50, those with higher levels of education and those living closer to mobile phone base stations. It was found, however, that proximity to a base station was not a valid measure of actual exposure. The final results of the study and its findings on the links to measured emissions or to an improved model of estimated emissions are not yet available.

At present, epidemiological studies of potential long-term effects of mobile phone use are limited by the relatively short time for which mobile phones have been in use. Particular difficulties are posed by the rapid development and spread of new technologies; this brings about frequent changes in the exposure scenario and makes dosimetric classification and the interpretation of results considerably more difficult.

---

19 *Research project E4: Schüz, J., Schlehofer, B., Berg, G., Schlaefer, K., Blettner, M.: Extension of an international epidemiological study on the association between high-frequency electromagnetic fields and the risk of brain cancer (INTERPHONE)* .

20 *Research project E8: Berg, G. et al., Blettner, M. et al., Schlehofer, B. et al., Potthoff, P. et al., Schüz, J.: Addendum to the cross-sectional study on adverse health effects by fields of mobile phone base stations*

4 Thematic area: Dosimetry

In view of the open questions and the dynamic expansion of mobile phone networks, the studis focussed on GSM and UMTS mobile communication technologies.

4.1 Everyday exposure situations

4.1.1 Transmission facilities

In order to determine the exposure of the general public in the surroundings of stationary transmission facilities (GSM, UMTS, radio, television, WLAN access points, DECT base units), suitable measurement techniques were developed and computation procedures evaluated (D2[21], D3[22], D6[23], D10[24]). This is also exceedingly important within the context of the necessary comparability of measurements, e.g. those produced by different measurement campaigns.

A large number of measurements of maximum and average exposures were carried out, and extensive simulations performed. The studies found that even maximum exposures only amount to percentages of the restriction levels; often measured levels are only a few thousandths of the power density permitted, or even lower.

Furthermore, analysis of the measurement data – although carried out for only some of the projects – shows that the distance from the transmission antenna is not suited as a predictor of the actual ambient exposure level. Project D7 developed a procedure for estimating ambient exposure levels; projects D3 and D6 measured ambient exposure levels and, through analysis of measured values, found that the main lobe direction of transmission and the line-of-sight are the key determinants.

As regards the change from analogue television to DVB-T, extensive measurements of the situation before and after the change were conducted at identical measurement points in two launch regions. These showed that the change was not only accompanied by the anticipated reduction in exposure, but that an increase in exposure may also occur. Therefore, changes in exposure cannot be generalized, but need to be checked case by case.

---

21 *Research project D2: Preiner, P., Schmid, G., Lager, D., Georg, R.: Determination of the field distribution of radio frequency electromagnetic fields of wireless LAN applications in urban environments*

22 *Research project D3: Bornkessel, C., Schubert, M., Wuschek, M., Schmidt, P.: Determination of the real RF field distribution in the surrounding of UMTS base stations*

23 *Research project D6: Bornkessel, C., Schubert, M.: Development of measurement and calculation methods for the determination of the public exposure due to electromagnetic fields in the vicinity of mobile phone base stations*

24 *Research project D10: Bornkessel, C., Schubert, M., Wuschek, M., Schmidt, P.: Determination of the public exposure due to electromagnetic fields of digital broadcast transmitters*

4.1.2 End-user devices

Measurements of exposures to emissions from end-user telecommunication devices such as WLAN, Bluetooth and DECT systems or baby monitors (project D8[25]) have shown that if the devices are used close to the body a greater percentage of the local basic restriction is reached than in the case of base stations. The reference levels for electric and magnetic field quantities may be exceeded by some end-user devices such as mobile phones or babyphones. Nonetheless, even these exposures are below the SAR basic restrictions.

Project D9 [26] studied the SAR values that arise in everyday mobile phone use. The investigation of the actual transmission behaviour and power control of GSM mobile phone handsets has shown that the opportunities for reducing output power by means of control algorithms are not fully exploited in everyday use. Depending upon network structure and the specific user, on average, the effective radiated power in everyday use was between 10% and 70% of the maximum radiated power. Depending upon the scenario, mobile phone handsets even transmit at maximum power for between 5 and 30% of call duration. Where network supply is good, output power averaged over time is lower than where supply is poor. The findings further show that power reduction can also be deactivated by the network operator. Cursory measurements of UMTS mobile phone handsets found particularly low output power levels and thus low SAR values. However, in view of the development and expansion of networks and the general increase in traffic load that have taken place in the meantime, these findings need to be re-examined.

Project D11[27] studied the elevation of exposure that can occur during indoor use of mobile phones. The findings have shown that for individuals not using a mobile phone basic restrictions are not exceeded. Exposure levels may be elevated for them by a factor of 10 compared to mobile phone use outdoors, but these exposures still remain at a very low level. An earlier theoretical analysis which showed that excess of basic restrictions can be expected in worst-case indoor scenarios has thus not been confirmed.

For active users of mobile phones, the potential elevations of SAR values in the case of indoor use compared to outdoor use are moderate (assuming maximum output power in each case). They are in the order of the computational uncertainty of approx. 10-15%. If, however, the mobile phone handset is near reflecting metal structures, SAR values can be significantly elevated, by up to approx. 50% compared to outdoor use.

---

25 *Research project D8: Schmid, G., Lager, D., Preiner, P., Überbacher, R., Neubauer, G., Cecil, S.: Determination of human exposure caused by indoor wireless communication technologies applied in homes and offices*

26 *Research project D9: Georg, R., Landstorfer, F.M., Jakobus, U.: Determination of the specific absorption rate (SAR values) occurring during day-to-day mobile phone use*

27 *Research project D11: Georg R., Schmid, G., Landstorfer, F.M.: Determination of the real exposure from using mobile phones in partly shielded rooms compared to the exposure occurring under advantageous conditions in free space*

4.1.3 Exposure assessment for epidemiological studies

A key task when performing epidemiological studies is to determine the exposure of a large number of individuals with sufficient reliability to be able to classify them in different exposure groups. Although the distance from base stations is repeatedly used in the literature, there is agreement that this is not suited as a surrogate of exposure assessment.

As comprehensive determination of exposures by means of measurements conducted in the field would involve major effort, an aim of project D7[28] was to develop, notably for use in project E8, other approaches providing sufficient reliability. The estimation procedure developed by that project takes account of the technical data of a wireless transmission facility (radiated power, transmission characteristic) and the geo-coordinates of the facility and transmission origin, and makes use of empirical transmission factors for wave propagation in different parts of human settlements as well as factors for capacity to penetrate indoor spaces. A test using measured data found a correlation coefficient of 0.6 between measured and estimated values of power density. Differences in power densities typically ranged between 10 and 100-fold. Although this technique can be used to perform a rough dichotomous classification into exposed and non-exposed, it is not a decisive advance. Much greater expectations can be placed in personal dosimeters – these, however, still need to be studied in more depth, for instance with regard to isotropy, the accuracy of their display especially with regard to the aspect of their being worn close to the body compared to the "without-body" situation, crosstalk in neighbouring frequency ranges etc. The results of an ongoing validation study and a comparison with the results of the British mobile telecommunications research programme should yield further findings.

4.2 Determination of intracorporal SAR distributions

Both in order to objectify exposures when performing studies and in order to conduct comparisons with SAR basic restrictions, knowledge of the intracorporal distribution of the specific absorption rate has become essential.

Comparisons between (intra-species) animal experiments are only useful if the same organ-specific dose is delivered; the whole-body SAR value does not provide sufficient information in this respect. Project D1[29] therefore used numerical inhomogeneous anatomic models to determine exposures in the bodies of experimental animals, and validated these by means of measurements on dead animal bodies. Studies conducted with RF-exposed experimental animals in the frequency range between 450 MHz and 5 GHz delivered phenomenological insights with regard to the dependence of absorption distribution upon location, polarization and frequency. This has produced guidance for the design of exposure facilities, as well as

---

[28] *Research project D7: Neitzke, H.-P., Osterhoff, J., Peklo, K., Voigt, H., Wohlatz, T.: Determination of the exposure of groups of people that will be investigated within the scope of the project "Cross-sectional study for ascertainment and assessment of possible adverse effects by the fields of mobile phone base stations"*

[29] *Research project D1: Fröhlich, J., Torres, V.B., Klingenböck, A., Nikoloski, N., Kuster, N.: Analysis of the SAR-distribution in test animals exposed to electromagnetic radiation*

high-resolution animal models. The results deliver important findings for the design of animal experiments and the transfer of their findings to the human subject.

Project D5[30] performed a quantitative study of local exposure to the emissions of field sources carried close to the body, by determining the SAR distribution and estimating tissue warming. This demonstrated the fact that, as had already been known for some time, hotspots occur in layered media, especially in case of resonance. It has thereby been shown that the present type approvals, which use a homogeneous plane phantom, are not conservative enough for all frequencies. Moreover, the project calculated the temperature elevation generated by various end-user devices (walkie-talkie, GSM and UMTS mobile phone, WLAN). These ranged up to 0.8°C if convective heat dissipation is taken into account, rising to 2.5 to 3.5°C in the skin in an unrealistic worst-case scenario in which heat dissipation is completely ignored.

Project D4[31] studied the specific absorption and the temperature increase in sensitive organs within the human head such as the eye, inner ear and pineal gland, taking account of micro-structures. Finer discretization (with volume elements of 0.1 mm edge length) did not find any fundamentally higher figures compared to earlier simulations with less fine resolution. In no case did mobile phone use lead to a warming of inner organs by more than 0.1°C. Only in the case of the use of high-power walkie-talkies held directly in front of the eyes in the 400 MHz range was a warming of up to 1°C found.

5 Thematic area: Risk communication

Within the DMF, seven research contracts were awarded on the theme of risk communication. Two of these projects aim to develop or refine practical communication tools. Project R1[32] was concerned with an Internet portal the core of which constitutes a knowledge-based databank of empirical research on electromagnetic fields. Building up on the existing knowledge-based literature databank (WBLDB), a German-language information service tailored to the general public was created in the form of a new “EMF portal” and linked to the WBLDB. The Internet portal facilitates access to the EMF literature, making it possible for users to gain information – quickly and without great retrieval effort – about the state of knowledge on the biological and health effects of the electromagnetic fields associated with mobile telecommunications. This project aims to improve information – it does not focus on social science issues of risk communication research. Nonetheless, it does provide starting points for an in-process analysis of user behaviour and user appraisals. The user survey

[30] *Research project D5: Christ, A., Klingenböck, A., Samaras, T., Neufeld, E., Kuster, N.: Exposure from transmitters worn near the trunk of the body*

[31] *Research project D4: Schmid, G., Überbacher, R., Preiner, P., Samaras, T., Mazal, P., Jappel, A., Baumgartner, W.D., Tschabitscher, M.: Determination of exposure distribution from high frequency fields in the human body with regard to small structures and relevant thermo-physiological parameters*

[32] *Research project R1: Wienert, R., Dechent, D., Silny, J.: Knowledge-based database of literature describing the effects of electromagnetic fields on the organism and implants*

facility integrated in the portal is positive but, due to the small number of cases, difficult to interpret. A systematic user evaluation in the future is recommended. In view of its great practical benefit, the project – if possible complemented by in-process analyses – should certainly be continued.

Project R6[33] produced an Internet-based decision support system for municipalities in whose areas base station sites are planned. The aim of this project is to ensure that the public continues to receive information even in situations of conflict. An information and decision support system for local authorities was developed, proceeding from the traffic-light model developed by the Mobile Operators Association (MOA) (2001). The MOA approach proceeds from recognition of the fact that each site has specific communication characteristics, in view of which communication provision and needs must be adjusted accordingly. Using two assessment categories, namely community aspects and planning and environmental aspects, the site situation is described by one of three traffic-light colours. The extent of consultation required rises from green to red. Project R6 differs from the MOA approach in that it assumes that when conflict intensity rises, appropriate conflict resolution will above all require participatory approaches.

In methodological terms, the project is based on case studies, for which interviews were conducted and media analyses used in order to derive criteria for traffic-light colour rating. The approach is interesting; it remains uncertain, however, whether it can give municipalities improved guidance, as there is still a lack of robust empirical studies showing which attributes can be used to predict mobile phone siting conflicts. The project case studies which were used to develop the model can not be used simultaneously to evaluate that model.

The same problem arises on the resolution side: it is unclear which procedures are suited to preventing conflict. This is because there is a lack of studies that both meet methodological quality standards and relate to the issues surrounding base station siting. It would be desirable for further research to generate a robust empirical basis here.

Project R7 [34] aimed to develop dialogue-based communication strategies for conflict prevention in base station site planning. This produced a qualitative case study which certainly has exploratory value but, due to its methodological limitations, scarcely provides robust guidance for the dialogue-based resolution of mobile telecommunications siting conflicts.

---

33 *Research project R6: Ulmer, F., Hiller, S., Renn, O.: Innovative methods of conflict mediation when determining the location for mobile phone base stations*

34 *Research project R7: Hoffmann, A.: Support of the co-operation between the mobile telecommunication actors by the Local Agenda 21*

Project R5[35] aimed to gather data on public anxiety and fears concerning the potential hazards of mobile telecommunications electromagnetic fields, by means of annual representative country-wide telephone interviews conducted between 2003 and 2006. One striking finding is that the level of general public concern remains constant at about 30% over the study period. Comparison of the findings of different studies, however, yields considerable differences, depending upon question format. It turned out that base stations are perceived as more threatening than handsets. Overall, however, a lower degree of concern attaches to mobile communications compared to other technologies and hazardous substances. It is also striking that a substantial 73% of those interviewees who consider EMF a possible source of health problems also consider cancer to be a probable consequence of mobile telecommunications. As, in contrast to the report on project R5, the report on project R4 lacks information on the selection procedure used for sample generation it is not possible to assess the representativeness of the findings of R5.

Two projects were concerned with target-group analyses (R2[36], R4[37]). R2 used a representative survey and a cluster analysis building upon that survey. The report, however, lacks precise information on response rates and sample characteristics. No precise statements about the representativeness of the findings can thus be made. The cluster analysis is well-designed. A critical point, however, is that no detailed information is provided on the cluster analysis performed. It is thus not possible to evaluate the quality or appropriateness of the target-group segmentation that builds upon that analysis.

In addition to the target-group analysis, Project R4 also addressed the awareness of information activities relating to mobile telecommunications and the impact of these activities. The study results in a slightly different clustering. The estimate of the size of the group of concerned people differs markedly from that of study R2. However, presentation of the study is not always sufficiently transparent: for instance, the sampling procedure is not described in sufficient detail. There is no detailed information on the procedure used for the postal survey. Nor is there information on whether the telephone survey used the design developed by the working group of German market research institutes (ADM design), involving the generation of a three-stage random sample; for instance, there is no information on how the target person in the household was selected during the telephone interview. It is also not clear in the report whether and how the data were weighted. The quoted response rate of about 20% is low. The statement that the survey is representative is questionable. A further aspect is that on the basis of risk appraisals it is difficult to form practically relevant target groups that go beyond the question of openness to risk communication. The group of

---

35 *Research project R5: Belz, J.: Identifying the general public's fears and anxieties with regard to the possible risks of high frequency electromagnetic fields of mobile telecommunications (annual survey)*

36 *Research project R2: Büllingen, F., Hillebrand, A.: Analysis of target groups for differentiated information*

37 *Research project R4: Renn, O., Pfenning, U., Ruddat, M., Sautter, M.A., Ulmer, F.: Examination of the knowledge and effects of information activities in the field of mobile telecommunications and determination of further approaches to improve information of different population groups*

individuals uncertain about the issue is clearly the most susceptible to the type and context of information presentation (framing effect) and thus also for the source of the information about the risk. It also became apparent in study R2 that the question about wishes for information (a key aspect of target-group segmentation) produces very little difference between the groups (apart from the group of uninterested individuals who make great use of mobile phones).

Project R4 further contains analyses of communication effects that are of special relevance to risk communication as they result directly in guidance for the content and design of communication. Three questions were pivotal: Which messages on EMF reach the public, how do they influence opinion formation, and what empirically founded guidance can be given to improve risk communication? To explore these issues the authors use a range of methods: a narrative review of the available studies on EMF risk perception, a meta-analysis, content analyses of the messages of the various mobile telecommunications stakeholders, focus groups and an interview-based survey. Analysis of the knowledge of information measures and the effects of such measures led to the following findings:

- Messages from industry, mobile telecommunications opponents, politicians and scientists are rated differently depending upon prior attitudes to mobile telecommunications.
- People who have not yet made up their mind tend to agree with the “all-clear” messages rather than the warning messages.
- Some of the knowledge gaps in the general population with regard to the issues surrounding mobile telecommunications and health are substantial.

Project R3 was concerned with identifying and characterizing “electro-sensitive” persons. That project is has already been discussed in the section of this review dealing with “Electro-magnetic hypersensitivity”.

6 Concluding asessment

In its present review the SSK provides a scientific evaluation of the research projects that have been completed until the deadline, on the basis of the 36 available final reports. The assessment considers the suitability of the selected research themes, the scientific quality of the work performed, the resulting advancements in knowledge relating to health risk assessment of exposures to mobile telecommunication electromagnetic fields, and the issues that have remained unresolved or have emerged in the meantime from the development of the international knowledgee.

Overall, in agreement with reviewers the performed projects predominantly exhibit high scientific quality.

6.1 Original terms of reference

In its opinion paper published in 2001, the SSK identified a need for research on high-frequency electromagnetic fields in the following areas:

- In-vitro and in-vivo experiments on potential cancer-initiating and/or cancer-promoting effects,
- Studies of improved design and analysis techniques on the existence of relevant non-thermal interactions,
- Influences on the blood-brain barrier and on cell membranes, including potential permeability changes for calcium ions,
- Neurophysiological and cognitive processes,
- Potential effects of chronic exposure upon blood parameters, the immune system, reproduction and development,
- Improved dosimetry to clarify temperature side-effects in laboratory studies,
- Multinational epidemiological studies to examine potential increases in brain tumour risks as a result of mobile phone use.

The DMF took up these recommendations. In view of the thematic diversity, a necessary and reasonable process of concretization was performed and the range of themes broadened to include studies on “electromagnetic hypersensitivity” and risk perception and communication. At that time the selection of themes was rational and justified to meet the defined objectives . In retrospect it can also be considered appropriate, despite the fact that in detail some critical remarks could be added. The projects address relevant issues and make valuable contributions to the advancement of knowledge.

6.2 Advancements in knowledge

When the DMF was launched, research findings on some issues were in some respects contradictory. In awarding research projects the DMF therefore wanted to see research projects carried out whose study design reflected state of the art scientific research. In its recommendations on basic restrictions and precautionary measures in 2001 (SSK 2001), the SSK had already established that for established scientific evidence reproduction by independent groups and proofed causality need to be demanded. Therefore, in terms of radiation protection it was could not be expected that single research projects alone – even of outstanding quality – would be able to conclusively resolve a complex biological issue. It is therefore understandable that, despite the DMF activities, there remains further need for research in some fields. The projects conducted have, however, contributed substantially to reducing the uncertainties that prevailed when the DMF was launched. The indications and suspicions of potential risks that existed then can now be better assessed.

6.2.1 Biology

6.2.1.1 Electro-sensitivity

Overall, the studies performed have not been able to support the hypothesis that "electro-magnetic hypersensitivity" exists, in the sense of a substantially increased sensitivity of individuals to electromagnetic fields or an increased ability to perceive them. Nor has any proof been found that everyday electromagnetic fields are causally linked to non-specific health problems.

It must, however, be noted that in the three studies performed the object of study – namely "electro-sensitivity" – was not defined with sufficient agreement and clarity. The self-provided by survey respondents range from the subjective assumption that they have this otherwise unspecified ability without developing health symptoms, through to cases suffering from symptoms that severely impair their lives. Moreover, the recruitment strategies used are either insufficiently described or do not permit concluding that the sample is representative of the group of persons affected. These inherent difficulties limit comparability and possibility to extrapolate findings.

Project B13[38], which is still in progress, is designed to deliver additional findings on possible links to psychosomatic factors. Overall, the studies performed under the DMF have not confirmed the assumption of a causal link between electromagnetic fields and health symptoms. Despite disparate target group definitions and methods of recruitment, the overall conclusion, supported by the international literature, is that it is highly likely that "electro-sensitivity" does not exist. Further research should therefore take place outside EMF research.

6.2.1.2 Laboratory studies

The detailed studies of sense organs or their essential elements have not confirmed any significant influences with regard to either the visual or the auditory system. Nor could any causal link be found between mobile telecommunications use and the occurrence of tinnitus.

Studies on lifelong exposure have found no indications of impacts upon foetal or infant development. Better assessment of potential special sensitivities in children still requires further research and the closing of knowledge gaps that were identified. This calls for improved anatomic models of children of various age groups and age-specific tissue parameters. It remains to be awaited what supplementary contribution will be delivered by project B17[39], which is still ongoing.

---

38 *Research project B13: Dahmen, N.: Investigation of electrosensitive persons with regard to accompanying factors or diseases, such as allergies and increased exposure or sensitivity to heavy metals and chemicals (not yet completed)*

39 *Research project B17: Kuster, N. et al.: Investigation of age-dependent effects of high frequency electromagnetic fields based on relevant biophysical and biological parameters (main study) (not yet completed)*

The results obtained in the DMF provide no indication of cellular effects of EMF that could cause or contribute to carcinogenesis. The supposed increased occurrence of reactive oxygen species (ROS) has not been confirmed in immune system cells. Additional findings in the field of genotoxic effects are expected when ongoing projects have concluded. One aspect that still merits clarification is whether reported differences in the effects of pulsed GSM exposure and non-pulsed CW exposure were chance findings or whether they are attributable to pulsation-specific thermal effects.

The studies on individual neurons or artificial neuronal networks using a novel study design have not met expectations. Due to technical difficulties, they have yielded no usable results with regard to potential nonthermal interaction mechanisms. The localized elevation of the specific absorption rate by a factor of 10 found on cell membranes by means of high-resolution models has highlighted aspects of micro-dosimetry that merit further study. (The Non-Ionizing Radiation Committee of the SSK set up a Micro-Dosimetry Working Group already in 2007.)

The broad-scale, multi-generation studies on laboratory rodents chronically exposed to mobile telecommunications fields have not revealed any statistically significant effects with regard to either potential carcinogenicity and aspects of reproduction and development. Project B9[40], on long-term exposure, is designed to deliver further findings.

It can be noted in general that the projects initiated and supported under the DMF in the thematic area of biology have delivered important advancements in knowledge that substantially broaden the scientific basis for assessing potential risks arising from mobile telecommunications technology. The findings to date have not supported fears of adverse effects of mobile telecommunications fields on health, even due to chronic exposure.

An overall assessment of the DMF, however, will only be possible when the ongoing projects have been concluded.

6.2.2 Epidemiology

The feasibility studies of epidemiological cohort studies delivered valuable indications of limitations of epidemiological studies and the reasons for them, and have contributed substantially to decision-making on the further approach to be taken.

The German contribution to the INTERPHONE study found no elevated risk for any of the brain tumour types studied for less than 10 years of mobile phone use; however, in view of insufficient data an elevated risk of longer use cannot be excluded. No increased cancer risk attributable to the use of DECT base units could be found. No link was observed between mobile phone use and the occurrence of uveal melanomas.

---

40 *Research project B9: Forschungsverbund EMVU der TU/LMU München: In-vivo experiments on exposure to the high frequency fields of mobile telecommunication A. Long-term study (not yet completed)*

An extensive interview-based survey of attitudes to mobile telecommunications and its potential health risks found that fears correlate with proximity to a base station – a parameter that measurements have shown to correlate insufficiently with the true exposure situation. Measured field strengths, in contrast, did not correlate with any of the health problems surveyed. All in all, the epidemiological studies conducted under the DMF have not justified fears of risks associated with chronic exposure – however, because of the limited duration of mobile phone use, the predictive validity of these findings is limited.

6.2.3 Dosimetry

Suitable measurement techniques for recording maximum and average exposure levels have been developed and validated under the DMF. They have confirmed that distance from a transmitter is not a suitable predictor of the actual exposure situation. Even improved models that take account of the orientation of the main beam and of direct line-of-sight have proven to be useful at best for a dichotomous classification of exposed and non-exposed groups. This has underscored the importance of recording exposures by means of personal dosimeters.

In addition, the dosimetric studies designed to determine the exposure of experimental animals have helped develop principles for the design of experimental exposure setups and for the comparability of (intra-species) animal experiments on the basis of organ-specific exposures.

To record the exposure of the general public in the surroundings of stationary transmission facilities (GSM, UMTS, radio, television, WLAN access points, DECT base units), suitable measurement techniques have been developed and computation procedures evaluated. This is exceedingly important, especially with regard to the essential comparability of measurements. Power densities were found to reach at most percentage points of the basic restrictions; often the levels found were in the range of 0.1% or less of the restrictions.

The dosimetric studies have shown that, if used close to the body, some mobile phones and baby monitors can exceed reference levels. The output power minimization of mobile phone handsets (DTX operation) was found to depend upon network structure and operator. It was found that it can be substantially restricted by the operator. Studies in partially shielded rooms have shown that the level of ambient exposure attributable to mobile phone use can be elevated by a factor of 10 compared to the outdoor situation, but overall, that the additional exposure remains at a very low level. This has refuted studies which, based on simplified theoretical considerations, had reported an excess of basic restrictions in partially shielded rooms. Only if the handset is held close to reflecting metal structures can the person making a call be subject to SAR values that are up to around 50% higher than in the outdoor situation.

It must be noted that the quality of the projects varied. For instance, SAR calculations for everyday exposure situations were only validated in qualitative terms and only for one single mobile telecommunications device, and measurements failed to explore the dependence upon the type of phone. The quality of the calculation of ambient exposure levels in partially

shielded rooms is considered excellent, but the measurements were not conducted in a sufficiently systematic manner and are not described in a reproducible fashion.

The project designed to determine the exposure situation before and after the change from analogue television to DVB-T has shown that the change to digital transmission technology does not necessarily, as had been originally expected, lead to reduced exposure, but can in fact also be associated with increased exposure levels.

All in all, the dosimetric studies have yielded important principles for the improvement of animal experiments and for the recording of exposure levels in everyday life situations, as well as for epidemiological studies. They have shown that it is expedient to monitor the development of exposure levels attributable to new technologies by means of ambient measurements. It has furthermore become apparent that simultaneous exposure to several sources must be taken into account. This has confirmed the recommendation issued by the SSK that single sources should not make use of the entire exposure budget (SSK 2007).

6.2.4 Risk communication

The studies on risk perception have shown that the frequency of anxiety and fears with regard to mobile telecommunications is not linked to the extent of network expansion activities. It is clear, too, that it is only loosely linked to the extent and content of media reporting on mobile telecommunications. The base stations and not the mobile phone handsets are the factor dominating risk perceptions of mobile telecommunications. Mobile telecommunications have not, however, been found to be a first-order concern for the general public.

Compared to the contribution made by the DMF to enlarging knowledge about risk perception, its contribution to knowledge about effective forms of risk communication is small. This applies to information on the findings of research on the effects of EMF and to information about precaution and uncertainty. It also applies in part to conflict management. There is very little robust knowledge in this field. Risk communication tools such as the EMF portal, the Internet-based decision support system or the mobile telecommunications research programme itself are key elements of risk communication. Even if these elements of a risk communication strategy are plausible the specific value of these tools, as large as their utility is expected to be, is in the absence of stringent evaluation not as yet verified.

6.3 Unresolved issues and further research needs

In key issue areas, the biological studies performed under the DMF have made important contributions to clarifying unresolved questions. Non-thermal effects have not been verified. However, studies on non-thermal interaction models remain a current issue, especially with regard to potential genotoxic effects.

While a great volume of data is already available for the health assessment of acute exposures from a biological perspective, a need for research remains to assess long-term or lifelong exposures, particularly with regard to potential long-term effects. This also calls for further work on potential genotoxic effects and the possibility to extrapolate findings from animal experiments to the human subject. There also continues to be a lack of biological findings for the determination of a suitable exposure measure for time-varying and spatially inhomogeneous exposures as well as tolerable temperature changes and rates of change. Unresolved issues also remain with regard to the exposure of foetuses and children, and with respect to potential effects upon cognition, feelings of ill-health and sleep.

Because of the still relatively short periods over which mobile phones have been used, epidemiological studies of potential long-term effects have limited explanatory power. They can continue to be useful for health assessments, whereby an evidence-based selection of biological endpoints would make the findings more convincing. Particular problems arise when studying long periods, however, due to the rapid development and dissemination of new technologies, which lead to frequent changes in the exposure scenario and make dosimetric classification and interpretation of the results substantially more difficult. Non-specific health symptoms attributed by those affected to mobile telecommunications are difficult to clarify. Epidemiology can support such efforts, but it will also be necessary to use hypothesis-based and experimental study designs and strategies.

The question of whether further studies of the brain tumour risk should be performed should only be decided after publication and evaluation of the entire INTERPHONE study. Studies involving children, e.g. in multinational prospective cohort studies, could make an important contribution to health assessment. Such studies, however, require an improved recording of exposures and clarification of how to take account, over a longer period, of changing exposure scenarios, sources and fields when determining the exposure groups and the risk estimator.

The DMF has shown that it makes sense to assess exposures generated by new technologies such as TETRA, LTE, 4G, DVB-H, femtocells or RF-ID during technology deployment. This allows timely introducing information on technologies and exposures into health risk assessment. It remains unclear which exposure quantity (e.g. spatial and/or temporal average or maximum value) should be determined as well as how recording and assessment of exposure in inhomogeneous and near-source fields should be performed. For the purposes of exposure assessment by numerical simulation, there is a need to develop anatomical models for pregnant women in different stages of pregnancy and for children (and their heads) of different ages as well as high-resolution models for higher frequencies.

In view of higher frequencies, higher-resolution models and younger exposed persons, there is a need to challenge the size and form of the local body volume over which the specific absorption rate is determined (averaged). A key challenge is to more realistically calculate the temperature rise as a biological more relevant parameter for health risk assessment. In order to provide more reliable exposure estimate for epidemiological studies, personal dosimeters

need to be further developed and validated, taking account of different kinds of sources and positioning.

In future, risk communication research should be based not only on interviews and qualitative-exploratory research, but should be more hypothesis-driven and also make more use of experimental approaches. Apart from risk perception risk communication should receive more attention, Gaps in knowledge should be filled that can be characterized by the following questions:

- Which factors can lead to escalating risk perception?
- What are the effects of communication on uncertainty and precaution?
- Which public participation strategies are successful under which conditions?
- How does one communicate in the context of contradictory information and opinions?

7 Conclusion and outlook

All in all, the German Mobile Telecommunication Research Programme has made an important contribution to improving the scientific basis for health risk assessment of exposures to mobile telecommunication electromagnetic fields, and hence to risk communication.

Although a final evaluation of the DMF is only possible when the studies still in progress have been completed, the findings available to date show that the initial fears of health risks could not be confirmed. Nor have the research findings of the DMF led to any new indications of health impacts that have not previously been considered. In agreement with other international bodies (WHO, ICNIRP) it can be stated that the protection concepts underlying the present basic restrictions are not challenged.

In regard to radiation protection, however, it must be noted that in the field of biological interactions no single research project, even of best quality, can conclusively resolve a scientific issue. It is hence understandable that, despite the fact that the initial indications of potential health effects of mobile telecommunications have not been confirmed, a need for further research remains. Moreover, the ongoing dynamic development of new wireless technologies and the use of new frequencies and forms of transmission also make it rational to perform accompanying research, monitor ambient levels and evaluate EMF exposures.

It will be a task of the SSK to elaborate a comprehensive assessment based on the results of all DMF projects, also taking account of the meanwhile published scientific literature and results of other national research programmes.

8 References

Christ, A., Kuster, N. (2005): Differences in RF Energy Absorption in the Heads of Adults and Children. Bioelectromagnetics Supplement 7: S31-S44

Conil, E., Hadjem, A., Lacroux, F., Wong, M. F., Wiart, J. (2008): Variability analysis of SAR from 20 MHz to 2.4 GHz for different adult and child models using finite-difference time-domain. Phys. Med. Biol. 53**,** 1511–1525

Lerchl, A., Krüger, H., Niehaus, J., Streckert, J.R., Bitz, A.K., Hansen, V. (2007): Effects of mobile phone electromagnetic fields at nonthermal SAR values on melatonin and body weight of Djungarian hamsters (Phodopus sungorus). J. Pineal Res. 44:267-272

Mobile Operators Association (MOA) (2001): Risk Communication Handbook - Working with the Community. http://www.mobilemastinfo.com/planning/Risk_Communication_Handbookv2.pdf

Repacholi, M.H., Basten, A., Gebski, V., Noonan, D., Finnie, J., Harris, A.W. (1997): Lymphomas in Eμ-Pim1 Transgenic Mice Exposed to Pulsed 900 MHz Electromagnetic Fields. Radiat. Res. 147: 631-640

SSK (2001): Limits and Precaution Measures to Protect the General Population from Electromagnetic Fields. Statement of the Commission on Radiological Protection (Grenzwerte und Vorsorgemaßnahmen zum Schutz der Bevölkerung vor elektromagnetischen Feldern. Stellungnahme der Strahlenschutzkommission). Published in BAnz Nr. 224 of 30 October 2001

SSK (2006a): Mobile Telecommunucation and Children. Statement of the Commission on Radiological Protection (Mobilfunk und Kinder. Stellungnahme der SSK). Publications of the SSK, Volume 61, pp. 253-303. H. Hoffmann GmbH, Berlin (2007)

SSK (2006b): Effects of Radio Frequency Fields on the Genome: Genotoxicity and Gene Regulation. Statement of the Commission on Radiological Protection (Wirkung hochfrequenter Felder auf das Genom: Genotoxizität und Genregulation. Stellungnahme der SSK). Published in BAnz Nr. 135a of 24 July 2007

SSK (2007): Principles for Deriving Emission Standards at Simultaneously Operated Field Sources. Statement of the Commission on Radiological Protection (Grundsätze bei der Ableitung von Emissionsstandards bei gleichzeitig betriebenen Feldquellen. Stellungnahme der SSK) Published in BAnz Nr. 127 of 12 July 2007

Table of acronyms and abbreviations

4G	Fourth Generation
ADM	Arbeitsgemeinschaft Deutscher Marktforschungsinstitute (working association of German market research institutes)
AKR/J mice	Genetically modified strain of mice with high spontaneous leukaemia incidence. This is a recognized animal model for human leukaemias, and is widely used in cancer research.
BfS	German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz)
BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)
COSMOS study	Cohort study on mobile phone use and health
CW	Continuous Wave (sine wave)
DECT	Digital Enhanced Cordless Telecommunication
DFG	German Research Foundation (Deutsche Forschungsgemeinschaft)
DMF	German Mobile Telecommunication Research Programme (Deutsches Mobilfunk-Forschungsprogramm)
DTX	Discontinuous transmission, a mobile phone transmission mode in GSM networks, in which data transmission is interrupted during pauses in speaking.
DVB-H	Digital Video Broadcasting for Handheld Terminals
DVB-T	Terrestrial Digital Video Broadcasting
EEG	Electroencephalogram
EMF	Electromagnetic field
GSM	Global System for Mobile Communications
RF	Radio-frequency
Hz	Hertz (unit of frequency)
ICNIRP	International Commission on Non-Ionizing Radiation Protection
INTERPHONE study	International case-control studies of the brain tumour risk associated

	with mobile phone use
LTE	Long-Term Evolution
MOA	Mobile Operators Association
RFID	Radio Frequency Identification
RIFA study	Case-control study of the risk of melanomas of the choroid
ROS	Reactive Oxygen Species
SAR	Specific Absorption Rate
SSK	German Commission on Radiological Protection (Deutsche Strahlenschutzkommission)
TETRA	Terrestrial Trunked Radio
TMS	Transcranial Magnetic Stimulation
UMTS	Universal Mobile Telecommunication System
W	Watt (unit of electric power)
WBLDB	knowledge-based literature databank (Wissensbasierte Literaturdatenbank)
WHO	World Health Organization
WLAN	Wireless Local Area Network

List of DMF research projects (as at 7 May 2008)

	B I O L O G Y
	Completed projects
B1	Investigation of mechanisms of action in cells exposed to the high-frequency electromagnetic fields of mobile telephone technology. B. Pineal gland
B2	Feasibility study on age-dependent effects of RF electromagnetic fields on the basis of relevant biophysical and biological parameters
B3	Influence of low- and high-frequency electromagnetic fields on spontaneous leukaemia in AKR/J mice
B4	In-vivo experiments on exposure to the high frequency fields of mobile telecommunication. B. Carcinogenesis
B5	Investigation of sleep quality of electrohypersensitive persons living near base stations under residential conditions
B6	Investigation of mechanisms of action in cells exposed to the high-frequency electromagnetic fields of mobile telephone technology A. Demodulation / communication
B7	Investigation of mechanisms of action in cells exposed to the high-frequency electromagnetic fields of mobile telephone technology. C. Functions
B11	Possible influence of high frequency electromagnetic fields of mobile communication systems on the induction and course of phantom auditory experience (tinnitus)
B12	Influence of high-frequency electromagnetic fields of mobile telecommunications on sensory organs B. The visual system
B14	Investigation of the phenomenon of “electromagnetic hypersensitivity” using an epidemiological study on “electrosensitive” patients including the determination of clinical parameters
B18	Influence of high-frequency electromagnetic fields of mobile telecommunications on sensory organs. A. The auditory system
B19	Studies of the effects of exposure to electromagnetic fields emitted from mobile phones on volunteers
B22	Long-term study on the effects of UMTS signals on laboratory rodents

	B I O L O G Y
	Projects awarded
B8	Influence of high frequency electromagnetic fields of mobile telecommunications on the metabolic rate in laboratory rodents
B9	In-vivo experiments on exposure to the high-frequency fields of mobile telecommunication A. Long-term study
B10	In-vivo experiments on exposure to the high-frequency fields of mobile telecommunication C. Blood-brain barrier
B13	Investigation of electrosensitive persons with regard to accompanying factors or diseases, such as allergies and increased exposure or sensitivity to heavy metals and chemicals
B15	Influence of mobile telecommunication fields on the permeability of the blood-brain barrier in laboratory rodents (in-vivo)
B16	Possible genotoxic effects of GSM signals on isolated human blood
B17	Investigation of age-dependent effects of high frequency electromagnetic fields based on relevant biophysical and biological parameters (main study)
B20	Investigation of sleep quality in persons living near a mobile base station Experimental study on the evaluation of possible psychological and physiological effects under residential conditions
B21	Influence of GSM signals on isolated human blood B. Differential gene expression

	D O S I M E T R Y
	Completed projects
D1	Analysis of the SAR-distribution in test animals exposed to electromagnetic radiation
D2	Determination of the field distribution of radio frequency electromagnetic fields of wireless LAN applications in urban environments
D3	Determination of the real RF field distribution in the surrounding of UMTS base stations
D4	Determination of exposure distribution from high frequency fields in the human body with regard to small structures and relevant thermo-physiological parameters
D5	Exposure from transmitters worn near the trunk of the body
D6	Development of measurement and calculation methods for the determination of the public exposure due to electromagnetic fields in the vicinity of mobile phone base stations
D7	Determination of the exposure of groups of people that will be investigated within the scope of the project “Cross-sectional study for ascertainment and assessment of possible adverse effects by the fields of mobile phone base stations”
D8	Determination of human exposure caused by indoor wireless communication technologies applied in homes and offices
D9	Determination of the specific absorption rate (SAR values) occurring during day-to-day mobile phone use
D10	Determination of the public exposure due to electromagnetic fields of digital broadcast transmitters
D11	Determination of the real exposure from using mobile phones in partly shielded rooms compared to the exposure occurring under advantageous conditions in free space

	D O S I M E T R Y
	Projects awarded
D12	Development of a practicable computational procedure for the determination of the actual exposure in complex exposure scenarios with several different RF-sources
D13	Studies on the issue, if macroscopic dielectric properties of tissues have unlimited validity in both cellular and subcellular dimensions
D14	Study on the influence of antenna topologies and topologies of entire devices of wireless communication terminals operated near the body on the resulting SAR values

Additional project
Determination of exposure by ultra wideband technologies

	E P I D E M I O L O G Y
	Completed projects
E1	Feasibility study for a cohort study: the cohort study should investigate highly exposed (occupational) groups to estimate the risk associated with high frequency electromagnetic fields
E2	Addendum to a case control study on uveal melanoma and radio frequency radiation (RIFA Study)
E3	Feasibility study for a prospective cohort study on mobile phone users
E4	Extension of an international epidemiological study on the association between high-frequency electromagnetic fields and the risk of brain cancer (INTERPHONE)
E8	Addendum to the cross-sectional study on adverse health effects by fields of mobile phone base stations

	E P I D E M I O L O G Y
	Projects awarded
E5	Epidemiological study on childhood cancer and proximity to radio and television transmitters
E6	Addendum to the cross-sectional study on adverse health effects by fields of mobile phone base stations
E7	Estimation of RF-exposure in INTERPHONE Study subjects
E9	Acute health effects by mobile telecommunication among children

Additional project
Validation of the exposure surrogate of the cross-sectional study of base stations

	R I S K C O M M U N I C A T I O N
	Completed projects
R1	Knowledge-based database of literature describing the effects of electromagnetic fields on the organism and implants
R2	Analysis of target groups for differentiated information
R3	Supplementary information about electromagnetic hypersensitive persons
R4	Examination of the knowledge and effects of information activities in the field of mobile telecommunications and determination of further approaches to improve information of different population groups
R5	Identifying the general public's fears and anxieties with regard to the possible risks of high frequency electromagnetic fields of mobile telecommunications (annual survey)
R6	Innovative methods of conflict mediation when determining the location for mobile phone base stations
R7	Support of the co-operation between the mobile telecommunication actors by the Local Agenda 21

Annex on restrictions

published in: Recommendation by the German Commission on Radiological Protection (Strahlenschutzkommission, SSK) titled "Limits and Precautionary Measures to Protect the General Population from Electromagnetic Fields"[41]

Excerpts from the SSK recommendation "Protection of the General Population from Electromagnetic Fields "[42] *and ICNIRP's guidelines on exposure limits*[43]

In establishing exposure limits for electromagnetic fields (EMF), a distinction needs to be made between basic restrictions and derived restrictions (also termed reference levels).

– *Basic restrictions*

  Restrictions on exposure to EMF that are based on established threshold levels of physical parameters effective directly in tissue and taking account of safety factors are termed "basic restrictions". Depending upon the frequency of the field, the effective physical quantities are electric field strength or the associated current density, and the specific energy absorption rate (SAR) in tissue. However, only the field strengths or power density in air, outside the body, can be measured readily at exposed individuals.

– *Derived restrictions*

  "Derived restrictions" have been introduced to assess exposures because the procedures needed to check compliance with basic restrictions are too complex. To define derived restrictions, parameters were chosen that can be determined in an individual's surroundings and can be measured directly. Some derived restrictions are derived from relevant basic restrictions using measurement and/or computational techniques, whereby often a "worst case" exposure situation is assumed, which leads to a conservative assessment. Other derived restrictions are related to perception and adverse indirect effects of exposure to EMF.

  The derived quantities are: electric field strength, magnetic flux density and power density outside of the body, and currents flowing through the limbs.

Compliance with derived restrictions will ensure compliance with the relevant basic restriction. If the measured or calculated value exceeds the derived restriction, it does not necessarily follow that the basic restriction will be exceeded. However, whenever a derived

---

[41] *SSK (2001): Grenzwerte und Vorsorgemaßnahmen zum Schutz der Bevölkerung vor elektromagnetischen Feldern", in: Berichte der Strahlenschutzkommission, volume 29 (2001)*

[42] *SSK (1999): Protection of the General Population from Electromagnetic Fields "*[42] *(Schutz der Bevölkerung bei Exposition durch elektromagnetische Felder (bis 300 GHz)"*

[43] *ICNIRP (1998): "Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz)", Health Physics 74(4), 494-522*

restriction is exceeded it is necessary to test compliance with the relevant basic restriction and to determine whether additional protective measures are necessary.

In addition to comprehensive documentation of the basic restrictions and the derived restrictions for continuous sine fields, the ICNIRP's recommendation further sets limits for pulsed exposure to high-frequency EMF, derived restrictions for contact currents that can arise when conducting objects are touched under field influence, and guidance for risk assessment in the case of simultaneous exposure to fields of different frequencies.

The recommendations on restrictions do not directly address rules to limit the emissions of technical devices. Nor do they deal with any techniques or methods used to measure or compute any of the physical quantities that characterize electromagnetic fields; comprehensive descriptions of instrumentation and measurement techniques for accurately determining such physical quantities may be found in technical standards.

The present recommendations on restrictions do not address the electromagnetic compatibility of devices. Compliance with them may not necessarily preclude interference with, or effects on, medical devices such as metallic prostheses, cardiac pacemakers and defibrillators, and cochlear implants. Interference with pacemakers may occur at levels below the derived restrictions. Stipulations on these issues are beyond the scope of the recommendations.

The limits further do not apply to medical applications of electric, magnetic or electromagnetic fields.

Table 3 *Basic restrictions for general public exposure to time-varying electric and magnetic fields for frequencies up to 10 GHz and for frequencies between 10 and 300 GHz*

Frequency range 0–10 GHz[a)]	Current density for head and trunk (mA/m^2) (rms)	Whole-body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
up to 1 Hz	8	-	-	-
1 - 4 Hz	$8/f$	-	-	-
4 Hz - 1 kHz	2	-	-	-
1 - 100 kHz	$f/500$	-	-	-
100 kHz -10 MHz	$f/500$	0.08	2	4
10 MHz -10 GHz	-	0.08	2	4

For frequencies between 10 and 300 GHz[b)]	Power density (W/m^2)
	10

[a)] Notes:

1. f is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2\ t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed 10 mJ kg^{-1} for workers and 2mJ kg^{-1} for the general public, averaged over 10 g tissue.
8. The basic restrictions for current density are intended to prevent acute effects in the central nervous tissue in the head and trunk. In other types of tissue, higher current density values can arise in the same exposure situation.

[b)] Notes:

1. Power densities are to be averaged over any 20 cm^2 of exposed area and a $68/f^{1.05}$-min period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases.
2. Spatial maximum power densities, averaged over 1 cm^2, should not exceed 20 times the values above.

Table 4 *Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)*[a]

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1-8 Hz	10 000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8-25 Hz	10 000	$4000/f$	$5000/f$	—
0.025-0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8-3 kHz	$250/f$	5	6.25	—
3-150 kHz	87	5	6.25	—
0.15-1 MHz	87	$0.73/f$	$0.92/f$	—
1-10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10-400 MHz	28	0.073	0.092	2
400-2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2-300 GHz	61	0.16	0.20	10

[a] *Notes:*

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 3, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies < 1 Hz, which are effectively static electric fields. Most individuals will not perceive disturbing surface electric charges at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.