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Biological Effects of Mobile Phone Use
– An Overview –

Statement by the German Commission on Radiological Protection

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Introduction

The German Mobile Telecommunication Research Programme (DMF) was carried out from 2002 to 2008 in response to public concern about possible health effects of high-frequency electromagnetic fields below existing limit values and in the context of increasing mobile phone usage. The programme comprised a total of 54 research projects in biology, epidemiology, dosimetry and risk communication. Its total budget was approximately 17 million euros, provided in equal parts by the mobile phone network operators and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU). The German Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) administered the funds, gave technical support, selected research topics and managed the research programme. In the early phases of the programme the SSK identified unresolved scientific issues, recommended research themes and took an active part in preparatory discussions.

At the Final Conference of the German Mobile Telecommunication Research Programme, held in June 2008, the SSK presented an evaluation of the 36 final reports that were available by April 2008 from the 54 DMF research projects (SSK 2008). Subsequently the BMU asked the SSK to evaluate the 18 research projects in biology, epidemiology and dosimetry that had not yet been completed. The present statement, which is based on this evaluation and builds on the findings reported in the SSK statement of 2008, summarizes and reviews the current state of knowledge on the biological effects of mobile phone use. It includes findings from other national and international research programmes and from publications that have appeared since then.

The evaluation of the 18 research projects that have now been completed is based on the final reports. It assesses them in terms of the research topics selected, the scientific quality of the work performed and the knowledge gained relating to health risks of mobile phone use. In addition, it looks at scientific issues that remain unresolved or that may have emerged in the meantime owing to developments in international research.

1 DMF projects completed since 2008

This section summarizes the 18 research projects that were still incomplete when the SSK prepared its report in June 2008 (SSK 2008). The final reports were analysed and evaluated by at least two independent experts from the SSK and its committees. External experts were also consulted. The projects were reviewed only by persons who were not directly or indirectly involved in them.

The following statement is based on the SSK's assessment of the final reports and draws on appraisals submitted by independent experts.

1.1 Thematic area: Biology

1.1.1 Introduction

Nine projects concerned with topics in biology were completed in 2008 and later. They can be grouped under the following headings:

- Electrosensitivity (B13)
- Sleep quality (B20)
- Blood-brain barrier (B9, B10, B15)
- Cognitive abilities (B9)
- Long-term exposure of laboratory animals: metabolism, reproductive behaviour, immune response and stress response (B8, B9)
- Gene expression and genotoxicity (B15, B16, B21)
- Age-dependent effects of high-frequency electromagnetic fields (B17)

1.1.2 Electrosensitivity

Project B13, which covered a wide range of issues, investigated the occurrence of accompanying factors and diseases among individuals who described themselves as "electrosensitive". The factors included allergies and increased sensitivity to heavy metals and chemicals.[1] The investigators worked with self-help groups to recruit subjects. Psychological as well as physiological-clinical parameters were assessed. The investigation was carried out as a case-control study (130 "electrosensitive" persons, 101 controls).

The investigation did not confirm the hypothesis of a difference between self-described electrosensitive individuals and control subjects in terms of immunological parameters, molecular genetic parameters of liver function or internal levels of heavy metals. The objective parameters measured showed no differences in health between the two groups in the study. Subjectively experienced health symptoms were reported more frequently in the medical histories of the "cases" than in those of the controls.

The study had some weaknesses that must be noted. The control group was relatively small, and the criteria for inclusion and exclusion were inadequately defined for both electrosensitive subjects and controls (changes in assignment to groups). Moreover, the methods applied had only limited suitability for confirming or ruling out the existence of the symptoms under study.

1 Research project 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

1.1.3 Sleep quality

Disruption of sleep is one of the most frequent complaints attributed to electromagnetic fields from mobile communications, although objective evidence has not yet been found. Laboratory studies are often difficult to interpret owing to the negative impact on sleep behaviour caused by an unfamiliar environment. Project B20[2] was a double-blind study of possible effects of mobile phone fields in a familiar domestic environment. Ten locations were selected in rural areas of Germany where mobile communication did not yet exist and background exposure to high-frequency fields was low. Mobile transmitters provided by mobile phone operators were used for exposure. Sleep quality was compared between five nights with exposure and five nights without exposure. Neither the subjects nor the researchers knew whether or not there was any exposure. A total of 376 subjects, age 18 to 81, took part; sleep quality was determined using established subjective and objective methods. An overview of all the recorded parameters showed that the study revealed no objectifiable effects on sleep quality. However, sleep quality was affected even when the transmitters were not in operation. The authors attribute this to concern about health effects.

1.1.4 Blood-brain barrier

Based on animal experiments, a number of publications have put forward the hypothesis that mobile phone fields affect the permeability of the blood-brain barrier. If this were true, it could have significant health consequences. For this reason the German Mobile Telecommunication Research Programme devoted considerable attention to this question. It supported three projects, using differing experimental approaches. Project B9, which involved extensive studies of long-term effects in laboratory rodents[3], investigated transport processes in the blood-brain barrier using radioactively tagged molecules. It also examined counts of CA1 neurons, which make up an especially critical brain structure. Besides being extremely sensitive to toxic substances, CA1 neurons react to stress, making them suitable as indicators of possible field effects. Three generations of rats were continuously exposed over a period of several months to GSM and UMTS fields (SAR 0.4 W/kg). In no case significant changes in the integrity of the blood-brain barrier were detected. Nor did the CA1 neuron counts differ from those in the control group.

In several previous studies the presence of “dark” (damaged) neurons in the brain was interpreted as a sign of damage to the blood-brain barrier. Project D15[4] was devoted to this question. A total of 1,120 rats were exposed to both GSM and UMTS fields. Although “dark” neurons were found in some cases, their occurrence followed a random pattern and no correlation could be found with the strength or duration of exposure. The authors therefore

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[2] Research project 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

[3] Research project B9: In vivo experiments on exposure to high frequency fields of mobile telecommunication. A. Long-term study. Sub-project: Permeability of the blood-brain barrier and CA1 neuron counts.

[4] Research project B15: Influence of mobile telecommunication fields on the permeability of the blood-brain barrier in laboratory rodents (in vivo)

concluded from their experiments that no influence on the blood-brain barrier could be demonstrated.

The above two *in vivo* studies were augmented by an *in vitro* study, B10[5]. Cultures of brain epithelial cells were exposed to either GSM 1800 or UMTS fields, with SARs between 0.4 W/kg and 8 W/kg. Microarrays were used to measure gene expression. In a few cases, where there were differences to the sham-exposed controls, quantitative real-time polymerase chain reaction (RT-PCR) was used for verification. As expected for statistical reasons in studies of large numbers of genes, changes in gene regulation were found in some cases. However, no systematic correlation with the duration or strength of exposure was found. The results thus contain no evidence of pathophysiological changes.

1.1.5 Cognitive functions

Project B9, which used long-term experiments with rats and standardized tests of cognitive function, studied whether mobile phone fields can cause cognitive impairment.[6] Learning and memory were tested using standardized methods for test animals (Skinner boxes) after long-term exposure at an SAR of 0.4 W/kg. In no cases were differences found between exposed and sham-exposed groups. Although these results are not necessarily transferable to humans, they at least fail to support the hypothesis that mobile phone fields can affect cognitive functions.

1.1.6 Long-term exposure of laboratory animals: metabolism, reproductive behaviour, immune response and stress response

A previous long-term study of laboratory rodents, B3[7], indicated possible effects of mobile phone fields on overall metabolism. Project B8[8] examined this hypothesis in a systematic manner and found no confirmation, at least for the SAR values tested in the previous project. Significant, but weak effects on skin temperature and metabolism were found only at an SAR of 4 W/kg, but this was expected as it was near the threshold of thermoregulatory response.

Other multi-generation studies were also performed.[9] As changes in reproductive behaviour can be confounders in studies of this type, progeny numbers, miscarriages and stillbirths were recorded over the entire period of the study. No relevant differences were found.

There was also a study of the immune system.[10] It used two groups of rats, age 20 weeks and 52 weeks. Reactions to various antigens were tested and antibody titres were measured at

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[5] Research project B10: In vitro experiments on exposure to the high frequency fields of mobile telecommunication. C. Blood-brain barrier

[6] Research project B9: In vivo experiments on exposure to the high frequency fields of mobile telecommunication. A. Long-term study. Sub-project: Studies of learning and memory in rats as measured by operant behaviour

[7] Research project B3: Influence of low and high frequency electromagnetic fields on spontaneous leukaemia in AKR/J mice

[8] Research project B8: Influence of electromagnetic fields of mobile telecommunications on the metabolic rate in rodents

[9] Research project B9: In vivo experiments on exposure to the high frequency fields of mobile telecommunication. A. Long-term study

different times during long-term exposure (GSM 900 MHz, UMTS 1966 MHz, SAR 0.4 W/kg). A statistically significant difference between exposed and non-exposed groups was found in only one of the twelve experiments. The authors interpreted this exception as a chance finding, especially as it did not occur in two other similar groups (“Given that only one significant result was found, we must conclude it to be incidental.”).

In the same main project[10] the question was explored whether prolonged exposure to mobile phone radiation can give rise to stress reactions. For this purpose the animals were injected with an additional stress-promoting substance (ACTH, adrenocorticotropic hormone). The researchers then measured the concentration of cortisol, a glucocorticosteroid hormone produced by the adrenal gland in response to ACTH and an indicator of stress. Only one of the six test groups showed a significant response to field exposure. The authors interpreted this result as incidental.

In the judgement of the authors, long-term exposure over many generations at an SAR of 0.4 W/kg does not give rise to pathological effects in rats. Although the findings cannot be transferred directly to humans, they lend no support to the hypothesis that such effects could occur in humans.

1.1.7 Genotoxicity and gene regulation

The question whether high-frequency electromagnetic fields can have genotoxic effects remains controversial. Although negative findings predominate in the literature, no final consensus has been reached. The DMF contributed to this research by carrying out an interlaboratory comparison.[11] The following parameters were studied in human lymphocytes stimulated by phytohaemagglutinin (PHA): structural chromosome aberrations, micronuclei, sister chromatid exchange (SCE) and DNA damage (strand breaks and alkali-labile damage) detectable by means of the alkaline comet assay. Blood samples were taken from 10 young subjects (age 16-20) and 10 older subjects (age 50-65), all of them healthy. The samples were exposed to intermittent (5 min. on, 10 min. off) GSM 1800 MHz radiation for 28 hours at SARs of 0, 0.2, 2 and 10 W/kg. The radiation was controlled by a random number generator, ensuring that the study was fully blind. The specimens from all groups were exposed and prepared in one laboratory and then distributed to three other laboratories for evaluation. Positive controls (gamma rays in doses up to 6 Gy) were created for all test parameters as a means of verifying the procedures. Mitomycin C (0-0.1 µg/ml) was used to induce SCEs, which are caused only in small numbers by ionizing radiation. The test protocol was designed to identify incidental results caused by differing evaluations. With such an approach prevention of errors in the exposure and preparation of samples is of critical importance, as any such error would lead to incorrect results in all participating laboratories. In this project, which was organized as an interlaboratory comparison, there were no independent replications.

[10] Research project B9: In vivo experiments on exposure to the high frequency fields of mobile telecommunication. A. Long-term study. Sub-project: Studies of potential effects on the immune system and stress

[11] Research project B16: Possible genotoxic effects of GSM signals on isolated human blood

Significant differences among the laboratory findings appeared already in the comparison of positive controls. These differences were also found in the quantitative values of the main study. Only one laboratory detected a significant effect of mobile phone radiation, and only for dicentric chromosomes at the highest SAR (10 W/kg). The other laboratories did not replicate this finding.

The results obtained in this project agree with those in the majority of published studies, supporting the conclusion that there is very little evidence of genotoxic effects. This conclusion is weakened, however, by the variability of the experimental data in the study, a consequence of the methodology.

A number of authors have claimed effects on gene expression and regard this as an indicator of genotoxicity. Today genetic analysis procedures such as microarray assays permit gene regulation to be studied for the entire genome. Because this involves a very large number of parameters, there is a high probability of incidental statistically significant results ("false positives"). Independent verification by means of other methods is therefore essential. For this purpose the additional performing of real-time polymerase chain reaction (RT-PCR) has become standard. In the broad-ranging project B21[12] both methods were used to study gene expression in human lymphocytes after field exposures with SARs of 0.2, 2 and 5 W/kg. In cases where increased gene activity was noted, Western blotting was used to determine whether a functional protein was formed in large quantities.

In a small number of cases, changes in gene regulation were found and verified by RT-PCR. However, they occurred only at SARs of 2 and 5 W/kg. The genes classified as "regulated" frequently encoded heat shock proteins (HSPs), and an increase in the Western blot was found only in genes of this type. These facts suggest that thermal effects cannot be excluded. The results do not permit the conclusion that mobile phone fields cause relevant changes in gene expression.

1.1.8 Age-dependent effects of high-frequency fields

Project B17 included both theoretical and experimental investigations of possible differences between children and adults in the absorption of mobile phone radiation by the head.[13] SARs were calculated, and in some cases experimentally verified using models, for exposures of various head regions with GSM 900 and GSM 1800 mobile phones. The calculations were based on new, refined numerical-anatomical head models of children (ages 3, 6 and 11) and adults. Age-dependent data on dielectric tissue characteristics were also used.

The local SAR averaged over 10 g, as measured in accordance with DIN EN 62209-1, showed no correlation with age-dependent dielectric tissue characteristics. Nor did differences in head geometry between children and adults have a systematic relation to local SAR values. That is, neither the calculations nor the experiments showed a correlation between head size

[12] Research project B21: Influence of GSM signals on isolated human blood. B. Differential gene expression

[13] Research project B17: Investigation of age dependent effects of high frequency electromagnetic fields based on relevant biophysical and biological parameters

and local SAR. Measurements of test subjects found no characteristic differences in the thickness of the pinnae between children aged 6 to 8 and adults that could have an effect on SARs.

Age-related differences in SAR distribution were found for exposures of certain tissues and brain regions. For the hypothalamus, pineal gland and hippocampus, all located deep in the brain, as well as the eye, the averaged SAR can be higher in children than in adults, depending on age, frequency range and position of the mobile phone. In other regions and for other combinations of parameters, the SAR was found to be lower in children than in adults. Children generally showed higher tissue-specific SARs than adults in the skull bone marrow and the eye. In the authors' view, the difference is due in the first case to the strong age dependence of tissue characteristics and in the second to the smaller distance between mobile phone and eye. Depending on the telephone's distribution of high-frequency currents, near-surface regions of the brain can likewise have different exposure levels due to their different positions relative to the ear in children and adults. The results of temperature simulations and measurements provide no evidence that tissue warming through absorption of high-frequency radiation is higher in children than in adults.

1.2 Thematic area: Epidemiology

Since publication of the SSK report (SSK 2008), five additional epidemiological research projects have been completed.

1.2.1 Mobile communications

A cross-sectional study, E8[14], was carried out to study possible adverse health effects of fields from mobile phone base stations. It was divided into three parts:

- Pilot study and feasibility test,
- Basic study: representative country-wide survey of 51,444 persons (response rate: 58.4%) on health problems, coupled with exposure data from geocoding and
- In-depth study[15] of selected subgroups (4,150 persons, response rate: 85.0%) using questionnaires and exposure measurements (1,500 persons) for risk analysis.

The study found no relationship between exposure from base stations and the health complaints reported by residents. Persons who attributed their non-specific health problems to base stations reported more symptoms. Positive features of the study included the large number of cases in each of the parts, a high willingness to participate, a non-responder analysis in the basic survey, geocoding, measurements in the in-depth study to estimate exposures in sleeping areas and the wide variety of study methods selected at the outset.

[14] Research project E8: Cross-sectional study to record and evaluate possible adverse health effects due to electromagnetic fields from cell phone base stations (Quebeb)

[15] Research project E6: Addendum to the cross-sectional study on acute health effects caused by fields of mobile phone base stations

Another cross-sectional study, E9[16], looked at the relation between well-being and individual exposure to electromagnetic fields from mobile phones as recorded by personal dosimeters. It included 3,022 children and adolescents. A total of 6,386 subjects were asked to participate, and a response rate of 52% was achieved in the measurements and detailed interviews. The study found no relation between RF-EMF exposure and chronic or acute complaints such as headache, irritability, nervousness, dizziness, fear, sleeping problems and fatigue. Although there were isolated significant reports (in two of a total of 36 tests) of acute complaints in the evening (increased irritability in adolescents and concentration problems in children), no consistent pattern could be discerned. The question remains open whether the reported health complaints were caused by the exposure or whether they were a consequence of increased mobile phone use. The authors of the study additionally determined that the results would not have been significant after a Bonferroni correction for multiple testing. For this reason the results were rated as incidental.

Project E10[17] used measurement data collected from personal dosimeters to validate the exposure surrogate model developed in a previous DMF project[18]. The exposure surrogate model comprised technical data from mobile phone base stations (radio system, installation height, geo-coordinates, safety distances) and information supplied by participants and interviewers on local conditions such as land-use class, storey height, building density and vegetation. Based on actual input parameters and a detailed sensitivity analysis of influences by individual parameters, the study showed that the exposure model did not make sufficiently good predictions at the individual level. A particular problem was the poor precision of geo-coordinates for base stations and residences. The model is therefore suitable only for initial classifications of exposure, and then only if the input data are sufficiently accurate.

Project E7[19] was concerned with retrospective estimation of RF exposure in INTERPHONE study subjects. The objective was to determine individual cumulative absorbed energy from mobile phone use at the anatomical location of the tumour for the cohort in the INTERPHONE study (Wake et al. 2009, Cardis et al. 2008). Owing to the large number of necessary calculations taking into account all used mobile phone technologies and phone types it was impossible to determine the individual SAR distribution for all subjects. Mobile phones were therefore first grouped in classes with similar SAR distribution profiles (clustering). The only clustering that was found to be robust was based on a division according to frequency band (800-900 MHz / 1500 MHz / 1800-1900 MHz). The normalized generic spatial SAR distribution was determined for each class by means of calculations with a large number of phones. This relative distribution was then linked with individual data on duration of use, taking factors into account like power control, DTX, land-use class and use of headsets. The influence of the user’s hand was not considered, however. For each subject the

16 Research project E9: Acute health effects by mobile telecommunication among children

17 Research project E10: Validation of the exposure surrogate of the cross-sectional study on base stations

18 Research project 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”

19 Research project E7: Estimation of RF-exposure in INTERPHONE Study subjects

individual SAR distribution was weighted with the median SAR of all phones in the relevant class rather than that of the particular phone used.

In view of the need for simplification to deal with the many types of phones, this is a reasonable and practical procedure. Retrospective studies always involve uncertainties in regard to individual factors. Nevertheless, it must be noted that some of the factors mentioned in the report were inadequately explained and arbitrarily defined. There was no estimate of the overall uncertainty for cumulative exposure. Consequently one cannot be sure to what degree the values calculated in this way are reliable and whether they can be put to further use in the INTERPHONE study.

1.2.2 Radio and television transmitters

The relation between incidence of childhood leukaemia and exposure to radio and television transmitters was investigated in an epidemiological case-control study.[20] The study was based on the records of 1,959 children age 14 and younger in the German Childhood Cancer Registry who contracted primary leukaemia between 1984 and 2003 and lived at some time in the vicinity of 16 long-wave and medium-wave radio stations or 8 VHF TV stations in West Germany. Controls, matched at a ratio of 1:3, were chosen from the population randomly by age, sex, broadcast region and time of notification. The analysis of the data found no statistically significant relationship between the risk of contracting leukaemia and exposure to electromagnetic fields from radio and television transmitters. The same finding held when AM and VHF/TV transmitters were considered separately.

The study is commendable for the epidemiological methods it used in selecting cases and controls. Another particular strength was the way in which it determined individual exposures. This was done by estimating the average exposure for residential addresses of the subjects in the year before diagnosis and doing the same for the matched controls. The estimates were based on a field strength modelling method that had originally been developed to check the quality of broadcast services. This required historical data on the operating states of the broadcasting stations. The estimation methods that were derived were validated by means of comparisons with current and historical measurement data.

For the subsequent statistical analysis, exposure levels were divided into classes based on the available data. Persons with exposure levels below the 90th percentile were regarded in the analysis as non-exposed or low exposed. The authors justified this cut-off choice by referring to the skewed distribution of the exposure data.

1.3 Thematic area: Dosimetry

At the time of the SSK report on the DMF in 2008 (SSK 2008), four projects in this thematic area had not yet been completed. They dealt with the following topics:

[20] Research project E5: Epidemiological study on childhood cancer and proximity to radio and television transmitters

- Exposure in complex exposure scenarios (D12)
- Dielectric properties of tissues at the cellular level (D13)
- Influence of antenna and housing topologies on SAR (D14)
- Exposure by ultra wideband technologies (D15)

The aim of research project D12[21] was to develop a practical method of calculating SAR values in complex exposure scenarios involving several different RF sources. The sources considered were far from the body (mobile phone base stations and radio stations), near the body (WLAN routers and DECT base units) and in contact with the body (mobile phones and DECT phones). This issue is especially important in view of the rising number of high-frequency sources located at various distances from users (for example, short-range signal transmission in residences as a replacement for cable connections, development of the TETRA and LTE base station network). Current recommendations on restrictions give only limited attention to superposition of radiation from these sources.

The researchers chose a modular approach to the problem. In Module A they created a catalogue with several hundred calculated distributions of power absorbed by the body. The catalogue distinguished between sources in contact with the body, sources near the body and sources far from the body. In Module B, depending on how the user defined the real scenario, each source under consideration was assigned an absorption distribution in the catalogue of Module A. Transmission paths were analysed using well-established propagation models and channel models, permitting the data to be weighted appropriately according to source, personal environment and source environment. Finally, in Module C the weighted power absorption distributions determined in Module B were summed for the whole body and locally for 10 g of tissue. The values were given in relation to the mass in question, allowing determination of whole-body SARs and maximum local SARs. These were compared with existing limit values. The data in the catalogue can be used by non-experts to determine emission levels from definitions of real scenarios, thus providing a simple alternative to previous field theoretical analyses of tissue absorption, which only experts were able to apply. The structure also permits new technologies, device usage scenarios and body models to be included in the catalogue at a later time, in this way keeping the procedure up to date.

The calculation model represents a compromise between accuracy and practical applicability. When applied to typical scenarios it confirms that sources far from the body, in contrast to those near the body, generally have a negligible effect on total exposure. Exposure limits are not exceeded through the accumulation of emissions from different sources. However, to resolve this issue definitively it will be necessary to investigate a much larger number of scenarios, especially those involving exposure to multiple nearby sources.

[21] Research project D12: Development of a practicable computational procedure for the determination of the actual exposure in complex exposure scenarios with several different RF-sources

Research project D13[22] studied whether the dielectric properties observed in tissues at the macroscopic level also hold without restriction at the cellular and subcellular levels. This question is important in view of the debate on possible non-thermal effects in cells such as resonances and non-linear processes. Dielectric measurements in the 100 MHz to 40 GHz frequency range were carried out using the coaxial probe method for water, electrolyte solutions, model membranes, blood, erythrocyte suspensions and cell suspensions at 20°C to 60°C. They were augmented by permeability measurements of model membranes, melanoma cells, fibroblasts and keratinocytes using the patch-clamp technique and by theoretical models.

With one exception, the dielectric measurements confirmed the dielectric behaviour of electrolyte solutions and cell suspensions described in the literature. The exception occurred in measurements of whole blood and erythrocytes. Here a weak additional relaxation was observed at approx. 3 GHz, contributing to about 20% on conductivity. The reason for this relaxation remained unclear, and the authors did not discuss the relevance of this observation to the averaging procedure of SAR at the macroscopic level as prescribed in current standards and recommendations.

In none of the biological systems analysed were the authors able to demonstrate non-linear effects from externally applied fields, a condition for demodulation. In patch-clamp measurements of three different human cell systems, performed up to SARs of 15 W/kg, no reproducible gating effects on ion channel currents were found within the range of measurement accuracy. Thus no effects on membrane permeability were demonstrated. No signs were found of resonance phenomena in cell membranes, which would have pointed to absorption processes in the cells.

Consequently, these investigations – with the exception of the one showing a weak additional relaxation at 3 GHz in blood and erythrocyte suspensions – confirm the current state of knowledge. It is unlikely, however, that the methods used would have been able to detect potential and as yet unknown microscopic interactions between electromagnetic fields and tissue.

Project D14[23] investigated ways to lower the SARs in users of mobile telecommunication devices by optimizing the design of the antenna and housing while not impairing communication performance. The researchers applied finite difference time domain (FDTD) calculations using a notebook with a plug-in card and Bluetooth adapter, a DECT base unit and a WLAN router. For adults the Visible Human, a high-resolution phantom, was used as a model. The adult model was scaled down for adolescents. In addition, a model of a sitting person was generated by bending the knee, hip and elbow joints. A total of 46 different

22 Research project D13: Investigation of the question, if macroscopic dielectric properties of tissues have unlimited validity at both cellular and subcellular levels

23 Research project 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

configurations were observed, providing a realistic picture of user's posture and the positions of mobile devices in home and work environments.

The investigations showed that the mobile devices studied reached only a small percentage of the exposure limit. In many cases the percentage was higher for local SAR than for whole-body SAR. The highest values generally occurred in the limbs (for sitting models in the hands). In the most unfavourable scenario examined (notebook on the user's lap) the whole-body SAR at maximum output power went up to approx. 11% of the exposure limit in adolescents, and the local SAR was as high as approx. 37% of the limit in adults. By optimizing mobile devices, in particular by changing the position of the antennas, it would be possible to reduce SARs by a considerable amount without impairing transmission quality (for example, moving the PCMCIA interface to the back of the notebook display would bring a reduction of up to 80%). These results could be useful for exposure situations involving multiple sources, especially in view of future developments in wireless communications.

An additional project, D15 [24], studied various ways of measuring exposure from ultra wideband (UWB) technologies. It used both physical measurements and numerical methods.

For measurements in the far field of a UWB source, spectrum analysers are preferable to oscilloscopes because they are more sensitive. At present, SAR measurements are impractical owing to a lack of suitable tissue simulating liquids and probes. Measurements performed at a distance of 15 cm from four different UWB devices showed time-averaged exposures of up to 0.32 mW/m^2. The peaks did not exceed 2.4 mW/m^2. Applications involving body contact were studied primarily with numerical calculations. These yielded maximum SAR_{10g} values of 0.013 W/kg under worst-case conditions (100% exploitation of the transmission spectrum permitted in Europe). These values would be 1-2 orders of magnitude lower under real conditions (lower spectral efficiency). The maximum specific absorptions (SA_{10g}) expected in Europe are typically below 10^{-8} J/kg, representing only a small fraction of the applicable exposure limits, as is the case with all other values. Thus UWB is of only minor importance in comparison with other EMF sources in the home (WLAN, DECT). Although this technology has only recently been introduced in Europe and measurements were available for only four devices, the study provided a reliable assessment of exposure from UWB devices thanks to the approach used.

2 Concluding assessment

In 2008, the SSK issued an initial evaluation of the DMF based on the findings available at that time. A number of questions had to be left open. The present review continues this assessment, augmenting it with findings from the projects completed since then.

All in all, the reports demonstrate that the projects were largely of high scientific quality.

24 Research project D15: Determination of exposure due to ultra-wideband technologies

The Commission on Radiological Protection originally recommended that the German Mobile Telecommunication Research Programme address the following questions:

- Does mobile phone radiation have a potential cancer-initiating or cancer-promoting effect?
- Does mobile phone radiation affect the blood-brain barrier?
- Are there effects on neurophysiological and cognitive processes or on sleep?
- Is there such a thing as electrosensitivity, and can mobile phone fields cause non-specific health symptoms?
- Does chronic exposure affect the blood and the immune system?
- Does chronic exposure affect reproduction and development?
- What levels of exposure are caused by wireless technologies?
- Are children subjected to increased health risks?
- How are the risks of electromagnetic fields perceived, and how can risk communication be improved?

The present review examines these questions, taking the findings of the German Mobile Telecommunication Research Programme and recently published international literature into account.

2.1 Does mobile phone radiation have a potential cancer-initiating or cancer-promoting effect?

The potential long-term effects of mobile phone use, especially as related to the initiation and promotion of cancer, are of major importance for radiation protection. A large number of epidemiological studies have addressed possible associations between EMF exposure and cancer. In general they have not been able to come to clear conclusions about the potential long-term effects of mobile phone use. This applies in particular to slow-growing tumours and cancers with long latency periods, because the technology has not been in use for very long. The analysis is complicated by methodological difficulties in determining exposure levels (insufficient accuracy, inadequate consideration of background exposure, distortion caused by inaccurate memory (“recall bias”), distortion arising from the choice of subjects). Additional problems include identification of individual confounders, selection of a suitable control group in case-control studies and definition of different exposure classes based on relative distributions of exposure data for the purpose of further epidemiological analyses.

A number of epidemiological projects in the DMF focused on determining whether high-frequency electromagnetic fields are able to initiate or promote cancer.

One carefully executed case-control study, involving 1,959 patients age 14 and younger, investigated possible relationships between childhood leukaemia and exposure to electromagnetic fields from radio and television transmitters. It found no evidence of an additional leukaemia risk from these sources. During roughly the same period, a case-control study was carried out in South Korea. It investigated 1,928 children with leukaemia and 956 children with brain tumours, all below the age of 15, along with an equal number of hospital controls. A corrected analysis (Ha et al. 2008) of the originally published data (Ha et al. 2007) found no indications of an increased overall leukaemia risk. The analysis of different exposure levels yielded two different results for the parameter “peak exposure” in the highest exposure quartile: an increased risk of lymphatic leukaemias and a protective effect for myeloid leukaemias. The authors did not discuss these findings in detail. A subsequent pooled evaluation of the data from Germany and South Korea showed no relationship between high-frequency electromagnetic fields and childhood leukaemia (Schüz and Ahlbom 2008).

Outside of the DMF, studies of cancer risk in the vicinity of mobile phone base stations have exhibited certain weaknesses. Two ecological studies, performed in Germany and Israel, found that cancer incidence rates rose with increasing proximity to the base stations studied (Eger et al. 2004, Wolf and Wolf 2004). Here it must be criticized that the findings were based on small numbers of cases and that distance, an inadequate surrogate, was used as a measure of exposure. A case-control study encompassing all registered cases of cancer in children aged 0-4 in Great Britain in 1999-2001 found no relationship between the risk of cancer in early childhood and estimated levels of maternal exposure to base stations during pregnancy (Elliott et al. 2010). The study used three surrogate measures of exposure (distance from the place of residence to the nearest base station, total power output of base stations within 700 m of the address, and modelled power density derived from distance, base station characteristics and geographical circumstances) but did not take other radio-frequency sources into account. One weakness is that it did not measure actual exposure, and the first two surrogates cannot be regarded as suitable.

In view of the fact that mainly the head is exposed during mobile phone use, many studies concentrate on tumours in this part of the body. Initial indications of a possibly increased risk of uveal melanoma (Stang et al. 2001) were followed up by a much more extensive study that was co-financed by the DMF (Stang et al. 2009). No effects of mobile phone use were found so that the previous results could not be confirmed.

The largest international study of mobile phone use and cancer to date is the INTERPHONE study, coordinated by the International Agency for Research on Cancer (IARC) and comprising 16 investigations from 13 countries. Besides evaluating data on tumour types and locations, it recorded duration of mobile phone use (up to more than 10 years) and cumulative information on the number and duration of calls. The data on mobile phone use were collected by means of interviews. Most of the results have been published, and they were analysed by Ahlbom et al. (2009). The results for the endpoints meningioma and glioma have now been published (INTERPHONE 2010).

Reduced odds ratios, for the most part statistically significant, were found for both glioma and meningioma, usually regardless of call time. The only statistically significant increase was found for glioma, and only for the highest cumulative call time (> 1,640 hours). This lone finding was not supported by the other data, however. No significant increases in odds ratios were found to be associated with increases in cumulative numbers of calls or years of use (in fact, the odds ratios here were always *lower* than those of the control group). In view of the implausibility of protective effects from mobile phone use, the authors suspected systematic biases in the collection of data. Among the possibilities discussed in detail were biases arising through interviewing of relatives (proxies) in cases where the patients themselves were no longer able to answer questions or had already died. In addition, there were implausible values of reported use (for example, more than 12 hours per day, a figure given only by persons diagnosed with tumours or by their proxies), errors in recollection (recall bias) and differences in the degree of participation by healthy controls and patients (participation bias). Finally, for both meningioma and glioma the data showed odds ratios that were often significantly lower for the side of the head opposite to where the phone was used, another implausible finding that could be explained by recall bias. Overall, the results of the INTERPHONE study did not point to any link between mobile phone use and the incidence of brain tumours (glioma and meningioma).

Methodological uncertainties in recording exposure were also evident in the two dosimetric studies relevant to epidemiology that were supported by the DMF. The retrospective estimation of exposure in the INTERPHONE study and the validation of the exposure surrogate used in cross-sectional studies of non-specific health symptoms both showed that the methods can and must be improved.

The report of the Swedish Radiation Safety Authority (SSM 2010), which covered studies up to 2010, concluded that a short-term risk of of mobile phone use on brain tumours can be excluded with a high degree of certainty. The study noted that if the use of mobile phones were a long-term risk, incidence data would have indicated increasing rates by now, unless the risk is very small. Two reports, SCENIHR (2009) and SSM (2010), called attention to the lack of long-term studies on the risk of brain tumours, especially among children. The WHO likewise sees a need for prospective cohort studies on children’s health including cancer (WHO 2010, van Deventer et al. 2011). It proposed determining the incidence of brain tumours from data in cancer registries and investigating possible relationships with ecological exposure data, in this way avoiding the difficulties encountered in previous studies with monitoring individual exposure plus the problem of low willingness to participate. This approach, however, has the drawback that it permits chance misclassifications of exposure, leading to underestimation of potential effects (Brunekreef 2008, Röösli 2007). It would not throw sufficient light on health problems related to mobile phone exposure because the effects discovered would be only minor.

A multinational (Denmark, Norway, Sweden and Switzerland) case-control study of 352 children and adolescents (age 7–19) with brain tumours and 646 controls matched by age, sex and region (CEFALO) found no association between mobile phone use and risk of brain tumours (Aydin et al. 2011). The authors concluded from their findings, which showed no exposure-response relationship in terms of the amount of mobile phone use or the tumour location, that there was no causal connection. In 2010, collection of data began for an additional international case-control study on the relationship between the incidence of brain tumours and the use of communication devices, including mobile phones, by young people age 10 to 24 (MOBI-KIDS). The study is expected to take five years. A total of 2,000 patients with brain tumours from 13 countries, including Germany, will be recruited along with a control group of equal size.

In addition to these large-scale case-control studies of brain tumours in young people, a prospective cohort study is currently under way to investigate incidence rates and mortality rates for various diseases (cancer, benign tumours, neurological diseases and cerebrovascular diseases) as well as changes in the frequency of unspecific symptoms such as headaches and sleep quality (Schüz et al. 2011). The study, which plans to follow a cohort of approx. 250,000 mobile phone users age 18 and older for more than 25 years, is being carried out in Denmark, Sweden, Finland, the Netherlands and the United Kingdom (COSMOS). Germany is not participating because of problems brought to light by a DMF-supported feasibility study. It was shown that although an investigation with such a design would be possible in principle, the low willingness to participate would require contacting an unrealistically high number of mobile phone users in order to ensure sufficient participation.

Another feasibility study supported by the DMF[25] addressed the question whether persons with occupational exposure to high-frequency fields have an increased risk of illness. It concluded that it would not be possible to develop a suitable design for an epidemiological study of this kind and gave a number of reasons, including cohort size, mixture of exposure from different sources and measurement of exposure.

To sum up, the vast majority of epidemiological studies have found no evidence of a relationship between mobile phone use and cancer. Methodologically, it remains difficult to study long-term mobile phone use and the resultant induction of cancer with a long latency period. This problem has been exacerbated by significant changes in technologies and exposure conditions in recent years.

There has been considerable interest in understanding the basic mechanisms of EMF exposure in order to better assess the long-term effects of mobile telephony. If it were possible to demonstrate a genotoxic effect or an effect on gene regulation and to interpret it by a plausible mechanism such as that known for ionizing radiation, this would point to carcinogenic effects from mobile phone fields. This is the reason why so many groups of investigators have addressed the issue in the past. The SSK did so at a very early date and concluded in a detailed statement that the existing literature did not contain sufficient evidence of genotoxic effects or effects on gene regulation below the applicable exposure limits (SSK 2007a). In the meantime a number of new publications on this topic have appeared. In a detailed survey article Verschaeve et al. (2010) reported that unrecorded temperature increases can give rise to so-called athermal effects in some cases. They concluded that recent studies had failed to

[25] Research project 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

provide a consistent picture. According to the authors, the evidence for genotoxic effects from mobile phone fields is weak. An interlaboratory study carried out as part of the DMF investigated various experimental indicators of possible genotoxic effects in stimulated human lymphocytes. Although there were considerable differences between the results obtained by the participating laboratories, the vast majority of experiments found no genotoxic effects.

In principle, changes in gene regulation could play a role in cancer promotion. For this reason it is important to determine whether fields generated by mobile communication systems have such an effect. Here, too, an extensive body of literature is available, but no definitive conclusions are yet possible. Studies of gene regulation require even greater precision with regard to exposure and dosimetry than those concerned with direct alteration of genetic information, because small thermal effects can have significant consequences. This applies in particular to heat shock proteins. It has even been asserted that their activation is a clear sign of thermal effects (Gaestel 2010).

In recent years studies of gene expression have been applying modern methods in genomics, which are considered by many researchers to be very useful in the detection of non-thermal effects. The experiments have focused in particular on genome-wide screening of gene activity with the aid of microarrays, a procedure that generates large volumes of data. For statistical reasons there is a risk of producing false-positive findings, making it necessary to validate the results using independent methods such as RT-PCR and Western blotting. In a comprehensive overview Vanderstraeten and Verschaeve (2008) concluded that the studies conducted up to that time did not carry a clear message, especially in view of the lack of convincing theoretical arguments and experimental evidence for an influence on gene activity by mobile communication fields. The extensive and carefully executed DMF project[26] on this issue confirmed these reservations; no significant changes in gene activity were found at low SARs. This was in basic agreement with the findings obtained in the previous reporting period related to effects on the blood-brain barrier.[27] Here too, no significant effects on gene regulation were observed.

There is a general lack of systematic studies investigating cytotoxic and genotoxic effects at the cellular level for a wide range of parameters. Most of them examine only few parameters as the comet assay and the micronucleus test.. None have found evidence of mutagenicity as a result of exposures near the recommended limits. Mutagenicity, however, is a necessary condition for cancer induction as most carcinogenic agents also have a mutagenic effect. Among other deficits, researchers have neglected to use established methods with bacterial test systems, observe colony formation and record changes in the cell cycle. Although individual studies have been devoted to these questions, such as mutations (Hamnerius et al. 1985, Chang et al. 2005, Koyama et al. 2007), a general conclusion does not emerge since the authors work with different exposure scenarios. The available data do not form a coherent

[26] Research project B21: Influence of GSM signals on isolated human blood B. Differential gene expression

[27] Research project B10: In vitro experiments on exposure to the high frequency fields of mobile telecommunication. C. Blood-brain barrier

picture. Nevertheless, the majority of the published results lend no support to the hypothesis that mobile communication fields below the exposure limits have genotoxic effects.

The animal studies carried out in the DMF likewise found no evidence of cancer-initiating or cancer-promoting effects. These recent results are in agreement with previously completed or published DMF projects and with the findings presented in reviews of the international literature (surveys by Sommer et al. 2010 and Tillmann et al. 2010). The results corroborate the general view that high-frequency electromagnetic fields are unlikely to have damaging effects. Of particular importance is the fact that the worst-case scenarios, including those involving prolonged exposure over several generations near the limit levels, showed no effects on fertility, mortality or development of progeny, and no relation to other endpoints. Although animal studies have the general limitation of not being directly transferable to humans, these negative findings, in particular those showing an absence of reproducible carcinogenic effects, agree with the results of *in vitro* studies and thus yield a consistent picture.

In summary, the projects conducted in the DMF have shown no evidence of cancer-initiating or cancer-promoting effects. Thus they are in agreement with most published studies and have provided important additional information.

The SSK weighed the overall evidence for a potential association between mobile phone exposure and carcinogenicity by assessing the diverse scientific approaches (physical interaction mechanisms, biological interaction mechanisms, dose effect, *in vitro* studies, *in vivo* studies and epidemiological studies) (SSK 2011). It found the evidence from physical interaction mechanisms to be insufficient (E0), and for biological interaction mechanisms the data were unreliable to make a classification (D1). The evidence from dose effect relationships was insufficient (E0), and the data in *in vitro* studies were inconsistent (D2). For both *in vivo* studies and epidemiological studies there was insufficient evidence (E0). Taken together, the studies thus give insufficient evidence for a carcinogenicity of mobile phone exposure (Table 1).

Table 1: Overall assessment of evidence related of the evidence of microwaves (MW) (SSK 2011)

MW	Physical interaction mechanisms	Biological interaction mechanisms	Dose effect	In vitro studies	In vivo studies	Epidemio-logical studies	Total evidence
Evidence	**E0**	**D1**	**E0**	**D2**	**E0**	**E0**	**E0**

E0: Lack or insufficient evidence for the existence or non-existance of causality: This applies if only a limited number of studies is available, but they predominantly report a lack of a statistically significant association between exposure and carcinogenicity. The studies may be of limited size with an insufficient number of different endpoints but must have been performed with sufficient methodical quality. Furthermore, the results must have been reproduced, at least in part, by independent groups. Bias and confounding should be low. It must be possible to explain the results in terms of established theoretical knowledge.

D1: Unreliable data: This applies if available studies are of insufficient size and were performed with insufficient methodical quality, with an insufficient number of different endpoints. Bias and confounding are probable.

D2: Inconsistent data: This applies if studies report conflicting or inconsistent results relating to an association between exposure and carcinogenicity. These studies have not been reproduced by independent groups, and bias and confounding cannot be excluded.

This assessment by the SSK differs from that of the International Agency for Research on Cancer (IARC), a part of the World Health Organization (WHO). In its session of May 2011 the IARC classified radiofrequency electromagnetic fields (RF-EMF) as “possibly carcinogenic to humans” (Group 2B). A summary report by the IARC (Baan et al. 2011) found “limited evidence” of carcinogenicity from radiofrequency electromagnetic fields, basing its conclusion on positive associations between both glioma and acoustic neuroma and radiofrequency electromagnetic radiation from mobile phones and cordless phones. It also found “limited evidence” of carcinogenicity in the results of animal experiments.

In its assessment of glioma and acoustic neuroma the the results of the INTERPHONE study (INTERPHONE 2010, Cardis et al. 2011), a report by a Swedish group (Hardell et al. 2011) and a report by a Japanese group (Sato et al. 2011) were relevant for IARC.

Two articles (Cardis et al. 2011, Larjavaara et al. 2011) reported on subgroups from the INTERPHONE study sample. Cardis et al. (2011) found a suggested higher risk of glioma and, to a lesser degree, of meningioma in long-term users of phones, depending on the amount of high-frequency energy absorbed at the tumour location. Energy absorption was estimated with the help of a model. An uncertainty analysis was lacking, however, providing no way to judge the reliability of the estimates and their suitability for evaluations in the INTERPHONE study (see also section 1.2.1). Larjavaara et al. (2011) reported from their analyses that glioma did not preferentially occur in those brain regions which, based on the distance between the centre of the glioma and the source of exposure (typical reported mobile phone position), had the highest expected field strength. However, Larjavaara et al. (2011) were only cited in the IARC press release of 31 May 2011 and not in the related *Lancet* article (Baan et al. 2011). In contrast, Cardis et al. (2011), who found an association, were cited in the *Lancet* article (Baan et al. 2011). The article additionally cited Sato et al. (2011), who reported ipsilateral acoustic neuroma associated with calls longer than 20 minutes. The authors cast doubt on these results, however (“This increased risk should be interpreted with caution …”). The INTERPHONE publication on acoustic neuroma (INTERPHONE 2011) likewise is very sceptical about the association reported for the group with the highest exposure (“This increase could be due to chance, reporting bias or a causal effect”). In the report summarizing the INTERPHONE project (INTERPHONE 2010) the authors, some of whom had participated in the above-mentioned studies, saw no increased risk of glioma or meningioma from mobile phone use. The members of the IARC group do not quote this conclusion in the *Lancet* article (Baan et al. 2011).

Re-examining the pooled results of their previous studies in Sweden, Hardell et al. (2011) found indications of a relationship between the latency period until occurrence of brain tumours and cumulative exposure to mobile phone radiation. One shortcoming of the studies by this working group is that exposure was determined by means of questionnaires sent by post, which were filled in by the subjects or family members. Methodologically, this is a great disadvantage in comparison to studies that use trained interviewers. In addition, the criteria for excluding subjects and forming case groups were problematic (Ahlbom et al. 2009). Finally, there is a contradiction between the very strong effects observed by Hardell et al. and the fact that brain tumour incidence rates have not increased in recent decades (Swerdlow et al. 2011).

In concluding that animal experiments showed an association between cancer and exposure to mobile phone radiation, the IARC relied on positive results from only three studies (Repacholi et al. 1997, Szmigielski et al. 1982, Hruby et al. 2008), as compared to a large number of negative results from other studies (it evaluated a total of more than 40). In the opinion of the SSK, the three studies had a number of weaknesses. The findings reported in the study by Repacholi et al. (1997) could not be verified by Utteridge et al. 2002 and Oberto et al. 2007 (see also SSK 2007a). The second study that was cited (Szmigielski et al. 1982, submitted in 1980) investigated the effects of 2450 MHz EMFs on tumour incidence (spontaneous mammary gland tumours and chemically induced skin cancer) in mice. Here the authors reported mean whole-body SARs of 2–8 W/kg, which thus were partly in the thermal range. The study, which was conducted more than 30 years ago, determined SARs using dosimetry that today can no longer be considered accurate. The third study (Hruby et al. 2008) was likewise unsuitable for demonstrating a relationship between EMF exposure and DMBA-induced cancer in rats, as the authors themselves admitted. There was no recognizable dose-effect relationship in the tumour rates, and the highest rates were found in the unexposed cage controls, leading the authors to call the results “rather incidental”.

Having examined the studies cited by the IARC, the SSK therefore reiterates its conclusion (SSK 2007a) that the data do not point to a relationship between mobile phone exposure and the initiation or promotion of cancer.

At present there is no immediate need for additional research in epidemiology, as the results of ongoing studies (COSMOS, MOBI-KIDS) are still being awaited. What is needed is a comprehensive study of possible genotoxic effects employing as many of the available tests as possible (Albertini et al. 2000, Brendler-Schwaab et al. 2004). Here it is important to ensure high standards of quality assurance and quality control. The multi-centre studies carried out in the past did not always do so because they were limited to small numbers of experimental endpoints (PERFORM-B [Stronati et al. 2006], REFLEX [EU 2004]). This applies to the projects supported by the DMF[28,29] as well.

The SSK recommends that future EMF research rely more on hypothesis-driven studies. Hypotheses about effects should be investigated in connection with basic research, taking established knowledge of radiation biology into account.

28 Research project B16: Possible genotoxic effects of GSM signals on isolated human blood

29 Research project B21: Influence of GSM signals on isolated human blood B. Differential gene expression

2.2 Does mobile phone radiation affect the blood-brain barrier?

Three DMF projects, based on different experimental approaches, were devoted to studying the integrity of the blood-brain barrier (BBB). All of them came to the conclusion that the blood-brain barrier is not affected by mobile phone fields in the range of currently existing exposure limits. This applied to functional parameters like permeability and to the expression of relevant genes. The studies, which adhered to high scientific standards throughout, thus did not confirm previously published findings related to effects on the BBB.

Only one study in the recent literature observed an effect on the blood-brain barrier (Eberhardt et al. 2008). The strongest effects were found with the lowest SARs rather than with the highest ones. This contradicted the findings reported previously by the same laboratory.

In a detailed discussion of this topic, the authors of a report by the Swedish Radiation Safety Authority (SSM 2009) similarly concluded that the changes in the blood-brain barrier observed by one working group had not been confirmed by other groups, thus raising doubts about the validity of the earlier findings. EFHRAN (2010) reached the same conclusion, as did two other reviews (Stam 2010, Perrin et al. 2010). In this connection it must be remarked that the permeability of the blood-brain barrier can be affected by rises in temperature as small as 1 °C (Stam 2010), making it necessary to perform experiments in a very careful manner.

The projects in the DMF did not find any effects on the BBB, even though they used new methodological approaches. Thus the DMF was able to make an important contribution to this debate. All in all, there does not exist sufficient evidence that exposure to mobile phone fields below the exposure limits can affect the blood-brain barrier. Further research on this topic is therefore not required.

2.3 Are there effects on neurophysiological and cognitive processes or on sleep?

Studies of possible effects by electromagnetic fields from mobile communications on the central nervous system (CNS) must distinguish between effects on the brain when it is relatively at rest and those when it is active according to cognitive demands. In the former case a further distinction can be made between a state in which exogenous factors are largely absent (sleep) and one in which the brain is awake but relaxed. In addition, one must distinguish between studies based on physiological parameters such as sleep EEG and those based on subjective assessments of sleep quality (see 2.4). The latter assessments can deviate to varying degrees from measurements of sleep quality. They are discussed together with other subjective parameters related to non-specific health symptoms.

2.3.1 Sensory organs

Three studies on the function of sensory organs were completed in the previous reporting period (SSK 2008). Two projects were concerned with the auditory system [30,31] and one with the visual system[32]. The studies, which applied a variety of methods, largely ruled out effects by mobile phone fields on vision and hearing; in particular, there was no evidence that EMF exposure could cause tinnitus.

2.3.2 EEG

2.3.2.1 Sleep EEG

Studies of effects on brain activity during sleep have yielded inconsistent results. Three projects in the DMF[33,34,35] came to the conclusion that mobile communication fields do not impair sleep. In particular, they failed to confirm the increase in EEG power at spindle frequencies during NREM sleep that was repeatedly observed (but at different times of the night) by a Swiss group led by Achermann (see Regel et al. 2007 and other studies). The discrepancies in the results obtained by these studies, all of which used correct methodologies, can possibly be explained by different exposure scenarios. The study conducted in the DMF exposed subjects throughout the night, whereas the Swiss group, with few exceptions, exposed its subjects 30 minutes before the onset of sleep. Another difference was the size of the exposed brain region; in the Swiss studies the region was much larger.

The studies primarily used signals and SARs typical of mobile phones. They also used SARs typical of base stations, which are similar to those that occur with mobile phones.

Whereas studies of high methodological quality have consistently failed to observe effects of electromagnetic fields from mobile phones on sleep architecture, a Swedish study of persons who attributed their complaints to mobile communication observed a significant reduction in deep sleep time and an associated increase of deep sleep latency following exposure (Lowden et al. 2011). In addition, the study recorded a significant increase in stage 2 of NREM sleep. Since there was no increase in sleep latency, no wakeafter sleep onset, and no increase in the percentage of light sleep, these results cannot necessarily be interpreted as signs of sleep disturbance.

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[30] Research project B11: Possible influence of high frequency electromagnetic fields of mobile communication systems on the induction and course of phantom auditory experience (tinnitus)

[31] Research project B18: Influence of high frequency electromagnetic fields of mobile telecommunications on sensory organs. A. The auditory system

[32] Research project B12: Influence of high frequency electromagnetic fields of mobile telecommunications on sensory organs. B. The visual system

[33] Research project B19: Studies of the effects of exposure to electromagnetic fields emitted from mobile phones on volunteers

[34] Research project B5: Investigation of sleep quality of electrohypersensitive persons living near base stations under residential conditions

[35] Research project 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

At present it is not possible to make a final statement about effects on sleep EEG. Hence there is a need for continued research. This was also the conclusion reached by the Swedish Radiation Safety Authority (SSM 2010). The first step could be to encourage increased cooperation, including comparative parallel studies, among the groups working on this topic. In addition, there should be studies covering persons of all ages, from childhood to old age, in order to identify possible age-dependent effects.

2.3.2.2 Relaxed waking (resting) EEG

The literature has described effects of exposure to electromagnetic fields on EEG power not only for sleep but also for waking EEG. Here the alpha frequency band (the basic rhythm of the resting EEG in approx. 85% of the population) seems to be involved. Many older studies must be criticized for methodological reasons (one reason being a simple-blind exposure design), and recent studies are to some extent contradictory. In the study supported by the DMF[36] a time-of-day effect was more pronounced than an exposure effect. A study by Croft et al. (2010) investigated age dependence of the exposure effect on EEGs in the alpha band for GSM and UMTS. Whereas no changes were observed for UTMS exposure and the DMF study also showed no effects, the Australian study (Croft et al. 2010) observed an effect on the alpha power in the resting EEGs of 19- to 40-year-olds. It found no such effects among adolescents (age 13-15) and older persons (age 55-70), however.

A study by Vecchio et al. (2010) also found an age-dependent EMF effect on alpha activity in waking EEGs. Here older persons (age 47-84) were shown to have a statistically significantly higher interhemispheric coherence of the frontal and temporal alpha rhythm than younger persons (age 20-37). This might point to an increase in age-related synchronization of the dominant EEG rhythm under exposure.

For resting EEGs in the waking state, as in the case of sleep EEGs, there is a need for more research. This applies especially to possible age-dependent effects. Such studies must take care to follow strict experimental protocols (Regel and Achermann 2011).

2.3.3 Cognitive functions

Studies of the influence of electromagnetic fields on cognitive functions can be divided into those which evaluate behaviour parameters (reaction times and/or false or missing reactions to stimuli) and those which observe stimulus-coupled EEG changes.

The DMF-supported study, which included statistical time-of-day monitoring, observed no significant effects of GSM or UMTS exposure on event-related and slow EEG potentials (contingent negative variation [CNV], readiness potential [RP], slow potential in a visual monitoring task [VMT] and auditory evoked potential [AEP]). There have been relatively few studies in this area, and the results do not yield a consistent picture. A study by Tommaso et al. (2009) observed a decreased amplitude of the CNV, diffusely distributed over the scalp, in

[36] Research project B19: Studies of the effects of exposure to electromagnetic fields emitted from mobile phones on volunteers

a total of 10 persons (age 20-31) during exposure. The authors interpreted their results as the consequence of reduced arousal and expectation of warning stimuli, explainable in terms of effects by both the GSM signal and the ELF magnetic field produced by the battery and internal circuits.

Studies of auditory evoked potentials in children (Kwon et al. 2010a) and young adults (Kwon et al. 2009, Kwon et al. 2010b) found no effects by electromagnetic fields from mobile phones. Double-blind procedures were not used, however, at least in the study of children.

The DMF study B19[37] investigated EEG changes, reaction times and error frequencies in subjects who were given cognitive tasks. The results revealed no effect by electromagnetic fields from mobile communications (GSM and UMTS) on cognitive functions, but they did show the necessity of taking the time of day into account in such studies (see also Sauter et al. 2011). Two survey articles, published in 2009 (van Rongen et al. 2009) and 2010 (Valentini et al. 2010), and a meta-analysis (Barth et al. 2011) likewise concluded that electromagnetic fields from mobile communications do not affect cognitive functions. This was shown to apply to both children and adults (van Rongen et al. 2009).

Very carefully performed rat experiments using long-term exposure (0.4 W/kg, GSM 900 MHz, UMTS 1966 MHz)[38] showed no impairment of memory and learning. Although this finding cannot be simply transferred to humans, it suggests that such effects are unlikely. As important as these results are, one cannot say that final answers to these questions have been given.

One study with long-term exposure (918 MHz, 0.25 W/kg SAR, 2 hours per day) of transgenic Alzheimer model mice found a significant improvement in memory and cognitive performance in comparison to a non-exposed control group (Arendash et al. 2010). It will be necessary, however, to replicate these results using an improved design and larger groups.

A study of Wistar rats exposed to UMTS signals (0, 2 and 10 W/kg SAR) for a period of 120 minutes showed no differences at an exposure rate of 2 W/kg from the sham-exposed group in hippocampal derived synaptic long-term potentiation (LTP) and long-term depression (LTD), indicators of memory storage and memory consolidation. In contrast, at an exposure rate of 10 W/kg significant reductions of LTP and LTD were observed (Prochnow et al. 2011). The authors conclude that UMTS exposure at a rate of 2 W/kg is not harmful to markers for memory storage and memory consolidation. At higher exposures, however, effects occur that can be distinguished from the stress-derived background.

The WHO has called for further animal experiments on the effects of RF exposure on ageing and neurodegenerative diseases. In epidemiology it sees a need for case-control studies of

[37] Research project B19: Studies of the effects of exposure to electromagnetic fields emitted from mobile phones on volunteers

[38] Research project B9: In vivo experiments on exposure to the high frequency fields of mobile telecommunication. A. Long-term study. Sub-project: Studies of learning and memory performance as measured by operant behaviour

patients with neurological or neurodegenerative diseases and for provocation studies of children in different age groups (WHO 2010, van Deventer et al. 2011). The SSK supports these recommendations and additionally recommends provocation studies on possible effects of electromagnetic fields on brain function in ageing patients (including sleep EEG and resting EEG). Such studies would add to our understanding of structural and functional changes that are known to occur in the brain with increasing age and can ultimately result in neurodegenerative diseases like Alzheimer's.

Studies into the possible cognitive effects of EMF exposure must use reliable dosimetry and apply well-designed exposure protocols. In addition, they must pay attention to numerous other factors that can affect the test results. These include exposure design (crossover vs. parallel group design, exposure before or during testing, avoidance of carryover effects), selection of test subjects (age, sex, inclusion and exclusion criteria), consumption of caffeinated beverages and alcohol, motivation, test sequence and duration, and time of day. In a study of 30 young men, Sauter et al. (2011) showed that after correcting for multiple testing the time of day was the only factor that affected the results of cognitive tests; exposure had no effect.

2.4 Is there such a thing as electrosensitivity, and can mobile phone fields cause non-specific health symptoms?

The DMF supported two epidemiological studies on the possible relationship between sleep disorders, headaches, general physical complaints and physical/mental quality of life on the one hand and exposure to electromagnetic fields from mobile phone base stations on the other. The first study, which included more than 30,000 persons and used a surrogate measure of exposure based on geo-coordinates, found no connection between EMF exposure and adverse health effects or non-specific health symptoms. An in-depth study of 1,326 persons, which measured EMF exposure in bedrooms, likewise found no such connection. Observations of children yielded the same results. A DMF study[39] of acute health effects caused by mobile communications, which included measurements of individual exposure over 24 hours, found no consistent relationship. In contrast, studies of adults showed that persons who attribute their non-specific health symptoms to mobile phone base stations more often tend to report health problems. This can be interpreted as a nocebo effect similar to that observed in another DMF project [40].

Negative expectations can influence the results of studies on the effects of EMF exposure on non-specific health symptoms. This has been observed not only in epidemiological studies, but also in provocation studies of persons with self-reported "electrosensitivity" (also called idiopathic environmental intolerance attributed to electromagnetic fields, IEI-EMF) (WHO 2005). In their review of 46 blind or double-blind provocation studies comprising a total of 1,175 persons with IEI-EMF, Rubin et al. (2010) found no convincing evidence that

[39] Research project E9: Acute health effects by mobile telecommunication among children

[40] Research project 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

electromagnetic fields can cause the symptoms reported by these persons. In many cases there were indications that nocebo effects sufficed to explain the acute symptoms reported by such persons.

In this connection one must ask about the factors underlying “electrosensitivity” or “electromagnetic hypersensitivity” (EHS), in which people feel exposed to severe health hazards. In its Fact Sheet the WHO states the following: “EHS is characterized by a variety of non-specific symptoms that differ from individual to individual. The symptoms are certainly real and can vary widely in their severity. Whatever its cause, EHS can be a disabling problem for the affected individual. EHS has no clear diagnostic criteria and there is no scientific basis to link EHS symptoms to EMF exposure. Further, EHS is not a medical diagnosis, nor is it clear that it represents a single medical problem.” (WHO 2005).

The DMF established four projects to investigate this phenomenon. Three of them, completed in 2008, found no solid evidence of “electrosensitivity”[41,42,43]. These projects did not always have precisely defined selection criteria, however, a fact which made comparisons among them difficult. Project B 13[44] was designed to look into the additional question of a possible connection between EHS and psychosomatic factors. Again, unfortunately, the groups of subjects were not clearly defined, thus limiting the value of the results. The study did not confirm the hypothesis of a difference between “electrosensitive” persons and controls in regard to the parameters studied. The conclusion remains valid that there is no objective evidence for the phenomenon of “electrosensitivity”.

This conclusion is in agreement with statements by a number of international bodies (SCENIHR 2009, EFHRAN 2010, SSM 2009).

Thus, although the target groups were defined and recruited in different ways, one must conclude in agreement with the international literature that “electrosensitivity”, understood as a direct effect of EMF exposure, most likely does not exist. Further research on this topic should therefore be carried out beyond the sphere of EMF research.

In epidemiological studies of cancer and other health endpoints it is essential to measure exposure as exactly as possible while, at the same time, taking as many influencing factors as possible into account (including expectations in particular). Data are best collected using a prospective study design. Prospective studies must start with a large cohort, however, making them personnel-intensive and costly. They also require a high degree of compliance from participants. A feasibility study has shown that cohort studies of this kind cannot be carried out in Germany owing to low willingness to participate.

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41 Research project B14: Investigation of the phenomenon of “electromagnetic hypersensitivity” using an epidemiological study on “electrosensitive” patients including the determination of clinical parameters

42 Research project B5: Investigation of sleep quality of electrohypersensitive persons living near base stations under residential conditions

43 Research project R3: Supplementary information about electromagnetic hypersensitive persons

44 Research project 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

2.5 Does chronic exposure affect the blood and the immune system?

A number of older studies, especially from Russia, postulated that fields from mobile phones could have negative effects on the immune system (see Poulletier de Gannes et al. 2009). Recent experiments using modern experimental approaches have not been able to confirm these suppositions. Long-term studies with laboratory rodents carried out in the DMF found no cases of such effects. Thus it is permissible to conclude in agreement with studies by other authors that mobile phone fields have no effect on the immune system.

The many investigations of effects on various blood parameters (e.g. reticulocytes, “money-roll effect”), allegedly found in comparisons before and after the construction of mobile phone base stations, have been described by the Robert Koch Institute as “speculative and not based on a validated diagnostic approach” (RKI 2006).

2.6 Does chronic exposure affect reproduction and development?

The results of a multi-generation study of laboratory rodents (SSK 2008) were already summarized in the 2008 statement by the SSK (SSK 2008).[45] The study, which observed reproductive processes and development in four successive generations of animals exposed throughout the experiment to high-frequency electromagnetic radiation, found no evidence of adverse effects. These findings have now been confirmed by a further DMF study. Comparable studies are lacking in the recent literature. Certain aspects of reproduction in laboratory animals exposed to fields, namely effects on sperm cells, were studied by Dasdag et al. (2008) and Yan et al. (2007). Whereas Dasdag et al. observed no effects, Yan et al. reported an increased sperm cell death rate at SARs of 1 W/kg. Both studies, however, had inadequate exposure setups and deficiencies in dosimetry. Hence no definitive conclusions can be drawn from them.

According to the findings of DMF studies, it is highly improbable that exposure to mobile phones below the exposure limits can have adverse effects on reproduction and development. The SSK sees at present no need for further research in this area.

2.7 What levels of exposure are caused by wireless technologies?

In the context of the DMF, researchers developed and validated methods for measuring and calculating maximum and average levels of public exposure. They examined stationary transmission facilities (GSM and UMTS base stations, analogue and digital radio and television transmitters, WLAN access points and DECT base units) as well as mobile devices (GSM and UMTS mobile phones, WLAN and DECT handsets, UWB devices). Uniform measurement procedures are especially important in view of the need to compare different measurement series.

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[45] Research project B22: Long-term study on the effects of UMTS signals on laboratory rodents

The peak ambient exposure from *stationary transmission facilities* in areas accessible to the public was found to be only a few percent of the power density exposure limit. Often the levels were in the range of 0.1% or less of the limit. For mobile phone base stations and for radio and television transmitters, both analogue and digital, the distance from the transmitter was found to be unsuitable as a predictor of the actual exposure situation. Of much greater importance was the position of the measurement point in relation to the main beam and the question whether it was in the line of sight of the transmission facility.

In their study of numerical predictions of individual exposure, the researchers found that accuracy depended to a large extent on the quality and level of detail of the input parameters as well as the propagation model chosen. They developed a practicable computational procedure for determining SAR values in complex exposure scenarios, thus laying the groundwork for evaluating exposure to multiple sources at different distances from the user. They showed that simplified numerical methods of predicting ambient exposure in epidemiological studies were useful at best for making a basic division into exposed and non-exposed groups, even when the model included the position of the measurement point in relation to the main beam and the question of a line-of-sight connection. Moreover, even for this it was necessary to have input data of sufficient quality. Portable dosimeters, which make it possible to record individual exposure profiles, now offer a new way to measure exposure to high-frequency radiation. Their accuracy (including sensitivity, frequency selectivity and correction for shadowing by the bearer) must be improved, however. Reliable measurement methods for large-scale exposure studies exist only rudimentary at present. They must be refined and validated.

A project for determining ambient exposure before and after the change from analogue TV to DVB-T showed that the change to digital transmission technology did not always lead to reduced exposure and in some circumstances even increased it. Important factors to consider here are changes in installed transmit power and in network configuration.

For base stations, several numerical studies conducted outside of the DMF have shown that in worst-case conditions basic restrictions (whole-body-averaged SARs) can be exceeded in children and small persons shorter than 1.5 m in the case of whole-body exposures at the reference levels. These effects were observed at frequencies of about 100 MHz and in the range of 1-4 GHz (Dimbylow and Bolch 2007, Conil et al. 2008, Kuehn et al. 2009, Christ et al. 2011). A study using anatomically correct numerical models of children and taking age-dependent tissue parameters into account (Christ et al. 2011) found that basic restrictions were exceeded by 30% at 100 MHz and by more than 50% between 1.5 and 4 GHz. These results showed that the assumed relationship between basic restrictions and reference levels in these frequency ranges is inconsistent.

For *wireless devices,* dosimetric studies have shown that when used close to the body they cause much higher exposures than do stationary transmission facilities. Reference levels can be exceeded for some mobile phones and babyphones used near the body, but here too the exposures are below the basic restrictions. It must be emphasized, however, that the SSK does not consider it acceptable that the emission of a single source is permitted to use up the exposure limit to its full extent (SSK 2007b).

Power control in mobile phones can generally reduce exposures below the SAR values measured according to the relevant standards. The power level depends on the network structure and network operator, and can be restricted by the operator. By optimizing handsets, in particular by changing the antenna position, SARs can be considerably reduced without impairing transmission quality. Studies in partially shielded rooms such as cars and trains have shown that mobile phones can produce SARs in nearby non-users that are as much as 10 times those of outdoors. Even with this additional exposure, however, the total level remains very low. These findings refute studies which, based on simplified theoretical considerations, have reported exposures exceeding the limits in partially shielded rooms. Increases in SAR can occur only if a mobile phone is used near reflecting metal structures, in which case the exposure can be up to 50% higher than otherwise.

Estimates of exposure in epidemiological studies of mobile phone use have large uncertainties, especially when made retrospectively. One project in the INTERPHONE study developed a model that permitted individual estimates of cumulative absorbed energy at the tumour location. Owing to the many uncertain factors, however, it is hard to say how reliable these calculations are. The problem of retrospective estimation of exposure remains open.

With the introduction of new wireless technologies it will be necessary to monitor changes in ambient exposure and usage scenarios. This will permit information on technology and exposure to be included in risk assessments at an early date. The assessments will have to include simultaneous exposure to several sources, because no single source should reach the exposure limit (SSK 2007b). One important challenge will be to adapt measurement technologies and methods to the ever-higher frequencies (e.g. terahertz technologies) and broader bands (e.g. UWB technology and LTE-Advanced) that future wireless services will use.

For exposure levels in the far fields of transmission facilities there is no consensus on which quantity (spatial average or peak) should be used for determining compliance with guidelines. The point raster method, which measures reference levels on a grid representing the exposed person with subsequent averaging of exposure, is preferred in many current emission measurement standards. However, under certain circumstances (multi-path propagation) this method can underestimate the actual exposure situation in the far field of a transmission facility (Kuehn et al. 2009). For this reason the sweeping method is recommended for determining the local peak.

The SSK calls attention to the finding in dosimetric studies of children and persons shorter than 1.5 m that there is an inconsistency in the assumed relationship between basic restrictions and reference levels at frequencies of about 100 MHz and from 1-4 GHz. One can therefore no longer assume that compliance with reference levels will also ensure compliance with basic restrictions.

Recent investigations (Li et al. 2010) have shown that a phone user's hand may increase the SAR in the head over the SAR where no hand is present. Further studies are necessary here, because the standardized SAR measurement at the head specified by DIN EN 62209-1 currently does not take the hand into account.

2.8 Are children subjected to increased health risks?

Children differ from adults in the fact that they will potentially spend a greater portion of their lives using mobile phones or other means of mobile communication. In addition, it is thought that they are more vulnerable because their nervous system is still developing, their brain tissue is more conductive and they have greater specific absorption rates. One basic problem in assessing possible health risks in children is that the term "child" is used in different ways. Depending on the study in question, a child can be anyone up to the age of 18, although morphological and physiological differences between the first years of life and the end of puberty do not justify lumping them together.

The SSK published a statement on mobile communications and children as early as 2006 (SSK 2006). It summarized the results as follows:

1. *The scientific studies published to date show that head absorption rates are higher in children than in adults but that the differences rapidly decrease after the first years of life. The differences between 5-year-olds and adults are already smaller than interpersonal variations. Studies of younger children are not yet available.*

2. *The few studies of children age 5 and older show no reliable evidence of increased sensitivity among children and adolescents.*

3. *The current epidemiological literature contains no reliable data showing adverse health effects from long-lasting exposure to fields from mobile communications. There are no special studies of children.*

4. *There are no scientific studies to date on the possible effects of fields from mobile communications on the physical or mental development of children and adolescents. No evidence has been found of effects on cognitive functions in children or adults.*

Several projects supported by the DMF have investigated these issues. One case-control study[46] looked for possible relationships between childhood leukaemia and exposure to electromagnetic fields from radio and television transmitters. This study, as well as a pooled analysis with a South Korean study carried out at nearly the same time, found no evidence of an additional leukaemia risk in children from these sources. The South Korean study investigated both leukaemia and brain tumours in children below the age of 15. For neither of these endpoints did it find a statistical connection with exposure to electromagnetic fields

[46] Research project E5: Epidemiological study on childhood cancer and proximity to radio and television transmitters

from radio and television transmitters (Ha et al. 2007). A case-control study encompassing all registered cases of cancer in children aged 0-4 in Great Britain in 1999-2001 found no relationship between the risk of cancer in early childhood and estimated levels of maternal exposure to base stations during pregnancy (Elliott et al. 2010) (see also section 2.1). None of the studies of children and adolescents carried out to date have found a relationship between mobile communication fields and a risk of cancer.

Links between health problems or non-specific health symptoms and the use of mobile communications were reported in several epidemiological studies of young people (Punamäki et al. 2007, Söderquist et al. 2008, Koivusilta et al. 2005), but they used questionable methods (self-reported exposure data). A DMF-supported project[47] therefore investigated potential acute health effects from mobile communications (mobile phones, base stations, WLAN) in children and adolescents. This epidemiological cross-sectional study was the first to use personal dosimeters for recording individual daily exposures over 24 hours. The design of the dosimeter did not permit measurements during night rest, however. Thus the representativeness of the results was limited. In general, the exposure to fields from mobile communications was low. There were no consistent indications of links between exposure (current morning or afternoon exposure or total exposure during waking hours as an average percent of the limit value) and self-reported health and behaviour parameters (current, noon/evening, chronic). With its improved methodology, this investigation significantly weakened the evidence of a relationship between health effects in children and adolescents and exposure to fields from mobile communications.

Thomas et al. (2010) performed a supplementary evaluation of the questionnaire data on individual weaknesses and strengths from this DMF study. They found that for the adolescents (but not the children) with the highest EMF exposures (top quartile) there was a link between the total questionnaire score and exposure. This relationship was particularly visible in the adolescents’ answers to questions about behavioural problems. For children the link to EMF exposure was significant only for this special group of questions and was no longer significant in the total score. However, it remains unclear whether the higher exposure was the cause of the reported behavioural problems or whether the problems led to increased mobile phone use. This was only a first study on possible links between exposure to electromagnetic fields and mental health, and it brought some surprising findings to light using data that were not easily reproducible. Thus further confirmatory studies are necessary. These should be designed to facilitate verification. In addition, they should be based on sample size considerations and permit individual dosimetry.

A simple-blind study of auditory evoked potentials in children (Kwon et al. 2010a) found no effects by electromagnetic fields from mobile phones.

A number of studies are currently being carried out on potentially increased health risks for children. An international case-control study of 352 children and adolescents (age 7–19) with brain tumours and 642 controls (CEFALO) found no evidence of an association between

[47] Research project E9: Acute health effects by mobile telecommunication among children

mobile phone use and incidence of brain tumours (Aydin et al. 2011). Regular users of mobile phones showed no increased risk of brain tumours compared to non-regular users (OR = 1.36; 95% CI: 0.92 – 2.02). In addition, there was no evidence of a greater risk of brain tumours in the regions with the highest exposure levels. In 2010, collection of data began for an additional international case-control study on the relationship between the incidence of brain tumours and the use of communication devices, including mobile phones, by young people age 10 to 24 (MOBI-KIDS 2011). A total of 2,000 patients with brain tumours from 13 countries, including Germany, will be studied along with a control group of equal size.

A multi-generation study of mice found no effects on fertility, development and several behavioural parameters in juvenile animals from different exposures (0, 0.08, 0.4 and 1.3 W/kg whole-body SAR, 24 h/day, UMTS) (Sommer et al. 2010).

One important question from a dosimetric point of view is whether children are more strongly affected by high-frequency fields from mobile communications than adults. Base stations as well as mobile phones must be included in the discussion.

For base stations, several numerical studies conducted outside of the DMF have shown that in worst-case conditions basic restrictions (whole-body-averaged SARs) can be exceeded in children and small persons shorter than 1.5 m in the case of whole-body exposures at the reference levels. These effects were observed at frequencies of about 100 MHz and in the range of 1-4 GHz (Dimbylow and Bolch 2007, Conil et al. 2008, Kuehn et al. 2009, Christ et al. 2011). A study using anatomically correct numerical models of children and taking age-dependent tissue parameters into account (Christ et al. 2011) found that basic restrictions were exceeded by 30% at 100 MHz and by more than 50% between 1.5 and 4 GHz. These results showed that the assumed relationship between basic restrictions and reference levels in these frequency ranges is inconsistent.

For mobile phones many numerical SAR studies of exposure have been published in recent years, some of them controversial. They investigated possible differences in energy absorption as a function of head size, anatomy, thickness of the pinnae and dielectric properties of head tissue. Whereas some studies reported a significant increase in peak SAR averaged over 10 g of tissue in children’s heads, others were not able to reproduce these results. Earlier studies had based their head models of children on linearly scaled down models of adults. In contrast, current studies use refined models based on MR images. The DMF study B17[48] also took account of possible differences in the thickness of pinnae and in head tissue parameters in its investigations of absorption rates. No characteristic differences between adults and 6- to 8-year-old children in the thickness of the pinnae were found that could affect SARs. Data for younger children are not available. With the exception of bone marrow, no systematic influence of the tissue parameters age dependency on the local exposure was found. In measurements of peak 10 g SARs no characteristic differences were found between the child models studied (ages 3, 6 and 11) and the adult model, taking

48 Research project B17: Investigation of age dependent effects of high frequency electromagnetic fields based on relevant biophysical and biological parameters

individual differences between different adult models (factor 2) into account. In regard to local SAR distribution (i.e., without 10 g averaging) differences were found between children and adults. In children exposure in some tissues and organs (such as the eye) was higher owing to the shorter distance from the mobile phone. In contrast, other areas of the head had lower exposure in children than in adults. These results must be taken into account when interpreting epidemiological and experimental studies of children.

The laboratory studies of humans and animals carried out to date do not support the hypothesis of a postulated higher sensitivity in children and adolescents, nor do epidemiological studies. The SSK calls attention to the finding in dosimetric studies of children that there is an inconsistency in the assumed relationship between basic restrictions and reference levels at frequencies of about 100 MHz and from 1-4 GHz. One can therefore no longer assume that compliance with reference levels will also ensure compliance with basic restrictions. Dosimetric studies of head exposure in children to mobile phones have shown quantitative differences from adults in SAR distribution. The relevance of these results to health remains to be studied.

The WHO has given high priority to studies of children and adolescents, including children in the early and juvenile development phases. This applies to epidemiological studies (prospective cohort studies), studies of humans (provocation studies) and studies of animals (WHO 2010, van Deventer et al. 2011). These recommendations have already given rise to a number of multinational and national studies. The SSK therefore sees no need at present for additional research, especially since the available findings have not confirmed the originally expressed fears (Kheifets et al. 2005) of increased sensitivity in children.

2.9 How are the risks of electromagnetic fields perceived, and how can risk communication be improved?

Studies on risk perception have shown that anxiety and fear with regard to mobile telecommunications are not linked to the extent of network expansion activities, and apparently they are only loosely linked to the extent and content of media reporting on mobile telecommunications. Public concern about base stations clearly exceeds concern about mobile phones. Mobile communications have not created the same degree of concern as other risks (e.g. air pollution or UV radiation). These facts, which were ascertained in the surveys carried out from 2003 to 2006, remain basically unchanged. A 2006 Eurobarometer survey additionally showed that concern about mobile communications is significantly lower in Germany than the EU average (Eurobarometer 2007). This was confirmed by the Eurobarometer survey in 2010 (Eurobarometer 2010). In fact, the survey showed that concern in Germany decreased by 6 percentage points from the level in 2006 (the average decline in the EU was 2 percentage points). Although these results indicate a fairly stable level of mobile phone risk perception in Germany, little is known about how individual perceptions of mobile phone risk may vary over time. The World Health Organization called attention to this in its most recent research agenda for radiofrequency fields (WHO 2010, van Deventer et al.

2011) and therefore recommended studies of changing patterns in risk perception over time and the factors affecting them.

The DMF's contribution to knowledge about effective forms of risk communication is rather small compared to its contributions on risk perception. This applies to information on the effects of electromagnetic fields and to information on precautions and uncertainty. It also applies in part to conflict management. There is very little robust knowledge in this field. The WHO research agenda accordingly calls for the development of new tools for communicating information on the health effects of electromagnetic fields and for empirical evaluation of their effectiveness (WHO 2010, van Deventer et al. 2011). Risk communication tools such as the EMF Portal (EMF Portal), the Internet-based decision support system[49] and the Mobile Telecommunication Research Programme itself are key elements of risk communication. But as useful as these elements may seem, their specific value must be verified through rigorous evaluation.

3 Conclusions and outlook

The German Mobile Telecommunication Research Programme has significantly improved the scientific basis for health risk assessment of exposure to electromagnetic fields from mobile telecommunications. In doing so it has also contributed to better risk communication.

The findings of the DMF have not confirmed the health risks that were initially feared to exist. Nor have these findings led to any indications of previously unanticipated health impacts. In agreement with other international bodies (ICNIRP 2009, WHO 2011) we can state that the protection concepts underlying the present safety limits are still sound.

In regard to radiation protection, however, the research projects did not provide conclusive answers to all of the questions pertaining to biological and medical effects of electromagnetic fields from mobile telecommunications. Thus, even if the initial indications of potential health effects were not confirmed, further research remains necessary. Moreover, in view of the dynamic development of new wireless technologies, the exploitation of new frequencies and the use of new forms of transmission, it will be necessary to perform further research, monitor ambient levels and evaluate EMF exposures.

The answers to the questions originally posed by the German Mobile Telecommunication Research Programme can be summarized as follows, taking the current international state of knowledge into account.

- *Cancer:* The studies carried out in the DMF have found no evidence that electromagnetic fields can initiate or promote cancer. Thus they are in agreement with most published studies and have provided important additional information. Taken together, they do not

[49] Research project R6: Innovative procedures for setting disputes with respect to the siting of mobile phone transmitters

give sufficient evidence that mobile phone exposure can cause cancer (SSK 2011). With this assessment the SSK differs from the International Agency for Research on Cancer (IARC), which in its session of May 2011 classified radiofrequency electromagnetic fields (RF-EMF) as "possibly carcinogenic to humans" (Group 2B) (Baan et al. 2011). At present there is no immediate need for additional research in epidemiology, as the results of ongoing studies (COSMOS, MOBI-KIDS) are still being awaited. What is needed is a comprehensive study of possible genotoxic effects employing as many of the available tests as possible (Albertini et al. 2000, Brendler-Schwaab et al. 2004). Here it is important to ensure high standards of quality assurance and quality control. The multi-centre studies carried out in the past did not always do so because they were limited to small numbers of experimental endpoints (PERFORM-B [Stronati et al. 2006], REFLEX [EU 2004]). This applies to the projects supported by the DMF[50,51] as well. The SSK recommends that future EMF research rely more on studies designed to test hypotheses. Hypotheses about effects should be investigated in connection with basic research, taking established knowledge of radiation biology into account.

- *Blood-brain barrier (BBB):* The projects supported by the DMF did not find any effects on the BBB, even though they used new methodological approaches. In summary, there is not sufficient evidence that exposure to mobile phone fields below the exposure limits can affect the blood-brain barrier. Further research on this topic is therefore not required.

- *Neurophysiological and cognitive processes, sleep:* Using a variety of methods, the studies largely ruled out effects by mobile phone fields on visual and auditory acuity; in particular, they found no evidence that EMF exposure could cause tinnitus. Effects on sleep behaviour were found neither in epidemiological studies nor in field studies. Laboratory studies of effects on brain activity during sleep yielded inconsistent results. At present it is not possible to make a final statement about effects on sleep EEG and resting EEG in the waking state. What is needed is a multi-centre study in which working groups from different laboratories use a common experimental approach to investigate a single issue. Such a study should include not only children, adolescents and young adults, but also older persons who might be more vulnerable to high-frequency electromagnetic fields owing to age-related morphological and functional changes in the brain. The results would also have a bearing on studies of possible effects by electromagnetic fields on pathological age-related changes in the brain (neurodegenerative diseases), a high-priority area of research for the WHO (2010, Deventer et al. 2011).

- *Electrosensitivity and non-specific health symptoms:* In agreement with the international literature it can be concluded that "electrosensitivity", understood as a direct effect of EMF exposure, most likely does not exist. Further research on this topic should therefore be carried out beyond the sphere of EMF research.

[50] Research project B16: Possible genotoxic effects of GSM signals on isolated human blood
[51] Research project B21: Influence of GSM signals on isolated human blood. B. Differential gene expression

- *Blood and immune system:* The results of the DMF permit the conclusion, in agreement with studies by other authors, that mobile phone fields have no effect on the immune system. Effects on various blood parameters (e.g. reticulocytes, “money-roll effect”), allegedly found in comparisons before and after the construction of mobile phone base stations, are speculative and not based on a validated diagnostic approach.

- *Reproduction and development:* According to the findings of DMF studies, it is highly improbable that exposure to mobile phones below the exposure limits can have adverse effects on reproduction and development. The SSK sees no need at present for further research in this area.

- *Exposure caused by wireless technologies:* The ambient exposure from stationary transmission facilities in areas accessible to the public was generally found to be about 0.1% of the power density limit or less, with peaks of a few percent. Handsets held close to the body or in contact with it were shown to produce much higher exposures, sometimes amounting to a large percentage of the basic restriction. There is a need for research to develop reliable methods for measuring exposure in epidemiological studies; in studies of stationary transmission facilities distance is not a reliable means of estimating exposure. Changes in ambient exposure and usage scenarios must be monitored when new wireless technologies are introduced. The SSK calls attention to the finding in dosimetric studies of children and persons shorter than 1.5 m that there is an inconsistency in the assumed relationship between basic restrictions and reference levels at frequencies of about 100 MHz and from 1-4 GHz. One can therefore no longer assume that compliance with reference levels will also ensure compliance with basic restrictions.

- *Mobile phones and children:* Epidemiological studies have significantly reduced the evidence of a link between health effects in children and adolescents and exposure to fields from mobile communications. Multi-generation studies of animals were unable to show effects from exposure to mobile phones. The studies carried out to date give no support to the hypothesis of a postulated higher sensitivity in children and adolescents. The SSK calls attention to the finding in dosimetric studies of children that there is an inconsistency in the assumed relationship between basic restrictions and reference levels at frequencies of about 100 MHz and from 1-4 GHz. One can therefore no longer assume that compliance with reference levels will also ensure compliance with basic restrictions. Calculations of head exposure in children to mobile phones have shown quantitative differences from adults in SAR distribution. The relevance of these results to health remains to be studied. At present, the SSK sees no need for research beyond the investigations of children and adolescents that have been initiated in response to the WHO recommendations (WHO 2010).

- *Risk perception and risk communication:* The frequency of anxiety and fears with regard to mobile telecommunications is not linked to the extent of network expansion activities, and it is only loosely linked to the extent and content of media reporting. Public concern about mobile phone base stations clearly exceeds that about mobile phones. Mobile telecommunications are not a first-order concern, however. Knowledge about effective forms of risk communication is currently rather scanty. New tools for this purpose must be developed and empirically evaluated for effectiveness.

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Table of acronyms and abbreviations

AM	Amplitude modulation
BBB	Blood-brain barrier
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)
CEFALO	An international case-control study on brain tumours in children and adolescents
CNS	Central nervous system
CNV	Contingent negative variation
COSMOS study	International cohort study on mobile phone use and health
DECT	Digital Enhanced Cordless Telecommunications
DMF	German Mobile Telecommunication Research Programme (Deutsches Mobilfunk-Forschungsprogramm)
DNA	Deoxyribonucleic acid
DTX	Discontinuous Transmission
DVB-T	Digital Video Broadcasting-Terrestrial
EEG	Electroencephalogram
EFHRAN	European Health Risk Assessment Network on Electromagnetic Fields Exposure
EHS	Electromagnetic hypersensitivity
ELF	Extremely low frequency
EMF	Electromagnetic field
FDTD	Finite-difference time-domain
GSM	Global System for Mobile Communications
HF	High-frequency
HSP	Heat shock proteins

Hz	Hertz (unit of frequency)
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEI-EMF	Idiopathic environmental intolerance attributed to electromagnetic fields
INTERPHONE study	International case-control studies of the brain tumour risk associated with mobile phone use
LTD	Long-term depression
LTE	Long-term evolution
LTP	Long-term potentiation
MOBI-KIDS	Study on communication technology, environment and brain tumours in young people
NREM2	Non rapid eye movement sleep, stage 2
PCMCIA	Personal Computer Memory Card International Association
PERFORM-B	*In-vitro* and *in-vivo* Replication Studies Related to Mobile Telephones and Base Stations
PHA	Phytohaemagglutinin
REFLEX	Risk Evaluation of Potential Environmental Hazards From Low Energy Electromagnetic Field Exposure Using Sensitive *in vitro* Methods
RF	Radio frequency
RP	Readiness potential
RT-PCR	Real-time polymerase chain reaction
SAR	Specific absorption rate
SCE	Sister chromatid exchange
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SSK	German Commission on Radiological Protection (Deutsche Strahlenschutzkommission)
SSM	Strål Säkerhets Myndigheten (Swedish Radiation Safety Authority)
TETRA	Terrestrial Trunked Radio

UMTS	Universal Mobile Telecommunications System
UWB	Ultra-Wideband
VMT	Visual Monitoring Task
W	Watt (unit of electric power)
WHO	World Health Organization
WLAN	Wireless Local Area Network

List of DMF research projects (as at 18 July 2011)

	BIOLOGY
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
B8	Influence of electromagnetic fields of mobile telecommunications on the metabolic rate in rodents
B9	In vivo experiments on exposure to the high frequency fields of mobile telecommunication. A. Long-term study
B10	In vitro experiments on exposure to the high frequency fields of mobile telecommunication. C. Blood-brain barrier
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
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
B14	Investigation of the phenomenon of “electromagnetic hypersensitivity” using an epidemiological study on “electrosensitive” patients including the determination of clinical parameters
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)
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

	B I O L O G Y
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
B22	Long-term study on the effects of UMTS signals on laboratory rodents
	D O S I M E T R Y
D1	Investigation of SAR distribution in laboratory animals exposed to electromagnetic fields
D2	Determination of the real field distribution of high frequency electromagnetic fields near wireless LAN installations (WLAN) in inner cities
D3	Determination of the real field distribution from high frequency electromagnetic fields near UMTS transmitters
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 exposure to the population living near digital radio and television transmitters
D11	Determination of the real exposure from using mobile phones in partly shielded rooms as compared to exposure under optimal conditions outdoors
D12	Development of a practicable computational procedure for the determination of the actual exposure in complex exposure scenarios with several different RF-sources
D13	Investigation of the question, if macroscopic dielectric properties of tissues have unlimited validity at both cellular and subcellular levels
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
D15	Determination of exposure due to ultra-wideband technologies
	E P I D E M I O L O G Y
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	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)
E5	Epidemiological study on childhood cancer and proximity to radio and television transmitters
E6	Addendum to the cross-sectional study on acute health effects caused by fields of

	B I O L O G Y
	mobile phone base stations
E7	Estimation of RF-exposure in INTERPHONE Study subjects
E8	Cross-sectional study to record and evaluate possible adverse health effects due to electromagnetic fields from cell-phone base stations
E9	Acute health effects by mobile telecommunication among children
E10	Validation of the exposure surrogate of the cross-sectional study on base stations
	R I S K C O M M U N I C A T I O N
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 procedures for setting disputes with respect to the siting of mobile phone transmitters
R7	Support of the co-operation between the mobile telecommunication actors by the Local Agenda 21

List of DMF publications

(Bfs, as at May 2011)

1. **Peer-reviewed journals**

Project	Article
	Biology
B1	Sukhotina I, Streckert J R, Bitz A K, Hansen V W, Lerchl A: 1800 MHz electromagnetic field effects on melatonin release from isolated pineal glands, J. Pineal Res. 2006, 40:86-91
B3	Sommer A M, Lerchl A: The risk of lymphoma in AKR/J mice does not rise with chronic exposure to 50 Hz magnetic fields (1 µT and 100 µT), Radiation Research 2004, 162:194-200
B3	Sommer A M, Streckert J, Bitz A K, Hansen V, Lerchl A: No effects of GSM-modulated 900 MHz electromagnetic fields on survival rate and spontaneous development of lymphoma in female AKR/J mice, BMC Cancer 2004, 4:77
B3	Sommer A M, Lerchl A: 50 Hz magnetic fields of 1mT do not promote lymphoma development in AKR/J mice, Radiation Research 2006, 165:343-349
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B5	Leitgeb N, Schröttner J, Cech R, Kerbl R: EMF-protection sleep study near mobile phone base stations. Somnologie 2008, 12:234-243
B6	Simeonova M, Gimsa J: Dielectric anisotropy, volume potential anomalies and the persistent Maxwellian equivalent body. J. Phys.: Condens. Matter 2005, 17(50):7817-7831
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B6	Gimsa U, Schreiber U, Habel B, Flehr J, van Rienen U, Gimsa J: Matching geometry and stimulation parameters of electrodes for deep brain stimulation experiments – Numerical considerations. J. Neurosci. Meth. 2006, 150:212-227
B6	Gimsa U, Iglic A, Fiedler S, Zwanzig M, Kralj-Iglic V, Jonas L, Gimsa J: Actin is not required for nanotubular protrusions of primary astrocytes grown on metal nano-lawn. Mol. Mem. Biol. 2007, 24:243-255

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B14	Hauser S, Frick U, Eichhammer P, Rehm J: Cognitive factors influencing symptom report on complaints allegedly related to electromagnetic fields: research strategies and results. In: C. del Pozo, D.Papameleti, P. Wiedemann, & P.Ravazzani (Eds.) Risk Perception and Risk Communication in EMF: Tools, Experiences and Strategies. Proceedings JRC/EIS-EMF Workshop, Ispra 13th July 2004. (pp. 66-75). Brussels: European Commission Directorate General Joint Research Centre, Institute for Consumer Health and Protection, 2006
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B19	Danker-Hopfe H, Dorn H, Bahr A, Anderer P, Sauter C: Effects of electromagnetic fields emitted by mobile phones (GSM 900 and WCDMA/UMTS) on the macrostructure of sleep. J. Sleep Res. 2011, 20:73-81
B19	Sauter C, Dorn H, Bahr A, Hansen M-L, Peter A, Bajbouj M, Danker-Hopfe H: Effects of exposure to electromagnetic fields emitted by GSM 900 and WCDMA mobile phones on cognitive function in young male subjects. Bioelectromagnetics 2011, 32:179-190
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B3 B4 22	Reinhardt T, Bitz A, El Ouardi A, Streckert J, Sommer A, Lerchl A, Hansen V: Exposure set-ups for in vivo experiments using radial waveguides, Radiation Protection Dosimetry 2007, 124:21-26
B9	Tejero S, Schelkshorn S, Detlefsen J: Concept for the controlled plane wave exposure for animal experiments using a parabolic reflector, Advances in Radio Science 2005, 3:233-238
B9	Schelkshorn S, Tejero S, Detlefsen J: Exposure setup for animal experiments using a parabolic reflector, Radiation Protection Dosimetry 2007, 124:27-30
B12	Ahlers M T, Bolz T, Bahr A, Ammermüller J: Temperature-controlled exposure systems for investigating possible changes of retinal ganglion cell activity in response to high-frequency electromagnetic fields. Radiat Environ Biophys 2009, 48:227-35
B12	Mann S: Rapporteur´s report, Radiation Protection Dosimetry 2007, 124:2-5
B12	The editors German Mobile Telecommunication Research Programme International Workshop on Final Results of Dosimetry Projects, Radiation Protection Dosimetry 2007, 124:1
B19	Bahr A, Dorn H, Bolz T: Dosimetric Assessment of an Exposure System for Simulating GSM and WCDMA Mobile Phone Usage, Bioelectromagnetics 2006, 27:320-327
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D4	Schmid G, Überbacher R, Samaras T, Jappel A, Baumgartner W-D, Tschabitscher M, Mazal P R: High-resolution numerical model of the middle and inner ear for a detailed analysis of radio frequency absorption. Phys. Med. Biol. 2007, 52:1771–1781
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D4	Schmid G, Uberbacher R, Samaras T, Tschabitscher M, Mazal P R: The dielectric properties of human pineal gland tissue and RF absorption due to wireless communication devices in the frequency range 400-1850 MHz, Phys Med Biol. 2007, 52:5457-68.

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D5	Christ A, Samaras T, Klingenböck A, Kuster N: Characterization of the electromagnetic near-field absorption in layered biological tissue in the frequency range from 30 MHz to 6000 MHz, Phys. Med. Biol. 2006, 51:4951-4965.
D5	Samaras T, Christ A, Klingenböck A, Kuster N: Worst-case temperature rise in a one-dimensional tissue model exposed to radiofrequency radiation", IEEE Transactions on Biomedical Engineering 2007, 54:492-496
D5	Christ A, Samaras T, Neufeld E, Klingenböck A, Kuster N: SAR Distribution in human beings when using body-worn RF transmitters, Radiation Protection Dosimetry 2007, 124:6-14
D6 D3	Bornkessel C, Schubert M, Wuschek M, Schmidt P: Determination of the general public exposure around GSM and UMTS base stations, Radiation Protection Dosimetry 2007, 124:40-47
D7	Neitzke H P, Osterhoff J, Peklo K, Voigt H: Determination of exposure due to mobile phone base stations in an epidemiological study, Radiat Prot Dosimetry 2007, 124:35-39
D7	Breckenkamp J, Neitzke H P, Bornkessel C, Berg-Beckhoff G: Applicability of an Exposure Model for the Determination of Emissions from Mobile Phone Base Stations, Radiation Protection Dosimetry 2008, 131:474–481
D8	Schmid G, Lager D, Preiner P, Überbacher R, Cecil S: Exposure caused by wireless technologies used for short-range indoor communication in homes and offices, Radiation Protection Dosimetry 2007, 124:58-62
D9	Baumann J, Landstorfer F M, Geisbusch L, Georg R: Evaluation of radiation exposure by UMTS mobile phones. Electronics Letters 2006, 42:225-226
D10	Schubert M, Bornkessel C, Wuschek M, Schmidt P: Exposure of the general public to digital broadcast transmitters compared to analogue ones, Radiation Protection Dosimetry 2007, 124:53-57
D13	Gulich R, Köhler M, Lunkenheimer P, Loidl A: Dielectric spectroscopy on aqueous electrolytic solutions. Radiat Environ Biophys. 2008, 48:107-114
E9	Radon K, Spegel H, Meyer N, Klein J, Brix J, Wiedenhofer A, Eder H, Praml G, Schulze A, Ehrenstein V, von Kries R, Nowak D: Personal Dosimetry of Exposure to Mobile Telephone Base Stations? An Epidemiologic Feasibility Study Comparing the Maschek Dosimeter Prototype and the Antennessa DSP-090 System, Bioelectromagnetics 2006, 27:77-81
Epidemiology	
E1	Berg G, Breckenkamp J, Blettner M.: Gesundheitliche Auswirkungen hochfrequenter Strahlenexposition, Dt. Ärzteblatt 2003, 42:A 2738
E1	Breckenkamp J, Berg G, Blettner M: Biological effects on human health due to radiofrequency/microwave exposure: a synopsis of cohort studies. Radiat Environ Biophys. 2003, 42(3):141-154
E1	Breckenkamp J, Berg-Beckhoff G, Münster E, Schüz J, Schlehofer B, Wahrendorf J, Blettner M: Feasibility of a cohort study on health risks caused by occupational exposure to radiofrequency electromagnetic fields. Environ Health. 2009, 29(8):23
E2	Schmidt-Pokrzywniak A, Jöckel K H, Bornfeld N, Stang A: Case-control study on uveal melanoma (RIFA): Rational and design, BMC Ophthalmology 2004, 4:1-9
E2	Stang A, Schmidt-Pokrzywniak A, Lehnert M, Parkin D M, Ferlay J, Bornfeld N, Marr A, Jöckel K H: Population-based incidence estimates of uveal melanoma in Germany: Supplementing cancer registry data by case-control data. Eur J Cancer Prev. 2006, 15:165-170

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E2	Stang A, Schmidt-Pokrzywniak A, Lash TL, Lommatzsch PK, Taubert G, Bornfeld N, Jöckel KH: Mobile phone use and risk of uveal melanoma: results of the risk factors for uveal melanoma case-control study. J Natl Cancer Inst. 2009, 101(2):120-123
E4	Schüz J, Böhler E, Berg G, Schlehofer B, Hettinger I, Schlaefer K, Wahrendorf J, Kunna-Grass K, Blettner M: Cellular Phones, Cordless Phones, and the Risks of Glioma and Meningioma (Interphone Study Group, Germany), Am. J. Epidemiol. 2006, 63:512-520
E4	Schüz J, Böhler E, Schlehofer B, Berg G, Schlaefer K, Hettinger I, Kunna-Grass K, Wahrendorf J, Blettner M: Radio frequency electromagnetic fields emitted of DECT cordless phones and risk of glioma and meningioma (Interphone study group, Germany), Radiat. Res. 2006, 166:116-119
E4	Berg G, Spallek J, Schlehofer B, Böhler E, Schlaefer K, Hettinger I, Kunna-Grass K, Wahrendorf J, Blettner M: Occupational exposure to radio frequency/microwave radiation and the risk of brain tumors: Interphone Study Group, Germany. Am. J. Epidemiol 2006, 164:538-548.
E4	Breckenkamp J, Berg G, Blettner M: Biological effects on human health due to radiofrequency/microwave exposure: a synopsis of cohort studies. Radiat Environ Biophys 2003, 42:141-154
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E5	Merzenich H, Schmiedel S, Bennack S, Brüggemeyer H, Phillipp J, Spix C, Blettner M, Schüz J: Leukämie bei Kindern in der Umgebung von Sendestationen des Rundfunks – Anforderungen an das Studiendesign. Umweltmed Forsch Prax 2007, 12:213-223
E5	Heinrich S, Thomas S, Heumann C, von Kries R, Radon K: Association between exposure to radiofrequency electromagnetic fields assessed by dosimetry and acute symptoms in children and adolescents: a population based cross-sectional study, Environ Health 2010, 9:75
E5	Schmiedel S, Brüggemeyer H, Philipp J, Wendler J, Merzenich H, Schüz J: An evaluation of exposure metrics in an epidemiologic study on radio and television broadcast transmitters and the risk of childhood leukemia. Bioelectromagnetics. 2009, 30(2):81-91
E5	Merzenich H, Schmiedel S, Bennack S, Brüggemeyer H, Philipp J, Blettner M, Schüz J: Childhood leukemia in relation to radio frequency electromagnetic fields in the vicinity of TV and radio broadcast transmitters. Am J Epidemiol. 2008, 168(10):1169-1178
E8	Berg-Beckhoff G, Blettner M, Kowall B, Breckenkamp J, Schlehofer B, Schmiedel S, Bornkessel C, Reis U, Potthoff P, Schüz J: Mobile phone base stations and adverse health effects: phase 2 of a cross-sectional study with measured radio frequency electromagnetic fields. Occup Environ Med. 2009, 66(2):124-130
E8	Blettner M, Schlehofer B, Breckenkamp J, Kowall B, Schmiedel S, Reis U, Potthoff P, Schüz J, Berg-Beckhoff G: Mobile phone base stations and adverse health effects: phase 1 of a population-based, cross-sectional study in Germany. Occup Environ Med. 2009, 66(2):118-123
E9	Heinrich S, Thomas S, Heumann C, von Kries R, Radon K: The impact of exposure to radio frequency electromagnetic fields on chronic well-being in young people – a cross-sectional study based on personal dosimetry. Environ Int 2011, 37:26-30
E9	Heinrich S, Thomas S, Heumann C, von Kries R, Radon K: Association between exposure to radiofrequency electromagnetic fields assessing dosimetry and acute symptoms in children and adolescents: a population based cross-sectional study. Environ Health 2010, 9:75
E9	Thomas S, Heinrich S, von Kries R, Radon K: Exposure to radio-frequency electromagnetic fields and behavioural problems in Bavarian children and adolescents. Eur J Epidemiol 2010, 25:135-141

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E9	Thomas S, Kühnlein A, Heinrich S, Praml G, von Kries R, Radon K: Exposure to mobile telecommunication networks assessed using personal dosimetry and well-being in children and adolescents: the German MobilEe-study. BioMed Central 2008, doi:10.1186/1476-069X-7-54
E9	Kühnlein A, Heumann C, Thomas S, Heinrich S, Radon K: Personal exposure to mobile communication networks and well-being in children – a statistical analysis based on functional approach. Bioelectromagnetics 2009, 30:261-269
E10	Bornkessel C, Blettner M, Breckenkamp J, Berg-Beckhoff G: Quality control for exposure assessment in epidemiological studies. Radiat Prot Dosimetry. 2010, 140(3):287-293
E10	Breckenkamp J, Neitzke HP, Bornkessel C, Berg-Beckhoff G: Applicability of an exposure model for the determination of emissions from mobile phone base stations. Radiat Prot Dosimetry. 2008, 131(4):474-481

2. Conference presentations

Project	Article
	Biology
B2	Schmid G, Pipal L, Widhalm K, Tschabitscher M: Feasibility and reasonable endpoints of investigations regarding a possibly higher RF-exposure risk for children, 27 Annual Meeting of the BEMS, 2005, Dublin, Ireland, Abstract Book p 543
B3	Sommer A M, A. Bitz J, Streckert V, Hansen V, Lerchl A: No effect from 900 MHz electromagnetic fields on the spontaneous development of lymphoma in female AKR/J Mice, 26 Annual Meeting of the BEMS, 2004, Washington DC, USA, Abstract Book p 258
B3	Lerchl A, Sommer A M: Consistent outcome of exposure of pre-leukaemic AKR/J mice to magnetic (50 Hz, 1, 100 and 1000 µTesla) and electromagnetic fields (900 MHz, 1966 MHz, 0.4 W/kg SAR), 8th Congress of the European Bioelectromagnetics Association, 2007, Bordeaux, Abstract S-7-5
B3	Sommer A M, Lerchl A, Bitz A, Streckert J, Hansen V: UMTS-modulated electromagnetic fields do not influence the development of lymphoma in female AKR/J mice, 27 Annual Meeting of the BEMS, 2005, Dublin, Ireland, Abstract Book p 177
B5	Leitgeb N: Subjective sleep impairment in the vicinity of mobile phone base stations, 8th International Congress of the European Bioelectromagnetics Association (EBEA), 2007, Bordeaux
B6	Haberland L, Simeonova M, Alsbach W, Brandt S, Dubois W: Analysis of literature (abstracts) on biological effects of EMF in the frequency range 2 – 3 GHz, 26 Annual Meeting of the BEMS, 2004, Washington DC, USA, Abstract Book p 28
B6	Sudsiri J, Wachner D, Gimsa J: Effect of temperature on the electrorotation behavior of human red blood cells: Implication for a transition in ion transport around 15°C, Annual Meeting of the BEMS, 2005, Dublin, Abstract Book
B6	Köster P, Scheinemann A, Baumann W, Glock H-W: A new exposure system for the in vitro detection of GHz field effects on neuronal networks, Joint Meeting Bioelectrochemistry, 2005, Coimbra
B7	Lantow M, Simkó M: 1800 MHz RF-EMF do not induce free radical production in different immune relevant cells, 26 Annual Meeting of the BEMS, 2004, Washington DC, USA, Abstract Book p 226
B7	Lantow M, Hartwig C, Maercker C, Simko M: Free radical production, Hsp70 expression and protein profiling after 1800 MHz RF exposure in different immune relevant cells, 27 Annual Meeting of the BEMS, 2005, Dublin, Ireland, Abstract Book p 126
B9	Bornhausen M, Stangassinger M, Erhard M, Stohrer M, Detlefsen J, Schelkdhorn S, Eberle J, Petrowicz O: Research project on the detection and analysis of alleged cognitive, biochemical and immunological consequences of chronic exposure of three generations of rats to electromagnetic GSM- and UMTS-fields of mobile communication, International Congress of the European Bioelectromagnetics Association (EBEA), 2003, Budapest, Hungaria, p 62
B9	Bornhausen M, Okorn S, Stangassinger M, Erhard M, Stohrer M, Detlefsen J, Schelkshorn S, Eberle J and Petrowicz O: Are there any health consequences of chronic exposure to GSM- or UMTS-fields? Research Project on eventual cognitive, immunological and blood-brain-barrier effects in three generations of rats, 26 Annual Meeting of the BEMS, 2004, Washington DC, USA, Abstract Book p 260
B10	Franke H, Streckert J, Bitz A, Hansen V, Young P: Differential gene expression at the RF-EMF exposed BBB in vitro, 28th BEMS Annual Meeting, 2006, Cancun, Mexico, 303-304
B10	Bitz A, Reinhardt T, El Ouardi A, Streckert J, Franke H, Zimmer J, Hansen V: Exposure of cell monolayers and hippocampal slice cultures inside radial waveguides, 28th BEMS Annual Meeting, 2006, Cancun, Mexico, 273-274

Project	Article
B12	Ahlers M T, Tillmans F, Deister F, Bolz T, Bahr A, Ammermüller J: Effects of GSM 900 electromagnetic field exposure on retinal ganglion cell responses, Meeting of the German Neuroscience Society, 2007, Göttingen
B12	Ahlers M T, Tillmans F, Bolz T, Bahr A, Friedl T, Ammermüller J: Effects of electromagnetic field exposure on retinal ganglion cell responses, European Retina Meeting 2007, Frankfurt, Germany
B14	Landgrebe M, Hauser S, Langguth B, Barta W, Rosengarth K, Greenlee M, Frick U, Hajak G, Eichhammer P: Dysfunctional cognitive strategies in subjectively electrosensitive patients – a fMRI study, 4th International Workshop on Biological Effects of EMFs, 2006, Crete, Greece.
B14	Frick U, Landgrebe M, Hauser S, Hajak G, Eichhammer P: Perceptive and motor response thresholds during single pulse transcranial magnetic stimulation of subjectively electrosensitive subjects as compared to controls – a replication study, 4th International Workshop on Biological Effects of EMFs, 2006, Crete, Greece.
B15	Billaudel B, Taxile M, Mayeur L, Ladeveze E, Laclau M, Haro E, Leveque P, Ruffie G, Poulletie de Gannes F, Lagroye I, Veyret B: Effects of a 4-week chronic head only exposure to GSM 1800 or UMTS signals on the brain of Wistar-HAN Rats, 8th Congress of the European Bioelectromagnetics Association, 2007, Bordeaux, Abstracts 127, p 43
B18	Münkner S, El Ouardi A, Streckert J, Hansen J, Engel J:(2007) Ionic currents through Ca2+ channels in mature mouse Inner Hair Cells under mobil phone field exposure, Meeting of the German Neuroscience Society, 2007, Göttingen
B19	Danker-Hopfe H, Dorn H: Dop GSM and/or UMTS electromagnetic fields have an effect on sleep? Abstracts 18th Cong. Europ. Sleep Soc, J. Sleep Res. 2006, 15 pp 1-253
B19	Danker-Hopfe H, Dorn H, Anderer P Do high frequency electromagnetic fields of the GSM and the UMTS standard for mobile communication affect sleep structure and/or sleep spindles? World Federation of Sleep Research and Sleep Medicine Societies, 2007, Cairns
B19	Danker-Hopfe H, Bahr A, Dorn H: Do high frequency electromagnetic fields of the GSM and/or the UMTS standard for mobile communication affect sleep? BEMS, 2007, Kanazawa, Japan
B19	Danker-Hopfe H, Dorn H: Laboratory study: Studies of the effects of exposure to electromagnetic fields emitted from mobile phones on volunteers, FGF Workshop: Sleep Disorders, EEG-Changes, Altered Cognitive Functions – Is There a Connection With the Exposure to Mobile Communication RF Fields? 2007, Stuttgart
B20	Dorn H, Danker-Hopfe H: Field Study: 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 FGF Workshop: Sleep Disorders, EEG-Changes, Altered Cognitive Functions – Is There a Connection With the Exposure to Mobile Communication RF Fields?, 2007, Stuttgart
Dosimetry	
B3	Bitz A K, Streckert J, Sommer A M, Lerchl A, Hansen V W: 2 GHz- exposure of non-restrained AKR/J mice in a slightly over-moded radial waveguide, 26 Annual Meeting of the BEMS, 2004, Washington DC, USA, Abstract Book p 139
B9	Tejero S, Schelkshorn S, Detlefsen J: Compact Setup for an Homogeneous Plan-Wave Exposure for In-Vivo Experiments, GeMiC German Microwave Conference, 2006, Karlsruhe, Germany
B9	Tejero S, Schelkskorn S, Detlefsen J, Okorn S, Bornhausen M, Petrowicz O: Setup for the controlled plane wave exposure at GSM and UMTS bands for in vivo experiments using a parabolic reflector, 27 Annual Meeting of the BEMS, 2005, Dublin, Ireland, Abstract Book p 483
B19	Bahr A, Dorn H, Bolz T: Exposure system for stimulating GSM and WCDMA mobile phone usage, 27 Annual Meeting of the BEMS, 2005, Dublin, Ireland, Abstract Book p 90

Project	Article
D1	Berdiñas Torres V, Fröhlich J, Klingenböck A, Nikoloski N, Kuster N: Relevant exposure parameters for the comparison of animal studies, International Congress of the European Bioelectromagnetics Association (EBEA), 2003, Budapest, Hungaria, p. 69.
D1	Fröhlich J, Berdiñas Torres V, Ladbury J M, Wilson P F, Kuster N: In vivo exposure systems for use in studies with large numbers of rodents at cellular telephone frequencies, 25th Annual Meeting of the Bioelectromagnetics Society, 2003, Maui, Hawaii, p. 147
D1	Fröhlich J, Chavannes N, Kuster N: Ratio of spatial peak and whole body SAR dependent on frequency and polarization in animals and humans, XXVII General Assembly of URSI, 2002, Maastricht, Netherlands
D1	Fröhlich J, Chavannes N, Nikoloski N, Kuster N: Rigorous analysis of EM absorption in high resolution anatomical models using FDTD, AP-S International Symposium and USNC/URSI National Radio Science Meeting, 2002, San Antonio, Texas, USA, p. 50.
D4	Uberbacher R, Schmid G, Tschabitscher M: New high resolution numerical model of inner ear organs for RF-dosimetry - preliminary results in the 900 MHz - 10 GHz range, BEMS, 2006, Cancun, Mexico
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