The following summaries relate to recently-published original scientific studies on the effects of mobile communication radio-frequency fields. The selection was made by the author, Professor Roland Glaser, reflecting his personal perspective on the studies' relevance.

News from Science

Often, the occurence of micronuclei is seen as proof of possible genetic damage caused by effects of RF fields. In 1999, during the BEMS meeting taking place in California, the group of Hooke et al. in two papers reported on the occurence of such anomalies in human blood cells following field exposure *in vitro*. In the context of these reports Vijayalaxmi et al. presented the results of experiments in rats exposed to a relatively strong 2.45 GHz field (whole-body SAR = 12 W/kg) over a period of 24 hours. For positive control, a treatment with the clastogene MMC was performed. Despite the intense field exposure producing a measurable, albeit small, increase of rectal temperature, no effects could be measured. The authors explain the results of Hooke et al. by errors in their procedures. They complain that these results were not published in detail in a scientific journal, thus leaving the technical details of the exposure and of the evaluation of the data unknown (Vijayalaxmi, Pickard, W.F., Bisht, K.S., Prihoda, T.J., Meltz, M.L., LaRegina, M.C., Roti, J.L.R., Straube, W.L., and Moros, E.G.: Micronuclei in the peripheral blood and bone marrow cells of rats exposed to 2450 MHz radiofrequency radiation. Intern. J. Radiat. Biol. 77, 1109-1115, 2001).

D'Ambrosio and colleagues followed up on existing studies of possible RF field genotoxic effects in lymphocytes *in vitro* which made available results – though under insufficiently-controlled thermal conditions – already as early as 1995. In the present study, the authors succeed in showing, by experiments with adequate temperature regulation, that an exposure of human lymphocyte cultures to 1.748-GHz fields (15 min, SAR: 2.25±0.87 W/kg) caused a significant ($p<0.01$) increase of the number of micronuclei (by 35%) only if these are phase modulated according to the GMSK standard. Unmodulated fields showed no effect whatsoever. However, the authors emphasize that this field effect is far weaker than effects potentially caused by mutagenes or by ionising radiation. A significant alteration of the lymphocyte division rate could not be observed in any of the cases (D'Ambrosio, G., Massa, R., Scarfi, M.R., and Zeni, O.: Cytogenetic damage in human lymphocytes following GMSK phase modulated microwave exposure. Bioelectromagnetics 23, 7-13, 2002).

In a first study, following comprehensive tests on potential genetic damage, a group from North Carolina dealt with the occurrence of DNA fragments (alkaline single-cell gel electrophoresis: SCG) and micronuclei (micronucleated binucleate: MN-BN) in human lymphocyte cultures exposed to continuously-modulated fields of 837 MHz or 1909.8 MHz with intensities of up to 10 W/kg, over 3 or 24 hours. The only distinct effect occurred in the extremely-highly-exposed cells (24 hours, 10 W/kg): an average 4-fold increase of the number of micronuclei. This effect was independent of frequency and modulation. At an exposure of 5 W/kg over 24 hours, a significant increase could be found using only those fields emitted by analogue and digital TDMA technology. The authors do not comment on the biological relevance of this finding. Despite good thermal control they do not exclude local thermal effects as a cause of the results (Tice, R.R., Hook, G.G., Donner, M., McRee, D.I., and Guy, A.W.: Genotoxicity of radiofrequency signals. I. Investigation of DNA damage and micronuclei induction in cultured human blood cells. Bioelectromagnetics 23, 113-126, 2002).

In a further study, Pakhomov and colleagues dealt with the question of whether there is a difference between pulsed and continuous RF radiation when the average SAR value is identical in both cases. To this end, they examined the cell division rate of yeast cells (saccaromyces cervisae) at exposure to 9.3-GHz fields. The cells were embedded in an agarose gel. Due to the limited penetration depth of the field, evaluation of the effect as a function of the distance to the gel surface at the same time resulted in establishing a dose dependence. At irradiation with unpulsed as well as with pulsed fields, the mean SAR value was 3.2 W/kg at the surface, decreasing to 0.6 mW/kg at the bottom of the 24 mm-thick sample. Despite the cooling of the gel columns there were steady-state temperature increases of up to 10° C. Further, it was shown that after 6-hours' exposure, the alteration of cell division rate corresponds exactly to the usual temperature dependence of this process, which in these cells reaches a maximum of 35° C either at continuous energy input or with pulses of 0.5 µs (10 pulses per second). This result is particularly surprising in view of the fact that the SAR peak value corresponding to the pulse radiation was 200,000-fold higher than the average value. Only under extreme conditions, at SAR peak values of 20 MW/kg, could slight differences between pulsed and unpulsed fields be found. The authors conclude that seemingly even at extremely high pulse intensities there are no athermal effects on cell growth (Pakhomov, A.G., Gajsek, P., Allen, L., Stuck, B.E., and Murphy, M.R.: Comparison of dose dependences for bioeffects of continuous-wave and high-peak power microwave emissions using gel-suspended cell cultures. Bioelectromagnetics 23, 158-167, 2002).

As part of the debate on effects of weak mobile-radio RF fields on human brain functions, a group working in neurology at the Karls University Prague presented the results of tests of 22 patients (48±11.7 years) suffering from narcolepsy-cataplexy, a spontaneous urge to sleep. In a double-blind experiment, subjects were exposed to a mobile phone radiating at 900 MHz, pulsed at 217 Hz (SAR value 0.06 W/kg), which was placed to the right of the head for 45-min sessions. Alterations of the EEG were not observed during these tests. Nor did the expected hypnotic effect occur, which is caused by low-frequency pulses. However, there were slight changes in the event-related potential of recognizing optical marks. With a probability of $p<0.05$ a response interval shortened by 20 ms could be detected; but compared to the absolute value of 600 ms this really is a slight effect. This finding is in line with that of other authors also reporting a shortening of response intervals at exposure (Jech, R., Sonka, K., Ruzicka, E., Nebuzelský, A., Böhm, J., Juklícková, M., and Nevsímalová, S.: Electromagnetic field of mobile phones affects visual event related potential in patients with narcolepsy. Bioelectromagnetics 22, 519-528, 2001).

The phenomenon of possible DNA single- and double-strand breaks caused by 2.45-GHz fields will be the subject of further studies, although G.M. Williams (96) has already pointed out problems and weaknesses in methods in the study presented by Lai and Singh (96). Moreover, in a subsequent study Malyapa et al. (97) did not succeed in replicating those results. A new study of Li et al. suggests that Malyapa et al. could not find any alteration, because they confined themselves to using fields with an SAR of 0.6 W/kg. Consequently, Li et al. performed tests applying CDMA and FDMA fields (847.74 and/or 835.62 MHz); SAR values were increased up to 5 W/kg. As an indicator again served the so-called comet assay, a gel electrophoretic method for identification of DNA fragments. Contrary to well-defined effects from exposure to ionising radiation (gamma rays of Cs-137) from 0.6 cGy upwards, no effects for RF exposure could be observed. Neither an extended field exposure for up to 24 hours, nor 4-hours' incubation of samples after field exposure as applied by Lai and Singh (96), changed the result. The study thus is to be seen as further disproving the data found by the above mentioned authors, obviously being a result of errors in method (Li, L., Bisht, K.S., LaGroye, I., Zhang, P., Straube, W.L., Moros, E.G., and Roti, J.L.R.: Measurement of DNA damage in mammalian cells exposed in vitro to radiofrequency fields at SARs of 3-5 W/kg. Radiation Research 156, 328-332, 2001).

There is no doubt that in future, in civilian life as well as by the military, millimeter waves will be increasingly used. These fields have a small penetration depth into the human body. For this reason, the issue of a possible induction or promotion of skin cancer is of increasing importance. Mason et al. performed a careful study of single and repeated irradiation of female SENCAR mice with 94 GHz fields (penetration depth about 0.3 mm). Here, by means of a chemical carcinogen (DMBA) the animals were induced with skin cancer. For positive control, in one group additionally a cancer promoter (TPA) was used. For the identification of potentially occurring effects caused by heating alone, controls were irradiated with infrared (1.5 W/cm²) radiation; thus, a heating (13-15° C) was produced identical to that caused by field exposure to 1.0 W/cm² microwaves. It was shown that neither a single-field exposure (10 s) nor long-term radiation (two times per week, over a 12-weeks period) led to an accelerated development of the DMBA-induced skin cancer, in contrast to the distinct effects of the promotor TPA (Mason, P.A., Walters, T.J., DiGiovanni, J., Beason, C.W., Jauchem, J.R., Dick, E.J., Mahajan, K., Dusch, S.J., Shields, B.A., Merritt, J.H., Murphy, M.R., and Ryan, K.L.: Lack of effect of 94 GHz radio frequency radiation exposure in an animal model of skin carcinogenesis. Carcinogenesis 22, 1701-1708, 2001).

In future, millimeter waves will gain importance not only considering radiation protection, but also with regard to medical applications. Fields of frequency 61.22 GHz penetrate only up to 0.2-0.5 mm deep into the tissue, thus affecting the cells only of top skin layers. For this reason, the effect of these fields on keratinocyte cultures was examined, 90% of skin cells being keratinocytes playing a crucial role in wound healing. Though a 15-30 minute field exposure at 770 W/kg had no effect on cell division (proliferation) and chemotaxis or on cell adhesion capability, it did significantly, albeit slightly, increase production of a protein which acts as a protector from inflammation processes (interleucine IL-8). Despite the fact that the production of this protein is induced also by a distinct temperature increase, the authors do not suggest that there is a non-thermal effect (Szabo, I., Rojavin, M.A., Rogers, T.J., and Ziskin, M.C.: Reactions of keratinocytes to in vitro millimeter wave exposure. Bioelectromagnetics 22, 358-364, 2001).

Does mobile phoning affect cognitive processes? In order to find answers to this question, 72 Hong Kong high-school pupils participated in several psychological tests, 37 of them as mobile phone users. A “mild facilitating effect” of mobile phone use was demonstrated which could not be verified by statistics, though (Lee, T.M.C., Ho, S.M.Y., Tsang, L.Y.H., Yang, S.Y.C., Li, L.S.W. and Chan, C.C.H.: Effect on human attention of exposure to the electromagnetic field emitted by mobile phones. Neuroreport 12, 729-731, 2001).

Quantitative immunohistochemical methods not only help to find evidence of possible alterations of neurotransmitter concentration in the brain, but also allow localisation of these alterations. Thus, for an exposure (2 hours) to 900 MHz (continuous) radiation, a decrease of the neurotransmitter GABA in the cerebellum of rats could be found. However, the corresponding SAR values of 32 W/kg suggest thermal effects. Field exposure with GSM-similar pulsation at an average SAR value of only 4 W/kg showed no significant changes. The authors claim their quantitative immunohistochemical method to be an important step towards elucidation of field effects on the Central Nervous System (Mausset, A.L., de Sèze, R., Montpeyroux, F., and Privat, A.: Effects of radiofrequency exposure on the GABAergic system in the rat cerebellum: clues from semi-quantitative immunohistochemistry. Brain Research 912, 33-46, 2001).

In the context of contradictory findings on the impact of radio-frequency fields on brain functions, an English group participating in a project of the British Ministry of Defence performed tests on effects of weak 700-MHz fields on 0.4 mm-thick rat brain slices (hippocampus). The cooperation of three institutions (Biomedical Sciences Department, Salisbury; Poynting High Voltage Ltd., Hawksworth; Dept. Electronic Engineering, London) vouched for the all-round competence of the investigations. The tissue slices, placed on a nylon mesh in a physiological solution under exact temperature control, were brought into an adapted waveguide. The cells were stimulated electrically (70 µs, pulses every 10-30 s); during some of the tests there was additional pharmacological stimulation (50-100 µM, 4-aminopyridine) to eliminate electrode artefacts. The collective evoked potential of the cells inside the slices was derived as an indicator of the impact of the applied fields. Already at field strengths of 50-70 V/m, equivalent to a calculated SAR value of 1.6 to 4.4 mW/kg, there were distinct responses. However, not all slices responded; sometimes there were even contradictory reactions. The time variations within the test results were fully convincing, though. Further, the mean values of the effects determined over several tests prove that there are significant decreases of evoked potentials, at least at field strengths of 70 V/m. The authors claim that a similar effect will occur if the tissue is exposed in a static electrical field of about 4 V/m. But how can a direct field develop, caused by radiofrequency field effects? In the view of the authors, the findings presented are not sufficient for drawing conclusions on a mechanism; however, the result is sufficiently conclusive to stimulate further studies (Tattersall, J.E.H., Scott, I.R., Wood, S.J., Nettell, J.J., Bevir, M.K., Wang, Z., Somasiri, N.P., and Chen, X.D.: Effects of low intensity radiofrequency electromagnetic fields on electrical activity in rat hippocampal slices. Brain Research 904, 43-53, 2001).

Repeatedly, there has been a demand to decrease limit values, on account of the sensitivity of some people to atmospherics (in short, “spherics”), which are weak atmospheric electromagnetic disturbances in the frequency range up to about 100 kHz usually preceding weather fronts. This theory was already presented in 1960 by R. Reiter, and has been subject of several studies of a group at the Faculty of Psychology at the Justus Liebig University, Gießen, Germany (Schienle et al. 1996-98). Recently, it has been again the focus of different investigations. In cooperation with the Department of Physics at the University of Munich, staff members of the University Clinic in Freiburg collected data from migraine diaries of 21 persons searching for some relationship with maximum values of electromagnetic disturbances. Only in 6 of the observed persons significant values could be found. Moreover, maximum health impairments, in some cases, occurred only several days after the electromagnetic event. Only one person showed a clear synchronisation of headache and frequency and/or intensity of the spherics. The authors suggest that this sensitivity could be a potential rare relict from primeval times when storm prediction possibly was important for natural selection. But they also deal with the question whether this minority does not rather, in fact, belong to the group of electrosensitive persons. If this is actually the case, we have to examine whether this sensitivity is also relevant regarding the mobile-radio frequency range. Until now, however, the number of persons examined is not sufficient to cast light on the matter (Walach, H., Betz, H.D., and Schweickhardt, A.: Sferics and headache: a prospective study. Cephalalgia 21, 685-690, 2001).

An Australian group performed experiments in transgenic mice in order to decide to what extent RF fields could be responsible for cellular mutations. The starting point was the genetic finding of the high significance of interchromosomal recombination, that is, the gene exchange between homologous chromosomes during cell division, for mutations. Here, the mouse stem pKZ1 is particularly sensitive to external disturbances. The animals were exposed to a GSM field (900 MHz, 217 Hz pulsed) under conditions of exact dosimetry. No heating of the animals could be measured. On the contrary, obviously due to the insufficient thermoregulation of the animals, there was even a decrease of body temperature during field exposure of up to 1° C. When the mice were exposed at a whole body SAR of 4 W/kg over a period of 5 weeks (30 min/day, 5 days/week), the number of recombinations of this type in cells of the spleen decreased by the significant factor of 40%. Not significant, on the other hand, were the also observed decreases at single or 5-fold field exposure. The authors discuss several reasons for this effect. Are there gene alterations at field exposure that can not be fully identified during the repair process? Is there a lack of expression of the required catalytic proteins? As per test only 10 or 20 animals were used, the authors think that these findings should be repeated (Sykes, P.J., McCallum, B.D., Bangay, M.J., Hooker, A.M., and Morley, A.A.: Effect of exposure to 900 MHz radiofrequency radiation on intrachromosomal recombination in pKZ1 mice. Radiation Research 196, 495-502, 2001).

After having established that RF fields do not affect liver cancer promotion (Imaida et al. 1998), the follow-up study of the Japanese group around Imaida focussed on skin cancer. Here, cancer was induced by painting rat skin with the known carcinogen DMBA. Subsequently, some of the animals were exposed to fields of the Japanese TDMA standard (PDC), that is, 1.49 GHz (50 pulses per second), over a period of 19 weeks, 5 days per week, for 90 min each, reaching a whole-body SAR of 0.084 W/kg and a local skin SAR of 2.0 W/kg. A repeated treatment of the animals with the cancer promoter TPA served as a positive control. Per group 30 or 48 animals were examined. In the control group (DMBA), one single animal developed skin cancer; at DMBA+EMF no case of skin cancer could be observed, whereas 29 of 30 animals of the positive control (DMBA+TPA) fell ill. In the view of the authors, the number of test animals was sufficient to conclude that the applied electromagnetic field does not act as a promotor of induced skin cancer (Imaida, K., Kuzutani, K., Wang, J.Q., Fujiwara, O., Ogiso, T., Kato, K., and Shirai, T.: Lack of promotion of 7.12-dimethylbenz[a]anthracene-initiated mouse skin carcinogenesis by 1.5 GHz electromagnetic near fields. Carcinogenesis 22, 1837-1841, 2001).

An Australian group of three institutions examined the highly-controversial issue of GSM field effects (898.4 MHz, 217-Hz pulsed) on the blood-brain barrier of mice. In contrast to positive controls treated with clostridium toxin, even after a 1-hour field exposure at a SAR of 4 W/kg no difference between exposed and non-exposed animals could be found. The few histologically-relevant points documenting albumin passage out of brain vessels in exposed as well as in control animals were leptomeningeal vessels that do not have a well-defined blood-brain barrier anyway (Finnie, J.W., Blumbergs, P.C., Manavis, J., Utteridge, T.D., Gebski, V., Swift, J.G., Vernon-Roberts, B., and Kuchel, T.R.: Effect of global system for mobile communication (GSM)-like radiofrequency fields on vascular permeability in mouse brain. Pathology 33, 338-340, 2001).

After investigating the thermoregulation of participants at various environmental temperatures (24°, 28°, 31° C) and additional RF exposure (2.45 GHz, continuous) with a flux power density of 35 mW/cm², the group of Adair has now published the results of their experiments at exposures of 50 and 70 W/cm². Here, the permitted limit values were exceeded and SAR values of up to 15.4 W/kg were reached. The authors claim this to be completely harmless making comparisons to the turnover of marathon runners which allegedly rises to about 18 W/kg. There is a normal response of heat regulation in participants at 45-min exposure, too. The study discusses in detail the relationship with various physiological and pathological situations of temperature regulation in the human body. However, the U.S. Air Force and the U.S. Department of Defense, having commissioned the study, distanced themselves from the authors' opinion (Adair, E.R., Mylacraine, K.S., and Cobb, B.L.: Human exposure to 2450 MHz CW energy at levels outside the IEEE C95.1 standard does not increase core temperature. Bioelectromagnetics 22, 429-439, 2001).

A military-related group from the USA presented tests on the effect of ultra-wideband (UWB) pulses on macrophages. These are nanosecond pulses with a wide frequency spectrum of 0 Hz up to microwave frequency being increasingly applied by the military as well as in civilian life. The dosimetry of these fields is exceptionally difficult. For the 0.98 ns pulses used here, a median frequency of 0.51 GHz and main frequencies between 0.0844 and 3.08 GHz were detected. The SAR value was assessed as being 0.106 W/kg thus disproving any assumption of significant temperature increases in the samples. The occurrence of the free radical NO in the culture solution after a 30-min field exposure of a macrophage culture (cell line RAW 264.7) was examined. An effect of the field impact on the NO concentration could be measured simply from an increase of the nitrate content in the nutrient solution. The biochemical reasons for this are not clear. There could be an effect on the NO-synthase caused by the UWB (Seaman, R.L., Parker, J.E., Kiel, J.L., Mathur, S.P., Grubbs, T.R., and Prol, H.K.: Ultra-wideband pulses increase nitric oxide production by RAW 264.7 macrophages incubated in nitrate. Bioelectromagnetics 23, 83-87, 2001).