

# Reproduction and elec

Ingeburg Ruppe

## The influence of occupational factors on reproduction

Recently, there have been more and more reports referring to studies on health effects from exposure to electromagnetic fields. Special attention is given to investigations into fertility resp. potential fertility disorders, e.g. in a publication of Davoudi from the year 2002, titled "The influence of magnetic waves on sperm motility" (in German: M. Davoudi, C. Brössner, W. Kuber, Zeitschrift für Urologie und Urogynäkologie 2002; 9 (3): 18-22), the "Hungarian Fertility Study" of Fejes et al. (presentation by Dr. Imre Fejes, University of Szeged, Hungary, during the Annual Meeting of the European Society of Human Reproduction and Embryology (ESHRE), 29 June 2004 in Berlin), or the recent "Australian Study" of the Royal Society, University of Western Australia, titled „Image content influences men's semen quality“, according to which mobile phones kept in the pants pocket may potentially lead to infertility (Sarah J. Kilgallon, Leigh W. Simmons; Evolutionary Biology Research Group, School of Animal Biology (M092), University of Western Australia, Crawley 6009, Australia).

With regard to these studies, media attention is of ultimate importance; the scientific contents seems to be secondary. Serious research has been done in this field for several years/decades, by different institutions. One example is the activity of the Federal Institute for Occupational Safety and Health (Bundesamt für Arbeitsschutz und Arbeitssicherheit – BAuA) in Berlin. The existing knowledge about effects from electric, magnetic and electromagnetic waves of different frequency ranges on biological systems, and especially on reproduction, is more thoroughly discussed in the following.





# disorders from magnetic fields

## Introduction

Every living organism on this planet is surrounded by natural and, in the industrialized countries, also by artificially produced electric, magnetic and electromagnetic fields of different frequencies and intensities, which constantly change their orientation and strength. Examples are the geomagnetic field, air electric fields, light, heat radiation and ultraviolet radiation.

Besides these external fields there are internal fields developing inside the organism itself, since all living phenomena are prone to potential change. Internal fields can be made visible by the recording of body functions. Known examples are the electrocardiogram, the electro-encephalogram and the electromyogram. The effects of artificially induced fields on human, animal and plant life are hotly discussed at present. As we cannot perceive them with our physical senses, their existence, their intensity and influence can be made evident and evaluated only by means of measurement devices. Intense research is performed worldwide in order to detect also effects of very low field strengths existing in our general environment. The effects of electric, magnetic and electromagnetic fields is dependent on their frequency. This is why, in the following, a short overview of frequency ranges is given.

## Biological effects of electromagnetic fields

Electromagnetic waves are composed of electric and magnetic fields.

### Biological effects in the low-frequency range

In the low-frequency range (50 Hz to 30 kHz) fields occur e.g. in the surroundings of high-voltage power lines, transformer stations, domestic appliances and electrically operated machines. The electric and 50 Hz low-strength magnetic fields in our normal environment cannot be sensed. However, if electric field intensity at certain workplaces is high enough to exert a stimulating effect, our skin prickles or we have muscle spasms. But it is not often that such high field intensities occur at workplaces or during therapeutic intervention.

### Biological effects in the high- or very high frequency range

This range comprises frequencies from 30 kHz to 300 MHz. High-intensity effects occurring at certain workplaces or during diagnosis resp. therapeutic applications are well-studied. Consequences may be a heating of body parts or of the whole body, and an overheating can result in tissue damages. If their energy is strong enough, electromagnetic fields can penetrate the body. They move molecules in the

body, against their binding forces polarizing them and creating molecular vibrations. The absorbed energy is transformed into heat, and the faster and more often vibrational changes happen, the stronger is the heating.

The degree of heating depends on various factors, such as frequency or wavelength, duration of impact, field strength or power density, the type of the exposure (pulsed or continuous), dimension and surface of the irradiated area, the dielectricity constant, the heat conductivity and the electric conductivity of the irradiated tissue components.

Dependent on the site, intensity and length of the impact, there is an increase in temperature in these body parts or the whole human or animal body, with all consequences of heating that are also known from the heating by other media (sauna, warm bath, hot tea, hot-water bottle, etc.).

The threshold up to which thermal effects in humans can be excluded with certainty is a power density of 10 mW/cm<sup>2</sup>. Respective well-founded experiments have already been conducted in the sixties and seventies (Michaelson 1971, 1972; Rose et al. 1970) and are still valid.


## Reproduction and development

It has long been known that a rise in body temperature during ontogenesis can have a negative influence on the development of offspring.

## Small animal experiments

Extensive studies on heating, and also experiments on potential reproduction disorders have been conducted in small animals. In rats, rabbits and cats, the heating threshold is correspondingly lower than that for humans. The study of Jensch from 1997 examined the impact on rats and their offspring at very high exposure, i.e. far above legal limits, at a frequency of 915 MHz, with 100 W/m<sup>2</sup> resp. at a frequency of 2.45 GHz with 200 W/m<sup>2</sup>. There are no differences revealed with non-exposed animals at these frequencies resp. high intensities. Exposure to 6 GHz with 350 W/m<sup>2</sup> showed a slight, but significant decrease in monocytes in maternal animals. The offspring of this group were sligher in the first 5 weeks, and showed subtle neurophysiological alterations, such as a delay in the opening of the eyes. Alterations caused at 6 GHz, with these very high intensities, are not relevant in the discussion about limits or potential precautionary





discussions. Gordon (1970) established a minimum threshold power flux density of 10 mW/cm<sup>2</sup> for the induction of embryonic and fetal damages in mice.

Among more recent studies performed in mammals, mostly rats and mice, the results of two investigations (Huuskonen et al. 1998 and Mulligan and Persinger 1998) show a statistically significant association between exposure and certain parameters, such as the occurrence of skeletal alterations in the fetuses of a specific mouse line, but not in other lines. The major part of studies, however, failed to determine influences on reproduction resp. teratogenic reactions (Brent 1999; Ryan et al. 1999 and 2000; Dawson 1998).

Exposure was continuous or intermittent (e.g. one hour alternately on/off). Aside from spermatogenesis and estrus cycle in the parent generation, teratogenic effects, weight and number of fetuses were examined, etc.

There is full agreement in experimental science on the fact that the results obtained from small animals cannot be directly extrapolated to humans, since size, degree of hairiness and body shape generate different absorption mechanisms.

### **Epidemiological studies**

More recent epidemiological studies exploring adverse influences of low-frequency fields on reproduction have mainly observed occupational exposure and exposure to electric appliances, above all to electric blankets. Fertility (Hjollund et al. 1999; Mur et al. 1998), spontaneous abortion (Belanger et al. 1998), sudden infant death and teratogenic reactions (Grainger et al. 2000; Shaw 1999) were examined. Due to crude exposure indices, too small samples or other methodological limitations, these studies were apt to detect only highly distinct relations.

Magnetic alternate fields from flux densities of few  $\mu$ T up to the mT range were applied for exposure, using supply network frequencies (50 Hz resp. 60 Hz), first harmonics (upper waves) as well as higher frequencies as can be produced e.g. by monitors (sawtooth, 10 kHz and 20 kHz).

### **Limits**

Power density limits for the very high frequency range at workplaces are between 1 and 5 mW/m<sup>2</sup> (Accident Avoidance Guideline, BGV B 11), dependent on the frequency.

Under normal work and environmental conditions, persons do not encounter power flux densities of more than 5 mW/cm<sup>2</sup>.

Limit setting is based on calculations of specific absorbed energy. The absorbed energy is measured in W/kg body mass and is called SAR (specific absorption rate). Based on cellular, tissue and animal tests resp. tests with human volunteers, biological effects were correlated with the SAR values. A SAR of 0.08 W/kg, averaged over the whole body, is seen as a safe value for the general population, as well as for children and pregnant women worldwide. Every human being produces heat in maintaining his/her body functions. The basic energy turnover is about 1 W/kg; it increases with physical activity. The body thus is able to regulate body temperature by increased blood circulation in the skin and by sweating, and can neutralize additional thermal exposure from heaters, hot baths, sun rays, etc.

To-date performed studies and experience show that a temporary increase in body temperature caused by external influences by 0.5° C to a maximum of 1° C is tolerated by the healthy body and has no adverse consequences. This value should not be exceeded without control. Thermoregulation of persons suffering from fever, metabolism disorders or affected by drugs can be disturbed.

### **Electromagnetic fields at the workplace**

The compliance with limits at workplaces of pregnant women has to be ensured. A rise of body temperature by more than 1° C is not permitted. This serves to avoid negative influences on embryonic development.

### **Working with computer monitors**

For years, computerized workplaces were suspected to have a negative impact on pregnancy. Epidemio-

logical surveys of the course of pregnancy have shown that, in general, the course of pregnancies of working women often was more unfavorable than of women without occupational activity. To date, there is no evidence of an increased number of negative pregnancy courses for computerized work, compared to the group of working women. Obviously, the occupational strain of pregnant women is not specifically related to computerized work, but has to be resolved in general terms, e.g. by avoiding long-duration ergonomically unfavorable body positions, avoiding psychomental overstrain by taking breaks and by reducing the time spent in front of monitors (Kroschwitz et al. 1990). Internationally, and also in the opinion of the much-cited Swedish experts, scientific evidence of the aforementioned complaints and symptoms being related to fields emitted by monitors is still lacking, so that field-related hazards for women of fertile age and pregnant women can be excluded according to the present state of knowledge.

### Electromagnetic fields in the general environment

In the household, in the garden and during the use of electric appliances when performing home handiwork, electric and magnetic low-frequency fields occur at close proximity to the device. The field strengths of these devices are much below the limits the general population may be exposed to without being at risk. These limits are set in the Regulation on the Implementation of the Federal Immission Control Act – 26. BImSchV “Electromagnetic fields” (1996), amounting to 5 kV/m for the electric field strength, and to 100 mT for the magnetic field strength.

### Mobile radio

During the application of mobile radio technology radio frequency electromagnetic fields are emitted. When using a mobile phone, electromagnetic radiation for the transmission of information during talking is delivered directly at the user’s head. Part of this energy unavoidably penetrates the head. For this energy not to provoke health damages, it is limited by

regulations. There is no evidence of damages occurring below the limits in humans.

There are uncertainties and fears also over the radiation emanating from base stations installed on towers or rooftops. But the general population is concerned only marginally by this. There are very low-energetic fields below base stations, since they emanate horizontally to the antenna for better distribution. When they hit the earth or residential areas, field strength has diminished with the distance to an extent that they do not pose any danger. They are still well below the fields emitted by mobile phones.

### Electromagnetic fields in medicine Therapy

Correspondingly high electromagnetic energies can be introduced in therapeutic applications of radio and very high frequency fields in the form of so-called short- and microwave therapy, where an intentional heating of the treated body part by some few degrees Celsius can occur.

In therapeutic applications with radio and very high frequency fields in the form of so-called short- and microwave therapy high electromagnetic energies can be introduced and the treated body part can be heated by some few degrees Celsius.

During treatment of the abdominal area of pregnant women with short-wave radiation, Hofmann (1966) and Dietzel and Kern (1970) observed thermogenetic malformations and miscarriages.

As soon as it became known that a distinctly increased body temperature, as in the above mentioned tests with small animals, led to malformations and abortions also in humans, extensive studies on heating due to electromagnetic fields and their effects on reproduction were performed. The result was that the observed reactions were pure heating effects, such as develop from too hot baths, frequent sauna visits or ultrasound therapy, and not “specific“ field effects. It was therefore suggested that pregnant women are not be treated with radio or very high frequency radiation, especially in the abdominal area, and to



not let pregnant women work in such facilities resp. to ensure that a distance of at least 2 m is kept after switching on the therapeutic device. This distance is seen as sufficient, since the strength of electromagnetic fields decreases with the square of the distance.

#### NMR diagnostics

A heating of the abdominal area due to applied low- and radio frequency fields is possible during diagnostics by means of magnetic resonance tomography (MR). Both field types are to be taken into account according to their interaction mechanisms.

There are recommendations on how to avoid health risks during the application of magnetic resonance techniques in medical diagnostics (1997) related to diagnosing pregnant women and the use of pregnant workers in MR facilities.

#### Electrosensitivity

The knowledge about existent fields and uncertain fears over them can influence the autonomous nervous system and manifest in functional disturbances of the cardiovascular system. A heating of the organism does not occur, though. These functional disturbances were observed during serial tests conducted in workers exposed to continuous radio frequency fields over several years. (The) complaints remitted

after the end of exposure or at power densities below  $1 \text{ mW/cm}^2$  (Gorden 1970).

Voiced complaints are unspecific, and all attempts to find a causal association with an environmental factor have failed yet. Observed were: fast fatigue, headache, disturbances of cardiovascular regulation with bradycardia and hypotony, alterations in the electrocardiogram, etc. Concerned persons were self-reportedly electrosensitive or sensitive towards environmental influences in general (Ruppe and Vogel 1998; Ruppe 1999).

Complaints were individually perceived and judged. A predisposition related to electromagnetic fields cannot be excluded, but can neither be proven. None of the surveys or tests described a special sensitivity of the female organism towards microwaves or radio frequency.

All this explains why there are no specific limits or constraints for women working in countries with set exposure limits.

Exceptions are pregnant women working in NMR facilities and with radio frequency therapeutic applications, since limits can be exceeded there.

In order to protect women against the impact of high power densities or field strengths, and also to exclude possible impairments of their general well-being, if only potential fears over field effects, we recommend to employ women at workplaces complying with the environmental limits of the 26. BImSchV.

## Male fertility disorders

There are several reports on disturbances of fertility in men at exposure to “fields“, or on men in corresponding occupations being able to father girls “only“. The “problem“ of “girls only“ is not confirmed by any statistics. For more details on fertility disorders see above.

At an overheating of the testes, however, disturbances of sperm formation can occur.

The male gonads are located in the scrotum because the elevated temperature inside the body is unfavorable to spermiogenesis. If the testes remain in the abdominal cavity or the inguinal canal, a normal spermiogenesis is not possible. The endocrinous function of the organ however remains intact. If cryptorchid testes are surgically transferred into the scrotum, sperm formation can begin.

An example from practice of the influence on spermiogenesis from heat is the impossibility of reproduction of animals coming from colder regions and being transferred to tropical areas. Breeding is only possible then, if the animals are housed under climatized conditions.

If the testes are heated from the outside, by pressure or friction, by too narrow clothes, intense sun rays, high temperature, or by electromagnetic fields during therapy with short- and microwaves and ultrasound, or by diagnostic applications using the MR tomograph, or when the person stays e.g. in front of an antenna, there is the possibility of functional disturbances. Protection can be provided by an apron made of absorbant or reflectant material.

## Summary

The German Commission on Radiation Protection (Strahlenschutzkommission – SSK) has commissioned an expert evaluation of most recent literature since 1998 covering the whole frequency spectrum. Results were summarized in the SSK report (2001). Special emphasis was put on the impact of the in-

creasing use of mobile radio and mobile phone which concerns the entire population.

- Both epidemiological studies and animal tests were conducted to investigate potential negative effects from low-frequency fields on reproduction. Recent papers also fail to provide any scientifically founded evidence of health impairments due to low-frequency fields with intensities below limits.
- Studies on genetic damages from radio frequency fields are scarcely comparable, as different parameters of exposure, such as frequency, modulation and field strengths, were applied. Results with regard to field strengths that are distinctly above limits differ. Studies investigating fields produced by mobile radio (continuous, amplitude- and frequency-modulated fields) give no evidence of a genotoxic potential. It is scientifically acknowledged that electromagnetic fields cannot have immediate genotoxic effects. Photon energy is too small compared to ionizing radiation to dissolve covalent DNA molecule binding.
- Studies in women working at exposure to electromagnetic fields in the range of permitted limits revealed a normal course of pregnancy and childbirth. There were no damages in reproduction at exposure to environmental electromagnetic fields. Heating effects in the fetuses are not possible, as intensities are far too low. A specific effect of fields could neither be proven in animal experiments.
- An overheating of the abdominal area and of the testes is to be avoided.

Overall, results of recent in vivo studies and epidemiological studies provide no scientific evidence of negative effects from low-frequency fields on reproduction, as long as limits are complied with.

*Dr. Ingeburg Ruppe, BAuA, Berlin*

## References

- Belanger K., Leaderer B., Hellenbrand K., Holford T.R., McSharry J.E., Power M.E., Bracken M.B. Spontaneous abortion and exposure to electric blankets and heated water beds, *Epidemiology*, 1998 (9), 36-42.
- Bericht der Strahlenschutzkommission (SSK) (2001) Grenzwerte und Vorsorgemaßnahmen zum Schutz der Bevölkerung vor elektromagnetischen Feldern, Heft 29
- Brent R.L. Reproductive and teratologic effects of low-frequency electromagnetic fields: A review of in vivo and in vitro studies using animal models, *Teratology*, 1999 (59/4), 261-286.
- Davoudi M., Brössner C., Kuber W. Der Einfluss von magnetischen Wellen auf die Spermienmotilität (*Zeitschrift für Urologie und Urogynäkologie* 2002; 9 (3): 18–22),
- Dawson B.V., Robertson J.G.C., Wilson W.R., Zwi L.J., Boys J.T., Green A.W. Evaluation of potential health effects of 10 kHz magnetic fields: A rodent reproductive study, *Bioelectromagnetics*, 1998 (19/3), 162-171.
- Dietzel, F. u. Kern, W. Fehlgeburt nach Kurzwellenbehandlung – Tierexperimentelle Untersuchungen *Arch. Gynäk.* 1970, 209, 237-255
- Empfehlungen zur Vermeidung gesundheitlicher Risiken bei Anwendung magnetischer Resonanzverfahren in der medizinischen Diagnostik vom 03.12.1997, *Bundesanzeiger*, Jg. 50 Nr. 11a , 17. Januar 1998
- Gordon, Z. V. Occupational health aspects of radio-frequency electromagnetic radiation, *Occupat. Safety and Health Ser.* 21, 1979, S. 159-174
- Grainger P., Wigfield R., Wright M., Fleming P.J., Preece A.W. Electric and magnetic fields of 50 Hz are not associated with sudden infant death syndrome, *International Journal of Environmental Health Research*, 2000 (10/1), 85-87.
- Hofmann, D. Aborte und Missbildungen nach Kurzwellendurchflutungen in der Schwangerschaft, 37 *Geburtsh. U. Frauenheilk.* 26, 1966, 5 S. 554-557
- Hjollund N.H.J., Skotte J.H., Holstad H.A., Bonde J.P.E.. Extremely low frequency magnetic fields and fertility: a follow up study of couples planning first pregnancies, *Journal of Occupational and Environmental Medicine*, 1999 (56/4), 253-255.
- Huuskonen H., Juutilainen J., Julkunen A., Mäki-Paakanen J., Komulainen H. Effects of low-frequency magnetic fields on fetal development in CBA/Ca mice, *Bioelectromagnetics* 1998 (19/8), 477-485.
- Jensch J. Behavioral teratologic studies using microwave radiation: is there an increased risk from exposure to cellular phones and microwave ovens?, *Reprod Toxicol*, 1997 (11), 601.
- Kruschwitz, S., Kupfer, J. u. Ruppe, I. Bildschirmarbeit aus arbeitsmedizinischer Sicht, *Z. gesamte Hyg.* 36, 1990, H. 7, S.350-353
- Michaelson, S.M. Biomedical Aspects of Microwave Exposure, *American Industrial Hygiene Association Journal*, Vol.32,1971,S. 338-345
- Mulligan H., Persinger A.S. Perinatal exposures to rotating magnetic fields demasculinize neuronal density in the medial preoptic nucleus of male rats, *Neuroscience Letters*, 1998 (253/1), 29-32.
- Mur J.M., Wild P., Rapp R., Vautrin J.P., Coulon J.P.. Demographic evaluation of the fertility of aluminium industry workers: influence of exposure to heat and static magnetic fields, *Human Reproduction*, 1998 (13/7), 2016-2019.
- Rose, V.E.; Powell, C.H.; La Nier, M.E. u. Swanson, J.R. A review of United States microwave exposure criteria, In: *Ergonomics and Physical Environmental Factors. Occupational Safety and Health Series 21*, Genf: International Labour Office.1970,S. 186-91
- Ruppe, I. u. Vogel, E. Lösen schwache elektromagnetische Felder subjektive Symptome aus und haben diese gesundheitliche Folgen- Ergebnisse eines EU-Berichtes, *Z. ärztl. Fortbild. Qual. Sich. (ZaeFQ)* 1998, 92:144-147
- Ruppe, I. Mögliche gesundheitliche Folgen schwacher elektromagnetischer Felder -"Elektrosensibilität" Fachverband für Strahlenschutz, 31.Jahrestagung – Nichtionisierende Strahlung, 27.9. –1.10.1999 in Köln. Bd. II, S.1131-1142
- Ryan B.M., Symanski R.R., Pomeranz L.E., Johnson T.R., Gauger J.R., McCormick D.L. Multigeneration reproductive toxicity assessment of 60-Hz magnetic fields using a continuous breeding protocol in rats, *Teratology*, 1999 (59/3), 156-162.
- Ryan B.M., Polen M., Gauger J.R., Mallett E.Jr., Kearns M.B., Bryan T.L., McCormick D.L.. Evaluation of the developmental toxicity of 60 Hz magnetic fields and harmonic frequencies in Sprague-Dawley rats, *Radiation Research*, 2000 (153/5), 637-641.
- Shaw G.M., Nelson V., Todoroff K., Wasserman C.R., Neutra R.R. Maternal periconceptional use of electric bed-heating devices and risk for neural tube defects and orofacial clefts, *Teratology*, 1999 (60/3), 124-129.
- Stellungnahme des Bundesamtes für Strahlenschutz (BfS) zum Artikel „Machen Handys ihre Nutzer unfruchtbar?“ („Die Welt“ vom 29.06.2004)
- Unfallverhütungsvorschrift BGV B 11 (2001) Elektromagnetische Felder. Durch die BG FE erlassen am 1. Juni 2001
- Verordnung über elektromagnetische Felder (1996) - 26. BImSchV - 26. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes, *BGBl. Teil I*, Nr. 66, 20. Dez. 1996