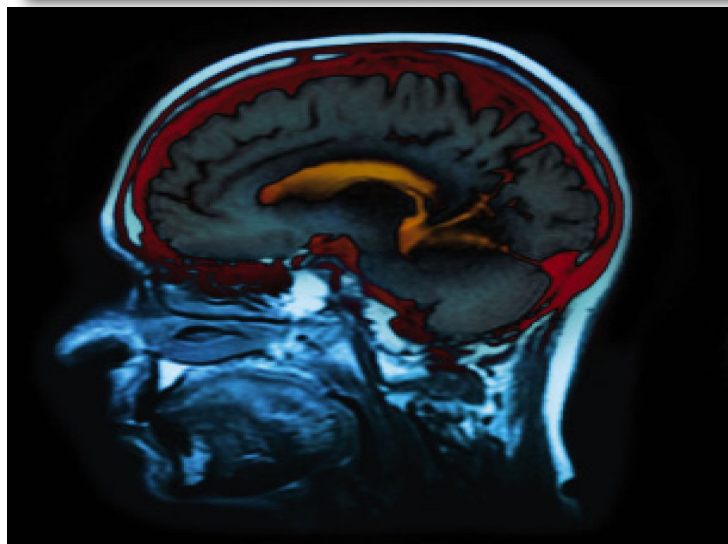


# The Possible Harmful **Biological Effects of Low-Level Electromagnetic Fields** of Frequencies up to 300 GHz

2012 Position Statement provided by the Institution of **Engineering and Technology**



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About This Position Statement

The Institution of Engineering and Technology (IET) acts as a voice for the engineering and technology professions by providing independent, reliable and factual information to the public and policy makers. This position statement aims to provide an accessible guide to the findings of the IET's Biological Effects Policy Advisory Group (BEPAG). This position statement encapsulates the IET's position on the possible harmful biological effects of low-level electromagnetic fields of frequencies upto 300 GHz. For more position statements and factfiles on engineering and technology topics please visit [www.theiet.org/factfiles](http://www.theiet.org/factfiles)

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The IET is a leading professional body for the engineering and technology community, with more than 150,000 members in 127 countries, and offices in Europe, North America, and the Asia-Pacific region.

As engineering and technology become increasingly interdisciplinary, global and inclusive, the IET reflects that progression and welcomes involvement from, and communication between, all sectors of science, engineering and technology.

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## Summary

The Institution of Engineering and Technology (IET) has a special interest in any possible health effects of both occupational and general-population exposure to electromagnetic fields (EMFs) because of its leading role in engineering and technology, particularly in all aspects of electronic and electrical engineering. The IET remains determined to be at the forefront of the examination of the scientific evidence for any such effects and thus identify any emerging hazards as early as possible. To this end it maintains its Biological Effects Policy Advisory Group (BEPAG) on low-level EMFs.

BEPAG has concluded that the balance of scientific evidence to date does not indicate that harmful effects occur in humans due to low-level exposure to EMFs. This conclusion remains the same as that reached in its previous position statements, the last being in May 2010, and our findings have not been substantially altered by the peer-reviewed literature published in the past two years.

At power frequencies (50 or 60 Hz), the balance of evidence from the large body of scientific papers built up over several decades suggests that the existence of harmful health effects from environmental levels of exposure has not been substantiated but remains a possibility. No generally accepted experimental demonstration of any biological effect, harmful or otherwise, due to such fields has been established. Pooled analyses of epidemiological studies show an association between childhood leukaemia and higher levels (greater than about 0.4 microteslas) of power-frequency magnetic fields in the home. However, in the absence of convincing mechanistic and experimental evidence, these epidemiological findings do not provide good grounds for concluding that there is a causal relationship. Problems of study design including selection bias and confounding remain a possible explanation of these results.

At higher frequencies, the existing data do not provide persuasive evidence that harmful health effects exist. Perhaps the greatest area of public concern remains the possibility of adverse effects from long-term mobile-phone use. Mobile phones have been in widespread use for well over a decade and hence epidemiological studies of long-term health effects are currently limited to this time frame. The international collaborative INTERPHONE study, carried out in 13 countries, provides the largest analysis of long-term users to date. The INTERPHONE Study Group concludes that its results do not show an increase in brain tumours that could be interpreted as causal, but that possible effects of long-term heavy use of mobile phones require further investigation. Recent analyses of historical brain-tumour rates have not observed increases commensurate with the rapid expansion of mobile-phone use since the early 1990s, although the length of time before any such effects would appear is unknown. The ubiquitous nature of our exposure to mobile phones means that, even if the risk to individuals is low, a large number of people could still experience health effects. However, experimental studies have failed to demonstrate consistent effects and no mechanism has

been established whereby low-level exposure to radio-frequency fields can cause biological effects. Environmental power levels from base stations, often a cause of public concern, are broadly similar to those from other broadcast radio-frequency sources such as television and radio transmitters and are many times lower than the peak values experienced when using a mobile-phone handset. High-profile experimental studies that fail replication, or for which replications are never attempted, continue to be of concern. BEPAG remains of the view that scientists have a responsibility to ensure that their findings are as robust as possible before publication. It has formed the view that pressures on scientists to publish their work may encourage the reporting of apparent effects that have not been adequately investigated. This phenomenon has also been recently identified in the pharmacology literature. Research institutions have a vested interest in encouraging publications from their staff but there is little counterbalancing pressure to hold organizations to account if such publications are found to be erroneous. BEPAG recommends that all research institutions operate internal quality-control mechanisms to help mitigate this problem.

BEPAG regards the independent replication of experimental studies as essential in order to improve the quality of the existing literature and to verify any reported effect. It recommends that isolated reports of biological effects or epidemiological findings should initially be treated with caution, until confirmed by independent groups. BEPAG is also of the view that a journal which publishes an EMF study should be under an obligation to publish a well-conducted replication study even if this fails to confirm the original findings.

BEPAG notes that the media continue to feature stories on EMF health effects, sometimes giving them more prominence than scientifically warranted, which potentially heightens public concern. For example, a tabloid newspaper has recently reported supposed links between childhood asthma and fields emanating from power lines and domestic appliances. Similarly, a high-profile poster campaign has encouraged men not to keep mobile phones in their trouser pockets to avoid claimed effects on fertility. Complaints against the latter have subsequently been upheld by the Advertising Standards Authority which has ruled that the posters must be withdrawn.

Technologies that produce electromagnetic fields are continually evolving. Examples of this are 4G communication systems, and the future roll-out of smart metering technologies. BEPAG will keep these under review along with the rest of the EMF literature.

In summary, the absence of robust new evidence of harmful effects of EMFs in the past two years is reassuring and is consistent with our findings over the past two decades. The widespread use of electricity and telecommunications has demonstrable value to society, including health benefits. BEPAG is of the opinion that these factors, along with the overall scientific evidence, should be taken into account by policy makers when considering the costs and benefits

of both the implementation of precautionary approaches to public exposure and also in the development of public-exposure guidelines.

## Introduction

The Institution of Engineering and Technology (IET) is a registered charity in England and Wales (no 211014) and Scotland (no SC038698) with more than 150,000 professionally qualified members worldwide, all of whom are exposed to electromagnetic fields (EMFs, the electric and magnetic fields created by the flow of electricity) in both their professional and private lives. Some are particularly exposed because of their employment in industries where there can be relatively high levels of EMFs. Thus the IET has an interest in possible health effects of EMFs on behalf of both its members and the general public, and remains determined to be at the forefront of the examination of the scientific evidence for any effects of such exposures and thus identify any emerging hazards as early as possible.

Given this situation the IET created the Biological Effects Policy Advisory Group (BEPAG) on low-level electromagnetic fields (a phrase used to describe relatively weak fields that are lower than international exposure guidelines) in November 1992. Its initial brief was to consider the possible harmful effects of low-level low-frequency EMFs, primarily at power frequencies (50 or 60 Hz), and it was tasked with systematically reviewing the scientific literature on behalf of the public and the Institution's members. BEPAG is made up of experts in particular science and engineering disciplines; some come from within the Institution's own membership, but some are drawn from other professions so as to obtain the necessary specialist expertise. They are not remunerated by the Institution for their work on its behalf.

BEPAG first reported in June 1994, and then approximately every two years since that date. Its reports constitute the IET's position on these matters. In January 1998, the terms of reference of BEPAG were extended to include frequencies up to 300 GHz to reflect public concern over possible health effects of radio-frequency fields, especially from mobile phones. BEPAG has produced a Factfile that introduces the subject area and discusses some of the key public concerns.

■ <http://www.theiet.org/factfiles/bioeffects/emfhealth.cfm>

BEPAG uses refereed (also known as peer-reviewed) scientific papers as its source material, in order that the papers it reviews meet a minimum quality standard. These are retrieved from a broad search of a range of electronic databases. The methodology and sources used are described in the Appendix.

BEPAG's search criteria also identify papers concerning the use of the earth's magnetic field by animals, birds or fish for navigation. BEPAG considers it has now been largely established that some species are indeed able to detect and use the earth's field. However, the mechanisms needed for alternating fields (whether at 50 Hz or at radio frequencies) to affect biological systems are likely to be very different from those for static fields. BEPAG considers that until

any evidence emerges that the mechanisms involved are transferable to alternating fields, the evidence on animal navigation has no direct relevance to health effects in humans, and BEPAG maintains a watching brief on that literature rather than assessing each paper in detail.

The following analysis indicates trends in the EMF literature, based on the simple metric of paper numbers.

The searches retrieved a total of 726 relevant papers in 2010 and 2011 combined, 11% lower than previously (2009/2010). Of these, 42% (previously 44%) covered static and low-frequencies, primarily relating to 50 and 60 Hz fields associated with power generation and distribution. 48% (previously 46%) of the papers dealt with radio-frequency fields, and 67% of these were specifically related to mobile-phone frequencies (previously 64%). These figures show an overall decrease in the number of relevant studies and a continuing, but now small, trend for EMFs and health research to refocus from power frequencies towards mobile-phone frequencies.

An analysis of those papers which contain new experimental data shows that, at electrical power frequencies (50 or 60 Hz), 80% (previously 81%) of the 113 (previously 88) such papers report biological effects, whereas at mobile-phone frequencies the figure is rather lower, 59% (previously 54%) of 170 (previously 144) papers. Interestingly, these figures show an increase in experimental studies, against a backdrop of decreasing papers overall. However, in many cases the effects amount to small changes in one or more physiological parameters where the impact on health is unclear. At low frequencies, in the range often studied for possible medical applications (typically a few Hz to a few kHz, but excluding power frequencies), 87% (previously 91%) of the 78 (previously 91) papers show effects. Overall 75% of experimental studies report the detection of field effects, unchanged from 2009/2010.

BEPAG continues to regard the fact that three out of every four experimental studies report biological effects as significant. If these findings are all robust it would suggest that such effects are common and readily demonstrable. Whilst it is traditionally assumed that scientific studies which are published in peer-reviewed literature are replicable, this does not appear to be the case for the EMF literature and is increasingly being challenged in other areas. For example recent comments from the pharmaceutical industry suggest that over 60% of its studies fail to confirm previous published work. Possible reasons cited include: incorrect or inappropriate statistical analysis; insufficient sample size; positive publication bias; and pressure to publish combined with competition between scientists leading to negligence. In the EMF literature attempts have been made to replicate key studies, which have often been selected because of their apparently sound methodology, robustness and potential significance of findings (for example, the body of work of the EMF Biological Research Trust: <http://www.emfbrt.org/index.shtml> and of the Mobile Telecommunications and Health Research (MTHR) programme: [http://www.mthr.org.uk/documents/MTHR\\_report\\_2007.pdf](http://www.mthr.org.uk/documents/MTHR_report_2007.pdf). These attempts



have been unable to confirm any of the original reports. Such failed replications represent a significant challenge to the science of EMFs: the high proportion of original experimental studies reporting effects suggests that they are reasonably easy to find in most of the models studied. However, the identification of even a single robust effect which could be used as a starting point to determine such factors as dose-response curves (the variation of effect with exposure level and duration), whether the effects are caused by electric or by magnetic fields, and to allow investigation of the mechanism (how the effects are caused), has proved problematic and, in the view of BEPAG, has yet to be achieved. Arguably this remains the key goal for future laboratory studies of EMF effects.

Because of the relatively clear distinction between low-frequency and high-frequency studies, coupled with the different types of sources involved and the likelihood that any mechanisms of interaction are different, BEPAG has continued to divide its assessment of the literature into these two frequency bands without attempting to define them rigidly.

The literature has been further divided into five scientific areas: epidemiology, human studies, animal studies, cellular studies, and mechanisms of interaction, to reflect the main categories of experimental studies.

The points below summarize the views of BEPAG on the latest published peer-reviewed literature in these areas, and on which, together with the content of previous reviews, the conclusions in this statement are based.

## Epidemiology

- Epidemiology is the observational study of the occurrence and distribution of diseases in populations. Exposure and other conditions in EMF studies cannot usually be well-defined and controlled. Interpretation of findings needs to consider potential biases in exposure assessment, selection of study subjects and data collection. Exposure assessment is a particular challenge because direct measurements are often not available or feasible and therefore exposure levels need to be inferred from information such as job title, wiring configuration of a house, or residential proximity to a power line, radio or mobile-phone mast. An additional complexity is that in case-control studies it is past, rather than current, exposure that is relevant in terms of possible disease causation, and this past exposure has to be retrospectively reconstructed. Recent studies have increasingly carried out direct measurements in subjects' homes or work place, which is an improvement, but assumes that these measurements are an accurate reflection of the relevant exposure in terms of disease causation. Epidemiological studies often have to rely on self-reported exposure information, such as past mobile-phone use, which is open to recall bias.
- In 2001, the International Agency for Research on Cancer (IARC) classified extremely low-frequency magnetic fields as possibly carcinogenic to humans. This decision was strongly influenced by epidemiological studies having observed increased risks of childhood leukaemia at high levels (greater than about 0.4 microteslas) of magnetic-field exposure to power-frequency EMFs. Studies published after 2001 have shown results compatible with those published prior to then. Two studies have suggested that exposure to EMFs may adversely affect survival in children already diagnosed with leukaemia. A pooled analysis of four childhood leukaemia studies, with direct measurement of EMFs, showed no evidence that night-time exposure accounted for the overall increased risk for childhood leukaemia. A recent study observed no association between childhood leukaemia and exposure to electrical contact currents (the small currents that can flow in the body when, for example, a metal water pipe or bath tap is touched). Potential reasons for the EMF-childhood leukaemia association continue to be a common and unanswered topic of research in the absence of a known mechanism to guide the design studies.
- Studies have investigated residential proximity to high-voltage overhead power lines, a source of relatively high exposure to power-frequency EMFs, in relation to overall mortality, general well-being, cancer, neurodegenerative disease, and adverse birth outcomes. The childhood leukaemia studies were suggestive of an increased risk with closer proximity. A meta-analysis of 13 childhood brain-tumour studies did not show increased risk with close proximity, but could not exclude the possibility of a moderately increased risk at high measured or predicted exposure levels. A large Swiss study reported increased mortality from Alzheimer's disease in people living within 50 metres of an overhead power line, based on a small number of deaths in this group. Residential proximity to transmission lines was not associated with adverse birth outcomes in a recent study. A study reported increased risk of asthma in offspring of women with high measured EMF exposure levels during pregnancy. Further studies are required to confirm this finding.
- Adverse health effects of exposure to low-frequency EMFs continue to be researched, in particular in occupational studies, where exposure levels are generally greater than in the general population, thus providing greater potential for detection of effects. Many health outcomes have been addressed including various cancers, cardiovascular disease, reproductive hormone and melatonin levels, and neurodegenerative disease such as Alzheimer's disease and amyotrophic lateral sclerosis (ALS). A pooled analysis of fourteen studies of Alzheimer's disease showed a raised risk in those occupationally exposed, but with considerable variation in results between studies, and without a dose dependent response. In two later cohort studies, mortality from Alzheimer's disease was not increased in UK electricity generation and transmission workers but was increased in Swiss railway employees. Some association has also been reported for ALS. A recent study of Swedish twins suggested that occupational EMF exposure was related to dementia with earlier onset. Diagnosis of dementias is particularly problematic and exposure assessment from job histories needs to be standardised. Further occupational studies

of neurodegenerative disease in relation to power-frequency EMFs are needed. Epidemiological research has not indicated strong or consistent associations of occupational radio-frequency exposure with cancer risks or other health outcomes.

- Data from two recent studies, in Germany and Australia, did not find evidence that occupational exposure of parents to power-frequency EMFs increased risk of leukaemia, non-Hodgkin's lymphoma and central nervous system (CNS) tumours in their children. In contrast, a Canadian study observed increased risks of brain cancer in offspring after maternal exposures. Earlier, smaller, studies into childhood cancers did not find consistent increased risks.
- There is continuing scientific debate and public concern over possible adverse health effects of exposure to radio-frequency fields from mobile phones and base stations. A considerable number of studies have now reported on intracranial tumours (glioma, meningioma and acoustic neuroma, a benign tumour of the auditory nerve next to the ear) and there are some studies of other types of cancer. The largest study conducted was the INTERPHONE case-control study, carried out in 13 countries worldwide and coordinated by IARC, to investigate the risk of intracranial tumours and parotid gland tumours and the use of mobile-phone handsets. Results on glioma and meningioma showed an apparently overall decreased risk of tumours in regular users compared with people who did not use a mobile phone regularly. As it seems implausible that mobile-phone use would have a protective effect, this possibly reflects participation bias (over-representation of mobile-phone users among controls) or other methodological limitations. There was no association of risk with time since first use, or cumulative number of calls. Risk of glioma was increased in users in the top decile (10%) of cumulative call time, but this category included individuals reporting implausible daily usage times, and there was no upward trend in the other nine deciles. Results on acoustic neuroma were broadly similar to those for meningioma, although in a secondary analysis where only mobile-phone use more than 5 year prior to diagnosis was considered, an increased risk was observed in the top decile of cumulative call time. The study concluded that limitations in the data and lack of clear evidence of causality, such as dose-response, prevented a causal interpretation. Despite it being much the largest study done into this question, the study's power to investigate long-term risks was still limited, in particular for a slow-growing tumour such as acoustic neuroma. Future studies would need to address longer-term risks and rely less on self-reported exposure. A multinational cohort study, including the UK, is currently underway investigating health of mobile-phone subscribers.
- In 2011, a Working Group from IARC concluded that there is "limited evidence in humans" for the carcinogenicity of radio-frequency EMFs, based on positive associations between glioma and acoustic neuroma and exposure to radio-frequency EMFs from mobile phones from case-control studies. However, recent studies of historical brain-tumour rates in the UK, US and Nordic countries have not observed increases that could be due to the uptake of mobile-phone use in the population, including data up to 2009 in Sweden, one of the first countries to introduce mobile phones. If future updates of incidence data in countries with early and high-level uptake of mobile-phone technology fail to detect rate increases, it would provide strong evidence against a mobile-phone effect. Also, a cohort study of 420,000 mobile-phone subscribers in Denmark followed up for cancer has not shown increases in risk of brain tumours or acoustic neuroma.
- Studies of other types of cancer in relation to mobile-phone use have included leukaemia, non-Hodgkin's lymphoma, melanoma, testicular cancer and salivary-gland tumours, and have generally not found convincing evidence of an association.
- Recent studies have increasingly focused on other health outcomes than cancer in mobile-phone users. The Danish mobile-phone subscriber study also reported on other outcomes and showed no increase in risk of hospital contact for Alzheimer's disease, other dementia, ALS or other central-nervous-system disease with time since having the subscription. There are some reports of adverse effects of semen quality and an increased risk of tinnitus in mobile-phone users but these studies were small and methodologically weak.
- Studies increasingly focus on health effects of mobile-phone use in children, including cancer, well-being, cognitive effects and behavioural problems. A large international study of childhood brain tumours recently reported no association with mobile-phone use. Recent studies found no substantial evidence that children whose mothers used a mobile phone during pregnancy were adversely affected in neurodevelopment or other developmental milestones in infancy. Two studies reported increased behavioural problems at age 7 years after prenatal and postnatal exposure; this is potentially due to confounding by maternal behaviours. Another study showed that in adolescents, mobile-phone users had faster and less accurate responses to higher-level cognitive tasks but, such behaviours could have been learnt through frequent phone use, rather than be caused by radio-frequency EMFs.
- Mobile-phone base stations remain a cause of public concern, and an increasing number of studies have specifically reported on this. A British study recently reported no association between risk of early childhood cancers and estimates of maternal exposure to mobile-phone base stations during pregnancy. A recent German cohort study found no association between radio-frequency exposure and non-specific symptoms or tinnitus, and two other large cross-sectional studies, one of them in children, did not find evidence that measured residential exposure to radio-frequency EMFs was associated with a variety of health complaints.
- Two large case-control studies have investigated exposure to fields from radio transmitters and childhood-leukaemia risk. One, in South Korea, observed an excess risk of childhood leukaemia in proximity to AM transmitters, but not with individuals' predicted radio-

frequency exposure levels. The other, in Germany, did not find excess risk at close proximity, or with predicted exposure levels from AM or FM transmitters. These two studies weaken findings from earlier reports on leukaemia clusters around radio and television broadcast transmitters, which relied on distance alone as a surrogate measure of exposure.

- Studies of adverse effects of occupational exposures to radio-frequency EMFs, such as military personnel exposed to radar, include a large range of health effects. Overall no strong, consistent associations have been observed. Some recent studies looked at mortality, cancer and infertility. Some associations were reported, but the studies had weaknesses in exposure and outcome assessment as well as other methodological problems. Also, for cancer, it was often difficult to separate the effect of radio-frequency EMFs from other known hazardous exposures such as ionising radiation.

In summary, the epidemiological evidence over the past two years has not indicated a need for increased concern about health effects from electromagnetic fields, and the absence of clear evidence of health effects, despite on-going research, could be regarded as reassuring.

## Human Studies

- Overall, recent laboratory studies with volunteers continue to indicate that short-term exposure to EMF at levels usually found in the environment do not result in consistent or reproducible biological effects. Nevertheless, some studies have continued to report a variety of field-related effects often using new exposure or novel biological end-points. There is no obvious pattern or trend to the reported effects, nor obvious indications of a potential mechanism. The absence of replication studies represents a hurdle in evaluating this literature.
- Only a few studies using power-frequency fields have been undertaken. Subjects who describe themselves as sensitive to low-frequency fields have been shown to report increased symptoms when they think they are being exposed, even if they are not (the nocebo effect). Other studies have reported field-dependent cellular, cytogenetic and haematology effects as well as melatonin alterations.
- Reflecting current public concerns, most recent studies with volunteers have focused on the effects of radio-frequency fields associated with mobile phones.
- A wide range of endpoints have been investigated, with no obvious pattern to the results. For example, a negative impact on sperm quality and an asymmetry in hip mineralisation have been reported, as have subtle changes in heart rate and lipid biochemistry. Inconsistent results were reported in a correlation study between the years of use and prostaglandin synthesis, and in a study examining stress markers in people living close to base stations. Exposure to radio-frequency fields was reported to correlate with involuntary hand movements while driving and with behavioural problems in adolescents (but not in children). In cancer patients, use of radio-frequency fields was reported to have

a therapeutic effect by increasing the number and cytotoxicity of natural killer cells.

- Childhood exposures to mobile-phone frequencies do not appear to induce cognitive changes or to affect auditory potentials. In contrast, adult exposures were reported to induce changes in cochlear-nerve compound action potentials, but were not associated with hearing loss. Many adult studies consistently report no effects on cognitive function, performance, psychomotor effects, or on auditory brain-stem responses.
- A worsening of headaches associated with prolonged mobile-phone use has also been reported, although a causal relationship with radio-frequency exposure has not been shown. Most studies using base stations did not report an increase in symptoms or any physiological change.
- Most volunteer studies have focused on changes to brain activity observed using Electroencephalography (EEG). For example, two studies have reported that older volunteers showed an increase in the alpha rhythm, although another study reported this rhythm increased only in young adults. The type of mobile-phone signal may also influence any effect.
- Four studies investigating effects on sleep quality after exposure to radio-frequency fields did not report any change, although one study suggested that high use of mobile phones was associated with increased stress, sleep disturbances and depression in young adults. Sleeping near base stations was reported to adversely impact those concerned about EMFs, and to worsen symptoms. There were no differences reported in the sleep EEG of hypersensitive and normal volunteers under controlled exposure conditions.
- Terrestrial trunked radio (TETRA) is used by the emergency services in the UK. Two studies investigated (pulsed) TETRA signals, and both studies showed exposure did not cause any physiological or cognitive changes, although a study using a continuous field reported that exposure caused headaches, fatigue and concentration difficulties. However, perhaps of greatest interest was the study from the USA that reported exposure to mobile-phone signals increased brain glucose metabolism. This only occurred in the areas of the brain closest to the antenna, and the metabolism averaged over the whole brain was not affected. The mechanisms for the changes in glucose metabolism remain unclear.

## Animal Studies

- Recent laboratory studies with animals have continued to use a wide variety of experimental models and exposure conditions. Many of these studies have reported that exposure produces biological effects; some adverse, others beneficial, but none of these has been independently replicated.
- The main focus of laboratory research using static magnetic fields has been on oxidative stress. Daily exposure of rodents was reported to increase oxidative stress in the brain, heart and muscles. Static magnetic fields have also been reported to prevent preterm birth losses, and to have protective effects in diabetic mice.

- Studies using static magnetic fields have shown no effect on blood flow, cytogenetics or haematology. Effects on heart rate remain unclear, as do effects on learning.
- There continues to be interest in the biological effects of low-frequency magnetic fields. Effects on sperm morphology and embryo development have been reported. A small number of studies reported effects on invertebrate development, but it is difficult to determine the impact of these changes on human health.
- Several low-frequency magnetic-field studies report small changes in motor behaviour of rodents, possibly as a consequence of stresses associated with exposure. Memory deficits have been reported in prenatally exposed chicks and memory improvements in chronically exposed adult rats. Several studies on the antioxidant system in brain, heart and liver have reported increased oxidative stress and reduced antioxidant defence, while DNA damage has been reported after chronic exposure. An increase in apoptosis has been reported, but this was dependent on the organ studied.
- The synergistic effects of low-frequency fields and chemical agents have been investigated on tumour inhibition, with conflicting results; when used alone, these fields do not appear to affect lymphoma development or the progression of CNS inflammation. One study reported that chronic exposure in spinal-cord-transected rats may be protective.
- Low-frequency magnetic fields have been suggested to have beneficial effects by inducing angiogenesis and improving cardiac function. Beneficial effects in healing and repair have been reported, but, along with effects on bone and nerve excitability still appear inconclusive. Two studies reported that magneto-therapy alters the antioxidant response and this appeared to be dependent on exposure duration. A synergistic effect due to combined exposure to low-frequency fields and x-rays has been reported to increase tumour inhibition and survival time in mice.
- Interest has also continued in the possible biological effects of radio-frequency fields, particularly those associated with mobile phones. Exposure to radio-frequency fields has been reported to alter markers associated with inflammation, oxidative stress and metabolism. One study could not replicate an early Soviet study where blood taken from exposed animals and injected into pregnant animals resulted in increased mortality of offspring. In another study using prenatal exposure of mice to Wi-Fi signals, no effects were seen on pregnancy outcome, or B cell differentiation and function.
- A number of studies have looked at the possible therapeutic value of pulsed radio-frequency fields, and these include studies looking at the effect of increased pain thresholds. An anti-inflammatory effect on fatty acids has been reported, but another study reported that these fields do not affect tumour development.
- Some rodent studies have focussed on effects on male fertility (sperm count, mobility and motility). Many of these have reported effects but there are also well conducted studies reporting an absence of effects. In agreement with earlier studies, the majority of recent studies have shown no malformation effects on embryos or fetuses.
- The brain has been the focus of most animal studies with mobile-phone signals, and while various effects have been reported, there appears to be no obvious correlation between these results. Exposure was reported to cause an increase in local temperature and blood flow, as well as increasing the damage response, altering antibody production and the antioxidant response. Behavioural studies have reported memory deficits, but no effect on spatial learning or stress/anxiety. There appears to be no deficit in the auditory function of newborn or adult rats.
- The glial response in the brain remains the subject of much investigation, with most studies reporting a lack of microglial activation; several studies report that exposure causes cell loss, and others report increases in the numbers of apoptotic cells. However, there are numerous reports of an absence of cellular changes. Many of the reported adverse changes appear dependent on exposure duration.
- The most notable paper published within this time period is one which suggests a protective effect of mobile-phone exposure in a model of Alzheimer's disease. Both transgenic and normal animals showed improved cognitive performance following long-term repeated exposure. In addition, EMF exposure decreased the rate of plaque formation in the Alzheimer's mice. This has a potential impact on many other brain inflammatory conditions and needs to be independently replicated.

## Cellular Studies

- The direct effects of EMFs on isolated cells and molecules have been studied in a wide range of biological systems from bacteria to human cells. This type of study allows a wide variety of exposures to be tested relatively quickly in well-defined and controlled conditions. Such studies can focus on potential effects in areas of interest, for instance DNA damage, cell growth or metabolic activity; and also ascertain the mechanisms involved in these interactions. The limitations are that the experiments use very simplified biological systems, such as isolated cells grown in Petri-dishes, and the observed effects may not translate into real changes in animals or humans. Therefore, the effects found in these experimental systems, although very useful indicators cannot be directly extrapolated to a health risk.
- There have been approximately two hundred cellular publications in the last two years with two thirds of the number fairly equally divided between static, low frequency and power frequencies; mobile-phone and radio-frequency studies make up the other third.
- The static magnetic-field exposures used in cellular studies tend to be high (typically several tens of millitesla) in comparison to the earth's magnetic field to which we are all exposed (approximately 50 microteslas). The main area of research has been the possible effect on cell growth and metabolism; however, there has been an increasing interest into the possible effect on plant seeds. Most of the published studies claim a stimulatory effect but the lack of independent replication makes the



robustness of the claimed effects uncertain.

- About one in three of the cellular studies at low-frequency exposure (excluding power frequencies) are investigations of pulsed EMFs. These tend to be concerned with medical applications and in particular with repair or pain relief in musculoskeletal disorders. Most studies report effects, but despite the many publications over several years, the effects, in general, lack independent verification.
- Previously, there has been little evidence that EMF exposure (power frequencies, 50-60 Hz) can cause carcinogenic changes in cells. In the past two years there have been very few new publications on potential carcinogenic effects. There is still no good evidence that isolated cells are susceptible to low field strengths despite the association between exposure and childhood leukaemia shown in epidemiological studies. Most of the newer studies have investigated possible metabolic effects, such as cell growth, enzyme activity or free-radical production, and the majority find effects. However, the results obtained are divided between stimulatory and inhibitory effects. The few independent replications undertaken cast doubt about the robustness of the initial findings and add to the controversy as to whether claimed effects are real.
- The number of research papers devoted to possible cellular effects of exposure to radio-frequency fields has again been maintained at one in three of the total electromagnetic-field studies undertaken. Particular attention continues to be paid to the frequencies used by mobile telecommunications. A number of studies have focused on whether mobile-phone frequencies could be carcinogenic. The majority of studies find no evidence of such an effect. For studies that do report an effect, independent replication is lacking or has failed to confirm the finding. Although potential direct carcinogenic effects remain of interest, most of the published studies have investigated effects on cell metabolism and function. The results obtained are equally split between stimulation, inhibition and no effect; as none has been independently verified their significance, if any, is unknown.
- There is considerable doubt about the robustness of all claimed cellular effects (both beneficial and harmful) due to EMF exposure at any frequency using field strengths to which the public might be exposed. Relatively few independent replications of claimed effects have been undertaken and none of these replications has robustly confirmed the original observation. Furthermore, and importantly, the effects that are reported do not appear to follow a consistent pattern in terms of exposure parameters or biological response.

### Power-Frequency Mechanisms

- The absence of a plausible biophysical mechanism operating at environmental levels of exposure to power-frequency EMFs remains a significant component in the weight of the evidence against health effects. A focus remains on research around the effect of magnetic fields on free radicals as a possible mechanism, including possible insights gained from study of magnetoreception in birds and animals.

- Just as in previous years, there are major obstacles in the way of accepting any of the current candidate mechanisms as an explanation for the associations suggested by epidemiological studies. For free radicals, for example, it remains doubtful whether this mechanism could produce effects at the microtesla level implicated by the epidemiology, and whether any effect of power-frequency fields at these levels could be significant when compared to effects of the larger earth's static magnetic field and its variation with location around the world and due to distortion by ferromagnetic objects such as car bodies, lifts, reinforcing steel in buildings etc.
- However, in view of the importance of establishing a mechanism if there are in fact health effects, BEPAG considers that these and any other suggested mechanisms should continue to be studied objectively, but rooted firmly in their relevance to the parameters of public exposure and their health implications.

### Radio-Frequency Mechanisms

- For radio frequencies, well-established modeling and measurement techniques have been refined and applied to the comparative assessment of exposure of adults and children to EMFs from mobile-phones and environmental sources. Research in this field is driven by the need for testing compliance with exposure guidelines. High-resolution modeling is being used to assess the exposure from high-frequency sources up to and including the terahertz range.
- No mechanism has been established by which high-frequency EMFs can have biological effects at levels below those that cause heating; all known effects are heat-mediated.
- The hypothesis that localised regions of high-power deposition may occur at subcellular level is being studied using microdosimetry modeling of continuous and pulsed fields. With pulsed fields comes the possibility that they may give rise to non-linear interactions and that there might be some cellular component capable of demodulating these fields. The design of experiments to test such theories is notoriously difficult but a UK-funded project intended to detect non-linear responses at 900 MHz has failed to confirm the presence of a non-linear effect. At this stage, the hypothesis remains speculative.
- The magnetic properties of most biological materials are close to those of free space; however, reports of the presence of magnetite in animal brain tissue may provide a mechanism for direct interaction of magnetic fields with the central nervous system. Mechanisms have been proposed whereby biogenic magnetite in the brain could act as a transducer of both low-frequency magnetic fields and radio-frequency fields. These models rely on the fact that magnetite will couple strongly to the magnetic fields either through ferromagnetic resonance effects or mechanical effects. In theory, these effects could influence membrane ion channels and disrupt the normal functioning of cells in the brain. The work in this field is still very limited, the plausibility of the mechanisms is being debated, and the role of magnetite in the human brain is the subject of ongoing research.

## Appendix

### Search Criteria

BEPAG concentrates on peer-reviewed literature retrieved by broad category, computerised, monthly searches of relevant major databases, currently: INSPEC, MEDLINE and BIOSIS.

- **INSPEC** is a database maintained by the IET. Coverage is centered on four main subject areas: physics; electrical engineering; electronics and communications; computers, computing and information technology.
- **MEDLINE** is the database maintained by the US National Library of Medicine (NLM). It provides access to articles published in more than 3,900 biomedical journals published around the world.
- **BIOSIS** is an American 'not-for-profit organisation' that publishes biological abstracts and zoological records. It provides access to 6,000 periodicals covering biological and biomedical sciences.

### Previous BEPAG Reports:

1. 'The Possible Biological Effects of Low-frequency Electromagnetic Fields' (Public Affairs Board Report No 10 - July 1991)
2. 'The Possible Biological Effects of Low-frequency Electromagnetic Fields' (Supplement to PAB Report No 10 - June 1994)
3. 'Possible Harmful Biological Effects of Low-level, Low-frequency, Electromagnetic Fields' (IEE Position Statement - November 1996)
4. 'Possible Harmful Biological Effects of Low-level, Low-frequency, Electromagnetic fields' (IEE Position Statement - May 1998)
5. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IEE Position Statement - May 2000)
6. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IEE Position Statement - May 2002)
7. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IEE Position Statement - May 2004)
8. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IET Position Statement - May 2006)
9. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IET Position Statement - May 2008)
10. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IET Position Statement - May 2010)

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