The Institution of Engineering and Technology

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Do low-level **Electromagnetic Fields up to 300GHz** harm us?

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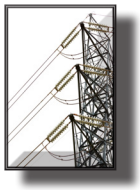
Summary

The Institution of Engineering and Technology (IET) has a special interest in possible health effects of occupational and general-population exposure to electromagnetic fields (EMFs) because of its leading role in engineering and technology, particularly in electronic and electrical engineering. The IET remains determined to be at the forefront of the examination of the scientific evidence for 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 in this report that the balance of scientific evidence to date does not indicate that harmful effects occur in humans due to low-level exposure to EMFs. Our examination of the peer-reviewed literature published in the last two years has not justified a change in the overall conclusions published in our previous report in May 2014.



Power Frequencies

At power frequencies (50 or 60 Hz, as used for electricity supply), 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 remains unsubstantiated. There is no generally accepted experimental demonstration of any biological effect, harmful or otherwise, due to such fields. Pooled analyses of epidemiological studies have shown an association between childhood leukaemia and higher levels of power-frequency magnetic fields (greater than about 0.4 microteslas). 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. A major epidemiological study published in early 2014 suggests that the risk of childhood leukaemia associated with living near high-voltage power lines has decreased over the past forty years and is no longer elevated, despite the magnetic fields from the lines having increased along with electricity consumption.

A subsequent Danish study has reported a similar decrease in risk with time. These findings make a link between the fields from power lines and leukaemia less likely and suggest potential new avenues for research, such as the effect of population changes on the incidence of the disease.

Higher Frequencies

At higher frequencies (such as those used for mobile communications), 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 health effects from long-term mobile phone use. Mobile phones have been in widespread use for some 25 years 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, remains the largest analysis of long-term users to date. The INTERPHONE Study Group concluded 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, which suggests (although the length of time before any such effects would appear remains uncertain) that the high risks reported in some studies are implausible.

The Group noted the publication of the final report of the UK Mobile Telecommunications Health Research (MTHR) programme in early 2014, summarising the findings of its studies from 2001-2012. The programme funded 31 projects, which have resulted in almost 60 papers in peer-reviewed science journals. Focused largely on mobile phone and TETRA signals the report concluded that none of the studies showed effects of the signals being tested. In particular they singled out their negative studies on the effects of signal modulation as having 'extremely important implications' and 'constitute a substantial body of evidence that modulation does not play a significant role in the interaction of radio-frequency fields with biological systems'.

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. Field 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.

Wi-Fi is now also widespread, from sources which include: mobile phones; tablets; laptop computers; home routers; networks in schools, universities, hospitals and similar large organisations; and, in some cases, city-wide municipal networks. Wi-Fi signals are similar in type to those from mobile phone networks and would not be expected to have unique health effects. Peak exposure powers are less than those from mobile phone handsets.

Robustness of the scientific literature and its reporting

Widely publicised experimental studies that subsequently 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 believes that pressures on scientists to publish their work may encourage the reporting of apparent effects that have not been adequately investigated or reliably demonstrated. This phenomenon has been specifically identified in the pharmacology and psychology literature and one major organisation has reported being unable to reproduce 47 out of 53 'landmark' cancer studies.

BEPAG recognises that many of the published papers describe EMF effects. This may be partly attributed to a natural tendency for journals to favour such studies and to a lack of motivation for researchers to submit for publication studies that show no effects. We would encourage both journals and authors to recognise the importance of all findings.

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 rigorous internal quality control mechanisms to help mitigate this problem.

BEPAG regards the independent replication of experimental studies to be essential in order to improve the quality of the existing literature and to verify reported effects. 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 a study should be under an obligation to publish a subsequent well-conducted replication study even if this fails to confirm the original findings. Replication of existing studies is often seen as 'unglamorous' by scientists but BEPAG is of the view that it should be actively encouraged and supported by funding bodies to ensure that the development of knowledge proceeds on sound foundations.

BEPAG notes that the media still feature stories on EMF health effects, sometimes giving them more prominence than scientifically warranted, which heightens public concern. Whilst understanding the drive for 'good copy' we believe the emphasis should be on the word 'good' and that the media must present a balanced view of scientific knowledge rather than leading on sensationalist, but unreplicated or unverified, reports.

New technologies

Technologies that produce electromagnetic fields are continually evolving. Examples of this are 4G communication systems, smart-metering, and non-contact charging devices. BEPAG will keep health-effects papers concerning these technologies 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 numerous health benefits. BEPAG is of the opinion that it remains important 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 any precautionary approaches to public exposure and 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 160,000 professionally qualified members worldwide, all of whom in both their professional and private lives are exposed to electromagnetic fields (EMFs, the electric and magnetic fields created by the flow of electricity). 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 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 assessing 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 and are specifically required not to be influenced by the interests of their employers, or other third parties.

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 and other sources such as Wi-Fi. BEPAG has produced a Factfile that introduces the subject area and discusses some of the key public concerns (http://www.theiet.org/factfiles/bioeffects/emf-factfile-page.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 50/60 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. Hence BEPAG maintains a watching brief on that literature rather than assessing each paper in detail.

Figure 1 shows the number of papers that provided the data for each of the Position Statements since 2004. The overall numbers have steadily declined since the peak in 2008 and are now some 42% lower. A comparison of numbers of papers for power and mobile phone frequencies shows a similar trend in the former with the latter remaining approximately constant. Approximately 40% of the papers fell outside these specific frequency categories, predominantly split between other radio and low frequencies.

Figure 1: Number of papers by EMF Frequency

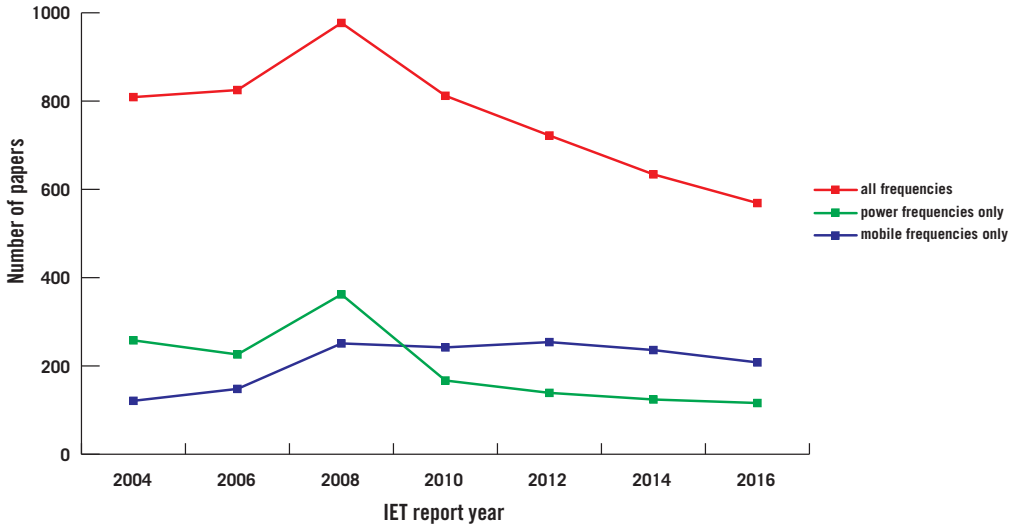


Figure 2 shows the split in papers based on their model type or methodology. Animal studies have continued to increase and have now become the most numerous in the BEPAG categories, which may be partly due to the increasing number of papers on EMFs originating from outside Europe and the USA. The largest decline, of over 90% since 2004, can be seen in the 'physics' category, which includes dosimetry studies.

This, perhaps, reflects the absence of any new mechanisms of interaction and the maturity of the topic of environmental dosimetry, but also the absence of an evolving basic scientific underpinning of the subject area.

Figure 2: Number of papers by category

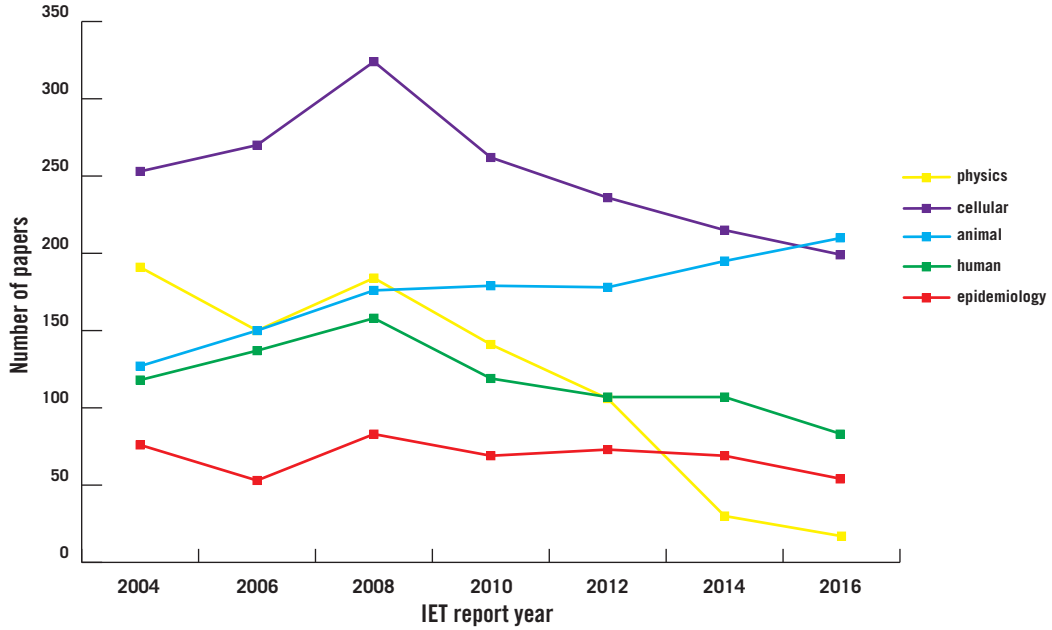
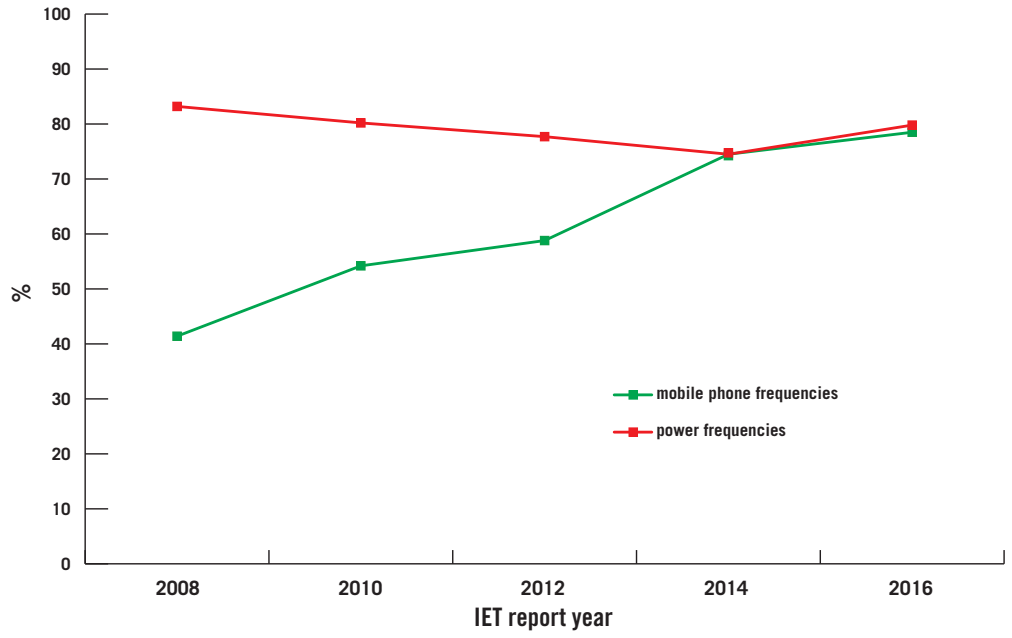


Figure 3 shows the continuing increase in the proportion of mobile phone studies which report EMF effects. This is perhaps surprising given that major research programmes predominantly report a lack of effects, and perhaps reflects a trend towards smaller isolated studies with less quality control. Over the same period, the percentage of power-frequency papers reporting EMF effects has remained largely unchanged.

BEPAG continues to find it remarkable that four out of five experimental studies, using a wide range of both models and exposure parameters, report the detection of a biological effect. Most of these effects are reported in animal or cellular models. If these findings are all robust they would suggest that such effects are common, not critically dependent on the experimental system or methodology and that they are readily demonstrable. Whilst it is traditionally assumed that those scientific studies which are published in peer-reviewed literature are both robust and 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 a majority 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, 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 and of the Mobile Telecommunications and Health Research (MTHR) programme: http://mthr.org.uk). These attempts have been unable to confirm any of the original reports. Such failed replications represent a major challenge to the science of EMFs: the high proportion of original experimental studies reporting effects would appear to indicate 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

Figure 3: Percentage of papers reporting an EMF effect



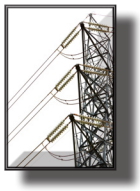
mechanisms of interaction are different, BEPAG has continued to divide its assessment of the literature into these two frequency bands without attempting to define them rigidly. Particular focus has been given to power-frequency (50/60Hz) fields and mobile-phone frequencies, as these are the source of most public concern and represent the majority of the papers evaluated. At frequencies above those used for mobile communications there are few health-effects studies.

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 summarise 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.

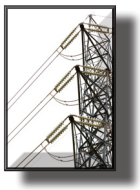
Epidemiology

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. Some recent studies have carried out direct measurements in subjects' homes, or work places, which are an improvement, but this 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 bias, and some rely on self-reported health effects which may be biased due to study participation.



Childhood leukaemia

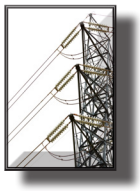
In 2001, the International Agency for Research on Cancer (IARC) classified power-frequency magnetic fields as possibly carcinogenic to humans. This decision was strongly influenced by epidemiological studies having observed increased risks of childhood leukaemia at comparatively high levels (greater than about 0.4 microteslas) of magnetic-field exposure to power-frequency EMFs. Studies published after 2001 have shown compatible results to those published prior to then, although a very large study in the United Kingdom published in early 2014 showed that the previously reported increased risk of childhood leukaemia within 200 meters of the nearest overhead power line was limited to cases diagnosed between 1960-1990 and was not present thereafter. Similarly, a subsequent Danish study could not detect risk increases in children exposed to more than 0.4 microteslas for leukaemia diagnosed 1987-2003, whereas risks were increased for diagnoses during 1968-1986. Some earlier studies have suggested that exposure to EMFs may adversely affect survival in children already diagnosed with leukaemia, but a subsequent study refuted these findings. Because a causative role of magnetic fields is largely unsupported by laboratory studies or a known mechanism, potential reasons for the EMF-childhood leukaemia association continue to be investigated. A decline in leukaemia risk in proximity to power lines over time as shown by the recent UK study suggests that the elevated risk is not related to a physical effect of power lines but perhaps to changing population characteristics among those who live nearby. The researchers also investigated distance from underground high-voltage cables and found no association between distance from the cable and childhood leukaemia, suggesting that associations with overhead cables may not be caused by magnetic fields. Corona-ions (atmospheric ions produced by powerlines which are blown away by the wind and when inhaled might be retained longer in the airways) have been proposed as an alternative explanation, but a recent study of the spatial distribution of leukaemia cases did not produce evidence in favour of this hypothesis.



Overhead power lines and health outcomes

Studies have investigated residential proximity to high-voltage overhead power lines, a source of relatively high exposure to power-frequency EMFs, in relation to a wide range of outcomes including overall mortality, general well-being, cancer, neurodegenerative disease, and adverse birth outcomes. Regarding cancer, nearly all studies were of cancers in children. The childhood-leukaemia studies, as discussed above, were suggestive of an increased risk with closer proximity, although the latest study suggests this might be confined to previous decades. Studies of childhood brain-tumours did not collectively show increased risk with close proximity, but could not exclude the possibility of a moderately increased risk at high exposure levels. A UK study of cancer in adults did not detect associations between risk for several types of cancer and distance from the power line or magnetic-field strength. Regarding non-cancer outcomes, 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. There are some individual reports of associations of measured maternal EMF exposure during pregnancy with asthma and obesity in offspring, findings which require validation by further research. There is no convincing evidence for an association of EMF exposure with birth outcomes; a recent study reported no association of adverse birth outcomes with residential proximity to transmission lines, although another study reported an adverse effect on birth weight.



Occupational exposure and health outcomes

Adverse health effects of exposure to power-frequency EMFs continue to be researched, in particular in occupational studies, where exposure levels are sometimes 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-response relationship. 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. A recent study of Swedish twins suggested that occupational EMF exposure was related to dementia with earlier onset. Diagnosis of dementia is particularly problematic and exposure assessment from job histories needs to be standardised. Reports that collectively reviewed evidence from all past studies recently concluded that there might be weak associations between power-frequency EMFs and Alzheimer's Disease, Motor Neurone Disease and ALS. Further occupational studies of neurodegenerative disease in relation to power-frequency EMFs are needed.

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 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.

Mobile-phone use and cancer

There is continuing scientific debate and public concern over possible adverse health effects of exposure to radio-frequency fields from mobile phones. There are considerable numbers of studies on intracranial tumours, glioma, meningioma, and acoustic neuromas (benign tumours of the auditory nerve near the ear); and some studies on other types of cancer. The largest study on intracranial tumours was the INTERPHONE case-control study, conducted in 13 countries worldwide and coordinated by IARC. The results, published in 2010/2011, showed apparently overall decreased risks of tumours in regular users compared with people who did not use a phone regularly, which possibly reflects participation bias (over-representation of mobile-phone users among controls) or other methodological limitations, with no clear or consistent associations 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 there was no upward trend in the other nine deciles. The study concluded that limitations in the data and lack of clear evidence of causality, such as dose-response, prevented a causal interpretation. While the INTERPHONE study and its preceding reports on results from individual study centres did not report evidence for substantial risk increases among mobile-phone users, if any at all, a research group in North Sweden continues to report relatively large risk increases among users, based on case-control studies. The stark contrast between results from this group and the large body of other studies argues against a causal association and suggests that methodological issues are in play.

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 some

case-control studies. This issue will hopefully be clarified with results from studies of prospective design which have methodological advantages over case-control studies. Recently, a follow-up study of 790,000 women in the UK found that brain-tumour risks were not raised among those who reported mobile-phone use for the previous 7 years, with the possible exception of acoustic-neuroma risk. For the latter, increased risks were reported which were no longer present after extending the follow-up time of the study. 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. Further insights are provided by studies of trends in brain-tumour rates in populations. Recent studies in China, the UK, the USA, New Zealand and Nordic countries have not observed increases which could be attributed to the uptake of mobile-phone use in the population, including data from 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.

Studies of other types of cancer in relation to mobile-phone use have included leukaemia, non-Hodgkin's lymphoma, melanoma and other skin cancers, testicular cancer and salivary gland tumours, and generally have not found convincing evidence of an association. There is one large international study of childhood brain tumours, which reported no association with mobile-phone use.

Mobile-phone use and other health outcomes in adults

Recent studies have increasingly focused on health outcomes other 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. They also reported no elevation of risk of multiple sclerosis among subscribers overall, but found some increases after 10 years since first subscription, which were restricted to females and based on a very small number of cases; nevertheless this finding might require further follow-up. There are some reports of adverse effects of semen quality and pregnancy duration and an increased risk of tinnitus in mobile-phone users but these studies were small and methodologically weak.

Mobile-phone use and other health outcomes in children

We observed increasing numbers of studies focussing on health effects of mobile-phone use in children, including cancer, well-being, cognitive effects and behavioural problems. Recent studies reported no substantial evidence that children whose mothers used a mobile phone during pregnancy were adversely affected in neurodevelopment or other developmental milestones in infancy. Some studies reported increased behavioural problems at age 7 years following prenatal and postnatal exposure; this is potentially due to confounding by maternal behaviours. A study in South Korean school children observed an association of mobile-phone use with Attention Deficit Hyperactivity Disorder (ADHD) but it could not be established whether the mobile phone had caused the ADHD or whether children with this condition are inclined to use the phone more. Another study showed that in adolescents, mobile-phone users had faster and less accurate responses to higher-level cognitive tasks; such behaviours could have been learnt through frequent phone use, rather than be caused by radio-frequency EMFs. Similarly, children and adolescents who use mobile phones have reported increased fatigue, decreased sleep quality and were found to have decreased memory performance, whether this is due to RF-EMF or due to intensive phone use is unclear.

Mobile-phone base station, other radio-frequency transmissions and health

Base stations remain a cause of public concern, and an increasing number of studies have specifically reported on this. A large UK study reported no association between risk of early childhood cancers and estimates of maternal exposure to base stations during pregnancy. There are increasing numbers of studies of adult cancer or mortality around mobile-phone masts but they

are methodologically inadequate. Due to the ubiquitous nature of masts, the small geographic areas that exposures relate to, and small numbers of cases within such areas, this issue is particularly difficult to investigate. A 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 increased risk of childhood leukaemia in proximity to AM radio transmitters, but not with individuals' predicted radio-frequency exposure levels. The other, in Germany, did not find increased risk at close proximity or with predicted exposure levels from AM or FM radio 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.

Occupational exposures and health

Studies of adverse effects of occupational exposures to radio-frequencies, 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, ECG changes, infertility and pregnancy outcomes. 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, coupled with that from earlier studies, does not indicate 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

Most human studies have been carried out using radio-frequency signals. There have been very few recent studies exposing volunteers to EMFs at the low-frequency EMF levels usually found in the environment. Generally there is an absence of biological effects. Those investigated include behaviour, oxidative stress and damage to DNA. The continuing absence of replication studies represents a hurdle in evaluating this literature.

Higher Frequencies

Most studies of EMF exposure in humans have used mobile phone frequencies. Many of these studies have used EEG as an endpoint, with some of the observed changes depending on individual human characteristics such as an introvert or extrovert personality, but no consistent effects have been seen between studies. In studies of epilepsy there appears to be no increased risk of seizures.

Two published studies on semen quality suggest slight detrimental effects but without adequate exposure assessment.

It has been suggested that the use of mobile phones may have an effect on sleep deprivation and day sleepiness. In a separate study a lack of synergistic effect of caffeine with mobile phone use was reported.

No associations were found with exposure and salivary flow and enzyme concentrations. In other studies using saliva, effects on oxidative stress are contradictory. No changes in genetic abnormalities, or an indicator of DNA damage, were found in oral epithelium.

Studies investigating biomarkers in the serum of individuals exposed to mobile phone frequencies found differing results - one study found increased levels of stress markers and an indicator of inflammation while another found no effect. ECG parameters and respiration rate have also not shown field dependent effects.

Studies of individuals exposed to radio frequency-fields have also mainly used EEG as an experimental endpoint, but the results are varying. These fields have also been reported to influence plasma melatonin and serotonin concentration but the studies have yet to be replicated.

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.

Very few studies have been undertaken using static magnetic fields, and some have used invertebrate models making it difficult to determine the impact of any observed changes on human health. In other studies, static fields were reported to be beneficial by improving outcome following inflammation in the brain, lungs and ear. There are also positive effects reported on nerve regeneration and bone tendon injury.

Lower Frequencies

There continues to be interest in possible biological effects of low-frequency magnetic fields, particularly the potential therapeutic effects that these fields may have for diabetes, heart disease and osteoporosis, and for inhibiting tumour growth. These fields are increasingly being studied for potential neuroprotective effects on the brain and central nervous system and have been reported to affect the antioxidant balance in various tissues.

Higher Frequencies

Most laboratory research has used mobile-phone signals; however, in contrast to previous reviewing periods, there was approximately the same number of studies showing no effect of exposure on central nervous system structure as those showing a field-dependent effect of exposure. Additional reported adverse effects on the brain include increased apoptosis, neuronal damage, modifications to brain biochemistry, changes in sleep patterns and altered gene regulation factors.

There has been an increase in the number of studies on the effect of prenatal or early life exposures, where some adverse effects were seen in kidney, the cochlea and the male reproductive system in the exposed offspring. Reproductive function and gestational outcome continue to be investigated. Again approximately the same number of studies showed no effect on function and outcome, including sperm characteristics and foetus growth, as those which showed an adverse effect on male reproductive function, including sperm motility and morphological parameters.

Oxidative stress in different tissues has been examined in many studies, and field-related effects have been consistently reported in various tissues, including brain and liver.

A few papers reported that there is no direct effect of mobile phone exposure on bone mineralisation or teeth hardness but that there is a potential adverse effect on connective tissues such as skin and bladder tissue.

A high-profile study on tumour promotion in mice was recently published following life-long RF exposure that was below guideline values. This study showed an increase in lung and liver tumours but there was no dose-response relationship, an essential requirement for any robust finding.

A small number of papers showed no effect of exposure on the brain in terms of behaviour or circulation, but in contrast, other studies on the brain showed oxidative stress, alteration of gene regulation factors, and DNA damage in brain tissue. It has also been reported that high frequencies can possibly be used therapeutically to reduce Alzheimer's Disease-like pathology and demyelination in nerve injury. Reproductive function continues to be an area of interest, where a detrimental effect has been reported in male and female rodents.

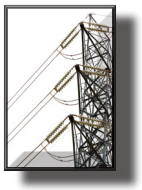
Cellular Studies

Cellular studies are used extensively to investigate possible biological effects of exposure to EMFs. The studies cover a broad range of investigations from individual proteins to human cells grown in plastic dishes. The advantage of these laboratory investigations is that they allow a wide variety of exposures to be tested relatively quickly in well-defined and controlled conditions. The techniques used can focus on potential effects in areas of interest, for instance genetic damage, cell growth or protein structure; they can also help ascertain the mechanisms involved in these interactions. The disadvantage is that the studies use very simplified biological systems, such as isolated cells grown in Petri-dishes. Hence the results are, at best, indications of what might happen in whole organisms and may not translate into real change in animals or man. Therefore, if effects are found in these experimental systems, although potentially useful indicators, they cannot be directly extrapolated to a health risk.

The number of cellular studies has decreased in the last two years, but is still a sizable body of literature. Almost a third of the publications were studies looking for biological effects of exposure to mobile phone and radio frequencies, a reduction in proportion from the previous review. The other studies mainly investigated low frequency effects; half of these were devoted to power frequencies (50 - 60Hz). There were only a few static field studies.

The static magnetic field exposures used in cellular studies tend to be high in comparison to the geomagnetic field, typically many milliteslas (the earth's static field being approximately 50 microteslas). This area of research has been mainly focussed on possible effects on cell growth and metabolism: most studies find effects, some are potentially adverse whereas others could be beneficial. There is a lack of overlap with previous studies in that each study uses a different exposure and cellular system. This lack of independent replication makes the robustness of the claimed effects uncertain.

About 10% of the cellular studies investigated pulsed EMFs. These tend to be aimed at medical applications: repair and pain relief in musculoskeletal disorders, or combined with other therapies to, for example, enhance anti-tumour or bacterial effects. Nearly all studies report potentially beneficial effects but, despite the many publications over several years, the effects, in general, lack independent verification.



Power Frequencies

There is little evidence that power frequency EMF exposure causes carcinogenic changes in cells. Very few new studies have investigated direct carcinogenic effects; most studies looking for adverse effects have investigated possible metabolic changes, such as cell growth, enzyme activity or free radical production. Interestingly, about a quarter of the studies have investigated potential beneficial effects such as stimulating stem cells to become bone forming cells. The majority (over 80%) of studies find effects; however, the whole research area is contradictory because opposing results can be found with apparently similar exposures and cells. Very few independent replications were undertaken in the last two year period, even less than previous years; this lack of independent verification is a serious problem for the interpretation of the data and adds to the uncertainty as to whether claimed effects are real.

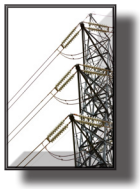
Higher Frequencies

The number of research papers devoted to possible cellular effects of exposure to radio-frequency fields has decreased from two years ago. However, most of these new studies are still investigating the frequencies used by mobile telecommunications. These studies have given no new insights and the evidence for a direct carcinogenic effect still remains weak. The majority of the studies investigated effects on cell metabolism and function; a few looked for potentially beneficial effects whereas others examined the possible harmful results of exposure. For the 75% of studies that report an effect there is a lack of independent confirmation. Since none of the findings have been independently verified, their significance, if any, is unknown.

In summary, there is considerable doubt about the robustness of all the 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 the majority of

these replications do not confirm the original observation. Furthermore, the effects that are reported do not appear to follow a consistent pattern in terms of exposure parameters or biological response. A major difficulty in understanding possible effects, or predicting biological systems sensitive to EMF, is the lack of any known mechanism of action between physics and biology for these low energy signals.

Mechanisms of interaction



Power Frequencies

At high enough levels, power-frequency EMFs interact with the body through the well-understood mechanism of inducing fields; these are the effects protected against by exposure limits. However, 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 at these lower levels. Ongoing research on one of the most promising candidates, the effect of magnetic fields on free radicals (including possible insights gained from study of magnetoreception in birds and animals), continues to refine the understanding of that mechanism, but has failed to demonstrate that it could be operating in the circumstances required to explain the epidemiological findings.

However, in view of the importance of establishing a mechanism as to whether there are health effects, BEPAG considers that this and any other suggested mechanisms should continue to be studied objectively, but stay rooted firmly in their relevance to the parameters of public exposure and any health implications which may result.

An alternative to EMF effects is that some of the epidemiological findings, specifically those related to high-voltage power lines, might be a result not of magnetic fields but of some other factor related to such power lines, perhaps the characteristics of the areas through which they pass. No specific mechanism has been identified, but it would be a way of explaining the absence of a plausible mechanism for magnetic fields. This line of thinking was given new impetus by the 2014 UK study suggesting that elevated childhood-leukaemia rates near power lines have decreased over time and are no longer elevated.

Higher Frequencies

Research continues into the effects of exposure to higher frequency electromagnetic fields, however the accepted scientific consensus including that of BEPAG, has not changed from previous position statements. It is that, at higher frequencies, the only established effect of EMF exposure on biological tissues is that of heating.

Furthermore, when the exposure levels are within current guidelines, human physiology can adequately dissipate the resultant energy deposition as these levels have been set with this specifically in mind.

There continues to be speculation that low-frequency pulsing of modulated high-frequency signals may give rise to non-thermal interactions and that there might be some cellular structures capable of demodulating these fields. However this hypothesis is unproven and studies which have been published in previous years mitigate against this.

With short-term exposures being well investigated and understood, epidemiological studies are thus the focus of many research groups in an attempt to identify additional mechanisms of interaction. These studies often focus on children and young adults to capture a cohort of potentially long-term-exposed people and thus increasing the chances of identifying exposure-attributed health effects which, in turn, may shed light on the mechanism of interaction.

Additionally it is worth noting that these research cohorts are also being exposed to an increasing number of other EMF sources with the current developments into connected homes and society. It is believed that this will lead to a different exposure model to which, although hard to define, the epidemiological studies should be sensitive. BEPAG will continue to monitor these studies, although they may not conclude and report for a number of years.

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. It has been suggested that biogenic magnetite in the brain could act as a transducer of EMFs. The work in this field is still very limited with no plausible mechanism being demonstrated. However, if significant effects involving magnetite are demonstrated such effects may also occur at low and power frequencies.

Conclusions

BEPAG has considered all the factors raised in this report, along with those in its previous reports, which now stretch back over twenty years. It has concluded that the balance of scientific evidence to date does not indicate that harmful effects occur in humans, or animals, due to low-level exposure to EMFs. Our examination of the peer-reviewed literature published in the last two years has not justified a change in this overall conclusion, which was published in our previous report in May 2014.

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 centred 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.

Records from monthly searches of these databases for peer-reviewed scientific EMF and health studies were sent to all members of BEPAG for assessment against a set of weighted criteria. The results of these assessments were fed back to the Secretary for inclusion within the contiguous indexed database. Identified trends in the assessed scientific knowledge for each discipline were used to inform, through consensus, the biennial IET position statement.

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)
11. 'The Possible Harmful Biological Effects of Low-level Electromagnetic Fields of Frequencies up to 300 GHz' (IET Position Statement - May 2012)
12. 'Are there harmful Biological Effects of low-level Electromagnetic Fields at Frequencies up to 300GHz?' (IET Position Statement - May 2014)

BEPAG Membership:

To inform its members, and the wider public, about any possible harmful health effects of exposure to low-level EMFs, the IET recruited, from within its membership, and where not possible from the UK's scientific community, a voluntary world-class expert group [BEPAG] knowledgeable in the issues and the underlying science. This multi-disciplinary group formulates and explains the IET's scientific evidence based position. To conform to requirements to participate in an IET committee the expert-group members bring to its work their professional knowledge, experience and expertise. They are specifically required to not be influenced by their employer's, or other third parties, interests.

BEPAG members

- Professor Anthony T. Barker (Chairman)
- Dr Kerry A Broom
- Dr Leslie A. Coulton
- Professor Sami Gabriel
- Dr Minouk J. Schoemaker
- Dr John Swanson
- Graham Barber (to 30 September 2015)
- Ciaran Molloy (from 1 October 2015)

Biographies:

Graham Barber BSc(Hons) CEng MIET
BEPAG Secretary and Principal Policy Advisor, The IET

To the role of BEPAG Secretary Graham brings experience from a prior career in broadcast and telecommunications engineering at both a technical and senior management level. This is enhanced through his IET work on providing technical knowledge to benefit the formation of evidence based public policy.

Professor Tony Barker BEng(Hons) PhD CEng FIET FIPEM
Consultant Clinical Scientist, Sheffield Teaching Hospitals NHS Foundation Trust

Tony has recently retired from the NHS Department of Medical Physics and Clinical Engineering at the Royal Hallamshire Hospital in Sheffield, where he was the departmental research lead. One of his main roles was to research the biological effects of electromagnetic fields, both for therapeutic and diagnostic purposes, and also their possible deleterious effects. His research studies include the stimulation of the human brain with very large magnetic-field pulses; using electrical stimulation to aid muscle function; and replication studies of electromagnetic-field effects in both cellular and human studies, carried out in laboratory, volunteer and clinical research environments.

Dr Kerry Broom BSc DPhil(Oxon) CBiol FSB
Principal Radiation Protection Scientist, Public Health England

Kerry's current responsibilities include experimental research studies on the biological effects of non-ionising radiation. She has until very recently previously provided secretariat support to the Committee on Medical Aspects of Radiation in the Environment (COMARE). Previously, Kerry has been responsible for the day-to-day scientific management of the Radiation Protection Research Programme for the Department of Health. Her research focuses on the effect of radiofrequency fields on the brain, and she is particularly interested in the potential behavioural impacts of EMF exposure in animal models of neurodegeneration. In addition, Kerry is a reviewer for the journal Bioelectromagnetics and also sits on a local committee for the Royal Society of Biology.

Dr Les Coulton BSc PhD
Senior Research Scientist, University of Sheffield

Les has recently retired having been involved in bone and bone cell research at Sheffield for over 30 years. Throughout that time he has had a research interest in possible biological effects of exposure to low-level electromagnetic fields, in particular effects on isolated cells at both radio and power frequencies. He was a member of the Advisory Group on Non-Ionising Radiation (AGNIR) for Public Health England (formally HPA) from 2001 to 2014.

Professor Sami Gabriel BEng(Hons) MSc FIET MIEEE
Chief Engineer, Vodafone Group Services Limited

Sami has studied engineering and information technology before becoming a researcher in bio-physics and organic chemistry. He worked extensively on the characterisation of the dielectric properties of biological tissues and the development of synthetic alternatives for use in safety and compliance evaluation. Sami continues his academic involvement as a guest professor of dielectrics. He now works as an EMF compliance expert advising on the use, testing and certification of wireless devices and base stations with national and international exposure limits within Vodafone Group. Internationally he has worked on compliance standards for over 15 years with IEEE, ICES, CENELEC and IEC.

Dr Minouk Schoemaker BSc MSc PhD
Staff Scientist, The Institute of Cancer Research, London

Minouk trained in Environmental Health Sciences in the Netherlands and in Radiation Biology, Medical Statistics and Epidemiology in the United Kingdom. Her research focus is on risk factors for cancer, including endogenous and environmental factors and lifestyle behaviours. She was intensively involved in a large case-control study of brain tumours in relation to mobile-phone use in the United Kingdom which contributed to the Interphone Study and several other international collaborations.

Ciaran Molloy LLB MUP
Principal Policy Advisor, The IET

Taking over from Graham Barber (who had acted as secretary for thirteen years), since September 2015 Ciaran Molloy has provided administrative support to members of the BEPAG committee. After two degrees in law, Ciaran then took a master's degree in urban planning at McGill University in Montreal. He has spent the last seven years in policy, mostly working for an association consisting of the major professions and research organisations related to the construction industry. Prior to that, he worked in legal publishing, specialising in presenting law and tax information to other professions.

Dr John Swanson MA DPhil CPhys CEng CRadP FInstP FIET FSRP
Scientific Advisor, National Grid

John has worked in the electricity industry on the issue of power-frequency EMFs for over twenty years. His training was as a physicist and his career started entirely in research, initially into understanding exposures and into mechanisms. He now continues with research, increasingly applying the understanding gained of exposures in epidemiology, but also has roles in policy and communication. Dr Swanson recently took over from Professor Tony Barker as chairman of the BEPAG committee.

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