Electromagnetic Fields

2015 Update

Source document:
SCENIHR (2015)

Summary & Details:
GreenFacts

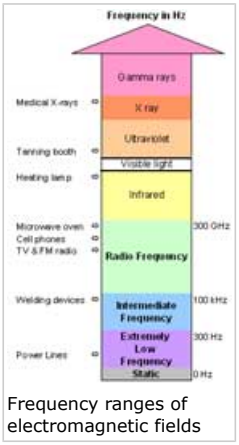
Level 2 - Details on Electromagnetic Fields

The answers to these questions are a faithful summary of the scientific opinion
produced in 2015 by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR):
"Potential health effects of exposure to electromagnetic fields (EMF)"

The full publication is available at: https://copublications.greenfacts.org/en/electromagnetic-fields/
and at: http://ec.europa.eu/health/opinions2/en/electromagnetic-fields/

1. Introduction to electromagnetic fields

1.1 What are electromagnetic fields?



Frequency ranges of electromagnetic fields

In this summary, the term electromagnetic field is used as a generic term comprising static magnetic and electric fields, low frequency alternating electric and magnetic fields and radio frequency (RF) electromagnetic fields. While up to the RF range electric and magnetic fields can be considered independently from each other, in the RF range, like the links of a chain they are tightly coupled together. They may be of natural origin such as the earth's magnetostatic field or friction-generated electric fields (which may be experienced as micro shocks when touching objects), or broad-band electromagnetic fields caused by lightning strokes or solar activity. The technical use of electricity mainly causes sinusoidally alternating fields which may be generated in the low frequency range (e.g. household appliances, power lines), intermediate frequency range (e.g. energy saving lamps, electronic article surveillance systems) as well as in the radio frequency range (e.g. broadcasting antennas, mobile telecommunication, microwave ovens).

Static magnetic fields of technical origin are generated by permanent magnets such as used in magnetic clasps or closures (e.g. in necklets, underwear, handbags or holders) or by direct currents such as in battery appliances while extremely high magnetostatic fields are applied at some workplaces and in medical imaging.

1.2 How have the health risks of electromagnetic fields been reassessed?

As part of its mandate, the SCENIHR is asked to continuously monitor new scientific evidence that may influence the assessment of risks to human health in the area of electromagnetic fields (EMF) and to provide regular updates to the Commission. The purpose of this Opinion was to update the SCENIHR Opinion of 2009 in light of newly available information and to give special consideration to areas where important knowledge gaps were identified in the previous Opinions. In addition, biophysical interaction mechanisms and the potential role of co-exposures to environmental stressors have been addressed.

The review of relevant scientific publications was undertaken. Studies used in SCENIHR opinions are obtained primarily from original research papers published in international peer-reviewed scientific journals and weighted according to criteria established by the SCENIHR Memorandum 'Use of the scientific literature for risk assessment purposes – a weight of evidence approach. The Committee has reviewed more than 700 studies published mainly after 2009 (when the previous Opinion was published) up to June 2014. Areas where the literature is particularly scarce are pointed out, and an explanation is given when studies are not included because their results do not add useful information to the database. This assessment evaluates both potential effects on groups of people who have been exposed to electromagnetic fields in their daily lives (epidemiological evidence) and potential effects observed in laboratory experiments carried out on human volunteers, animals, and cell cultures (experimental evidence).

Based on this combined evidence, the assessment estimates whether a causal link exists between exposure to electromagnetic fields and reported adverse health effects. The answer to this question is not necessarily a definitive yes or no, but reflects the weight of the evidence for or against a causal link between EMF exposure and effect. If such a link is found, the risk assessment estimates how strong the health effect is and how great the

health risk would be for different exposure levels and exposure patterns (dose-response relationship). The nature and the extent of uncertainties are highlighted and the way in which electromagnetic fields might cause effects (plausible mechanism) are evaluated.

1.3 What was the aim and outcome of the public consultation organised on the 2014 preliminary draft of Opinion on EMF?

In the process of preparing their Opinions, the Scientific Committee conducts open public consultations by presenting the preliminary Opinion and gathering specific comments and contributions. In the case of the Opinion on EMF, a public consultation was open on the website of the Scientific Committees from 4 February to 16 April 2014. In addition, a public hearing was held in Athens, on 27 March 2014. Fifty-seven organisations and individuals participated in the public consultation providing 186 comments to different chapters and sections of the Opinion. Each submission was carefully considered by the SCENIHR and the scientific Opinion has been revised to take account of relevant comments.

2. What are the sources of exposure to radio frequency fields?

Devices generating electromagnetic fields in the radio frequency (RF) range (from 100 kHz to 300 GHz) are in widespread use in our society. Key sources of RF fields include mobile phones, cordless phones, local wireless networks and broadcasting transmission antennas. They are also used in medical diagnosis and therapy, by radar systems and microwave ovens.

Local wireless computer networks generate radio fields
Credit: Ramzi Mashisho

Information about the strength of radio frequency fields generated by a given source is readily available and useful in determining compliance with safety limits. Assessing everyday exposure of individuals to radio frequency fields is much more difficult, however, such data are crucial for epidemiologic studies of potential EMF health effects. Knowledge could be increased by improved methods such as using personal exposimeters, devices carried by individuals to measure their exposure to electromagnetic fields over time. Exposure assessment should not be restricted to single sources only, like mobile phone base stations, but should consider multi-source exposure.

The fact that there is a continuous change of technologies, e.g. from analogue to digital broadcasting, and an emergence of new solutions like ultra-wide band (UWB) technologies on the market, leads to changing exposure patterns of the population on a long-term scale. Sources of RF EMF operate in different frequency bands. The strength of electromagnetic fields falls rapidly with distance. Over time, a person may absorb more RF energy from a device near the body than from a powerful source that is farther away. Cordless phones, local wireless networks and anti-theft devices are sources for small distance communications. Long-range sources include radio transmission towers and mobile phone base stations.

In 2014 the International Telecommunication Union estimated that there are about 7 billion mobile phones in use worldwide. Most mobile communication in Europe uses either GSM or UMTS technology. The European Union has set safety limits on the energy absorbed by the body from exposure to a mobile phone. Mobile phones sold in Europe must undergo standardised tests to demonstrate compliance in accordance with the Specifications of the European Committee for Electrotechnical Standardization (CENELEC). Typical frequencies for devices generating radio frequency fields.

Typical sources of electromagnetic fields

Frequency range	Frequencies	Some examples of exposure sources
Static	0 Hz	video display units; MRI (medical imaging) and other diagnostic or scientific instrumentation; industrial electrolysis; welding devices
ELF [Extremely Low Frequencies]	0-300 Hz	power lines; domestic distribution lines; domestic appliances; electric engines in cars, trains and tramways; welding devices
IF [Intermediate Frequencies]	300 Hz - 100 kHz	video display units; anti-theft devices in shops; hands-free access control systems, card readers and metal detectors; MRI; welding devices
RF [Radio Frequencies]	100 kHz - 300 GHz	mobile telephones; broadcasting and TV; microwave ovens; radar and radio transceivers; portable radios; MRI
THz technologies	300 GHz – 20 THz	applications are still in development, but currently mostly telecommunication applications and body scanners are considered.

2.1 How RF EMFs interact with the body?

The RF EMF interactions mechanisms are well established. Overall, it is energy absorption which is based on EMF's mechanical forces' that accelerate molecules (induce kinetic energy) which then collide with each other, subsequently causing tissue heating Even if the basic physical interaction is non-thermal, the biochemical and physiological responses depend on temperature. These established mechanisms allow extrapolation of scientific results to the entire frequency range and wide-band health risk assessment. They have been used to help limit exposure to EMF and provide the same degree of protection over the entire frequency range.

A number of studies have suggested other hypothetical mechanisms, however, none has been firmly verified as operating in the human body at a level of exposure below existing limits.

2.2 How high is the exposure from mobile phones and wireless devices?

When exposed to radio frequency fields, the **body absorbs** energy over time. The rate at which energy is absorbed is named the Specific Absorption Rate (SAR). It varies throughout the body. The 1999/519/EC European Council Recommendation) defines the basic restrictions and reference levels for limiting EMF exposure of the general public, setting maximum SAR values which should not to be exceeded. Since many of the physical quantities used for setting the basic limits cannot be readily measured, reference levels are provided for practical exposure-assessment purposes to determine whether the basic restrictions are likely to be exceeded.

For mobile phone handsets, the exposure is largely confined to part of the head closest to the phone's antenna. The Council Recommendation sets a radio frequency safety limit for a local Specific Absorption Rate (SAR) of 2 W (2000 mW) per kilogram, averaged over any 10g body tissue in human's head and trunk.

Mobile phones are tested assuming worst-case conditions namely with mobile phones operating at maximum power. In practice, depending on the transmission quality (the distance to the base station) the power transmitted during a mobile phone conversation is generally much lower, frequently several orders of magnitudes lower than the device's maximum power output. This is because the "power control" feature of a mobile phone continuously reduces the emitted power to the minimum needed for stable transmission. Moreover, output power depends on whether the user is talking or listening because transmission is considerably reduced during the listening period where no information is needed to be transferred (discontinued transmission mode). When a phone is in standby

mode, the exposure is typically two orders of magnitudes lower than during conversation. No exposure occurs when a mobile phone is switched off.

GSM phones transmitting at 900 MHz, a frequency allocated to mobile communication, have a maximum time-averaged output power of 250 mW. The power is averaged as GSM phones transmit radio signals in short repetitive bursts of information rather than continuously.

Mobile phones do not make use of the entire permissible exposure range. Depending on the models the test-SAR values might be range between 10 and 80% of the limit, hence based on the labelled information allows consumers making informed decisions.

Wireless devices intended for indoor communication, like cordless phones and wireless networks (WLAN), also generate radio waves but with less output power than mobile phones. A cordless phone handset used by a typical household generates about 10 mW of time-averaged power. Cordless phone base stations are usually no more than a few tens of meters from the handsets and, there is also the field from the cordless phone base station to consider. Their maximum time-averaged power level is the same as for a mobile phone handset. But in contrast to mobile phone handsets the cordless phone base station is distant from the body, and hence because the field strength falls rapidly with distance, exposure is reduced by orders of magnitudes.

The terminal of a wireless computer network (Wireless Local Area Network, WLAN) has a peak power of 200 mW, but since the time-averaged power depends on data traffic the actual power is usually considerably lower. Even near a wireless network station used in homes and offices, the field intensity is typically below 0.5 mW/m^2. Another system that is starting to be used in Europe is based on ultra-wide band (UWB) signals. The frequency range is centred around 500 MHz, applications are wireless microphones, health care applications and traffic control systems. With such systems, field levels are expected to be well below 0.1 mW/m^2.

Some anti-theft devices expose people to electromagnetic fields of radio and intermediate frequency. Increasingly used, the devices are located at store exits to detect shoplifters. The radio frequency exposure varies depending on the type but is below safety limits. Radio frequency fields are also used in industry such as for inductive metal heating.

The discussion about exposure of workers to EFM is outside the scope of this summary.

2.3 What is the level of exposure from mobile phone base stations and radio towers?

In contrast to broadcasting transmission towers, which are designed for one-way communication, mobile phone base stations must allow two-way communication. Therefore they necessarily form a network to link the individual mobile phones with each other across the country. Consequently, in European countries, base stations are now almost ever-present, ensuring mobile communication over large areas.

At 900 MHz, an important frequency for mobile communication and for **GSM mobile phone networks**, the EU recommends that people should not be exposed to a field stronger than 4.5 W/m^2 (power density). National measurement campaigns report that despite the increasing number of base stations and the deployment of additional mobile telecommunication technologies, the environmental electromagnetic radiation levels have essentially remained almost the same. The emitted power from indoor devices such as WiFi hotspots and DECT devices, even combined, still results in a very low exposure compared with reference levels of European and international guidelines.

For the newer UMTS networks, the use of Adaptive Power Control (APC), with which mobile phones reduce their output powers to allow for good signal quality, gives longer life to their batteries. The network continually monitors signal quality and may reduce the emitted power of a mobile phone by up to three orders of magnitudes for GSM and about nine orders of magnitudes for UMTS. Measurements of the exposure of the general population are limited as use of these mobile phones is low compared with GSMs. Where exposure has been measured, it was found to be at most a thousandth of a W/m^2 and usually much less (SCENIHR, 2009).

The problem with exposure measurements is that, typically, these only encompasses either a short-term measurement of a maximum of 48 hours with personal monitoring, or a spot measurement providing only a snapshot of instantaneous exposure at a single location.

Furthermore, for epidemiologic studies on health risks from EMF, given the lack of clearly established biological or biophysical mechanism of action, several alternative measures of exposure are evaluated (for instance field strength, exposure frequency, cumulative exposure, time since first exposure etc.). The relevant time period for which exposure data would be needed is a period of perhaps several years.

Other important sources of radio waves are **radio broadcasting** systems (AM and FM). The maximum values measured in areas accessible to the public are typically below 0.01 W/m^2. Close to the fence of very powerful transmitters, exposure of about 0.3 W/m^2 were reported in some cases.

As for the new digital **TV broadcasting** technology (DVB-T), the highest mean exposure was registered in the FM frequency band in office environments and was 0.096 mW/m^2. This is similar to the power densities of the older analogue TV broadcasting systems, but as digital systems require a denser network of, however, less powerful transmitters, higher exposure levels can be expected in some regions while there may be a reduction in others.

Other sources of long-range exposure to radio frequency fields are civil and military **radar** systems, private mobile radio systems, or new technologies like **digital audio broadcasting systems** and WiMAX.

Smart Meters are used to monitor energy consumption remotely and transmitting data to utility companies. There are a number of different types used, and one study concluded that smart meters "would make only minor contributions to the total background RF radiation level inside a home, which is in any event tiny in comparison to existing safety limits".

2.4 How are radio frequency (RF) fields used in medicine?

Electromagnetic fields in the RF range are used in medicine for diathermy to heat body tissue, which can ease pain or, at higher temperatures, kill cancer cells. As the aim is a biological effect, the patient's exposure to radio frequency fields is well above the recommended limits for the general public. Care must be taken to avoid exposure of medical staff exceeding limits for workers.

Another common application of RF fields in medicine is Magnetic Resonance Imaging (MRI), which in addition also uses very strong static magnetic fields (see question 8). MRI provides high-resolution cross-sectional images of the body including the head without shadowing by bony structures.

3. Can mobile phones cause cancer?

3.1 Can mobile phone use increase the risk of brain tumours?

There are mogre than 7 billion mobile phones in use today. Credit: Juha Blomberg

Whether the use of mobile phones is associated with an increased risk of brain tumours has been the research question of numerous small and a handful of large-scale epidemiological studies. Attention has focused on the possibility of tumours of the head and neck region because these tissues are primarily exposed to the RF fields emitted by hand-sets. Furthermore, some studies suggested a possible association between the exposure to RF EMF produced by mobile phones and an increased risk of cancer of the auditory acoustic nerve (acoustic neuroma) and brain tumours (glioma).

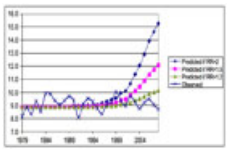


Figure 5. Observed glioma incidence rate in the Nordic countries and expected rates assuming mobile phone
[see Annex 1, p. 20]

However, the results of cohort and incidence time trend studies do not support an increased risk for glioma. The possibility of an association with acoustic neuroma remains open. In particular, the observed rate of glioma incidence in the Nordic countries has been compared to the predicted rates that would have been observed if there were an increased risk of 1.2, 1.5 and 2 related to a regular mobile phone use of 10 years or more. The observed cancer incidence does not show the predicted steep increase that would be expected if there were a causal link between mobile phones and cancer.

The fact that the rates of incidence of the corresponding tumours have not increased since the introduction of cell phones suggests thus precaution on the interpretation of such a hypothetical association.

3.1.1 What about an increased risk of cancer for children?

The only epidemiological study on mobile phone use and brain tumours in children which involved four European countries did not show an increased risk. However, more studies are needed.

3.1.2 What about an increased risk of other cancer types?

Epidemiological studies do not indicate increased risk for other malignant diseases including childhood cancer. A number of studies also looked into the potential cancer risk of exposure to radio frequency fields from transmission towers. In most cases, no conclusions on a cancer risk could be drawn.

3.2 Have experimental studies revealed an increased cancer risk?

A considerable number of well-performed *in vivo* studies using a wide variety of animal models have been mostly negative in outcome. Among these, a number of lifetime and long-term RF fields exposure studies were performed on laboratory animals by exposing them to 900 MHz GSM signals and other higher frequency signals at higher exposure levels than in earlier studies. All studies concluded that there was no effect of RF fields on the risk of developing tumours, even at the higher exposures. One study found a reduced survival rate in exposed animals, but this finding remains unexplained.

The results of the new experimental studies are consistent with results from previous studies and, overall, add to the evidence that the RF fields such as those emitted by mobile phones do not cause cancer in laboratory animals.

3.3 Have studies on cell cultures revealed genetic effects?

An analysis of 88 *in vivo* and *in vitro* studies published between 1990 and 2011 and assessing genetic damage in human cells exposed to RF showed that the magnitude of difference between RF- exposed and sham-exposed controls was small with some exceptions. Globally, these studies did not provide evidence for any effect of radio frequency field on the genetic material of cells.

Other potential effects were also investigated, such as cell death, expression of genes, of cell proliferation. Most of the studies did not find any effect.

4. Can mobile phones or base stations trigger headaches or other health effects?

4.1 Have headaches and other symptoms been linked to mobile phones?


Mobile phone base station
Credit: Pyb

Some people attribute non-specific health symptoms such as headache, nausea, dizziness, fatigue and skin irritation to their exposure to electromagnetic fields. Such complaints have raised concern that certain individuals may be more sensitive than others to EMF. These self-reported symptoms have been named electromagnetic hypersensitivity (EHS). The reported symptoms can sometimes be severe enough to cause serious impairments to a person's wellbeing. While their health concerns are valid, studies conducted since the previous Opinion (about 15 reviewed) adds weight to the existing body of evidence that exposure to RF does not trigger symptoms, at least in the short-term. While additional observational studies are required to assess whether longer-term exposure could be associated with symptoms, the evidence to date weighs against a causal effect.

For symptoms triggered by short-term exposure to RF fields (measured in minutes to hours), the consistent results from multiple double-blind experiments lead to a strong overall weight of evidence that RF fields do not cause such effects. For symptoms associated with longer-term exposures (days to months), the evidence from observational studies is broadly consistent but has gaps, most notably in terms of the objective monitoring of exposure. Current evidence weighs towards an absence of effects due to RF fields exposure.

Even when a participant's self-report of exposure to RF is accurate, it is still difficult to differentiate whether any association with symptoms is the result of RF exposure per se or whether the association is the result of a 'nocebo' effect (a negative placebo effect), whereby the participant's belief that they are being exposed is sufficient to trigger their symptoms.

Subjects who know they are exposed to some RF fields, e.g. because they use a mobile phone or live near a transmission tower, tend to report more symptoms, whereas double-blind provocations studies where subjects do not know whether they are exposed to RF fields or not do not find a consistent link between radio frequency fields and symptoms.

Actually, there is no scientific evidence that humans - either so-called sensitive groups or healthy control groups - can perceive radio frequency fields better than would be expected by chance.

4.2 Can mobile phones affect the brain?

Because mobile phones come in contact with the head, there have been concerns they could affect the brain.

Studies on possible effects of RF exposure on brain function in humans (such as *sleep, cognition, blood flow and oxygenation changes*) have given mixed results. The conducted studies are difficult to compare with one another, and so the observed effects were not sufficiently replicated. There are some studies indicating that effects might vary with age and gender; it is not known whether subjects with pre-existing medical conditions may be affected differently. Most of the recent studies have confirmed an effect of RF exposure on electro encephalograms (EEG). There have also been effects found on sleep EEGs but there is not yet any conclusive evidence. Several of the recent studies addressing RF effects on spatial learning, memory, and behaviour suggest an effect at low field levels but there remain significant questions regarding the experimental protocols. No conclusive evidence can be drawn at present.

Experimentally, a number of different end-points have been studied in both mice and rats. Globally these observations are inconsistent and appear mostly at levels well above guidelines values. One of those endpoints is the potential impairment of the blood-brain barrier. Recent studies do not show that exposure to RF has any effect, several of the studies are done in such a way that their relevance for risk assessment is questionable.

Overall, regarding neurological disorders and cognitive functions, locomotion or an increased risk of Alzheimer's, there is no evidence that RF exposure from mobile phone use have a health-relevant effect.

4.3 Have effects from RF fields of mobile phones on reproduction and development been reported?

Numerous large and well-conducted studies have investigated potential effects of RF fields on development of animals, including mammals and birds and clearly show that RF fields can cause birth defects when the exposure is well above safety guidelines and therefore high enough to significantly raise temperatures in tissue. No consistent evidence of effects has been found at exposure levels that do not cause relevant heating of tissues.

No significant effects were seen from almost continuous, lifetime exposure of mice over four generations. More recent epidemiological studies have not shown increased risks of neurological disease or reproductive effect related to RF exposure; effects on foetuses from mothers' mobile phone use during pregnancy are judged not plausible due to the low level of exposure. The data available provide no clear evidence of consistent adverse effects on human semen quality.

The previous SCENIHR Opinion (2009) concluded that there were no adverse effects on reproduction and development from RF fields at non-thermal exposure levels. The inclusion of more recent human and animal data does not change this assessment.

There are still no substantiated indications of any other health effects.

4.4 Are children more vulnerable to possible effects of mobile phones?

With so many children using mobile phones, there is concern about how radio signals may affect them. Some people worry that children could be more vulnerable than adults because their nervous systems are still developing, their brain tissue is more conductive, their heads might absorb more energy from mobile phones and children using mobile phones will have a greater lifetime exposure than people who were adults when they began using them. Children can also be exposed through other sources, such as baby monitors. Few studies have addressed the possible effects of radio signals on children, and extrapolating from adult studies remains problematic. Overall, current evidence does not demonstrate that children might be more vulnerable to RF EMF, however, due to physiologic reasons they tend to be higher exposed from mobile phones than adults.

5. Conclusions on mobile phones and radio frequency fields


Few studies have looked at effects on children

Extensive research has been conducted in recent years on how RF fields, including those generated by mobile phones, might affect health. Carcinogenicity and a variety of possible effects have been studied, both inside the laboratory and among human populations.

Conclusions of the Opinion are based on thorough examination of all pertinent and very numerous epidemiological and experimental studies from three independent lines of evidence (studies on humans, animals, and cell cultures).

Overall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region.

A considerable number of well-performed *in vivo* studies using a wide variety of animal models have been mostly negative in outcome.

A large number of *in vitro* studies pertaining to genotoxic as well as non-genotoxic end-points have been published since the last Opinion was adopted. In most of the studies, no effects of exposure at non-thermal levels were reported.

The theory that RF exposure may affect brain activity, as supported by evidence from previous EEG studies conducted during sleep and wakeful periods, was also supported by some recent studies although the small physiological changes remains unclear and mechanistic explanation is still lacking. Overall, there is a lack of evidence that RF EMF affects cognitive functions in humans.

Symptoms that are attributed by some people to RF EMF exposure can sometimes be strong enough to cause serious impairments to a person’s quality of life. However, research conducted since the previous SCENIHR Opinion adds weight to the conclusion that RF EMF exposure is not causally linked to these symptoms.

Relevant studies show no adverse effects on reproduction and development from RF fields at non-thermal exposure levels.

6. Intermediate frequency (IF) fields like those from induction ovens

6.1 What are the sources of intermediate frequency fields (IF fields)?

In this summary, intermediate frequency (IF) fields designate electromagnetic fields with frequencies ranging from 300 Hz to 100 kHz, roughly the frequencies that are lower than radio frequencies (RF) and higher than extremely low frequencies (ELF).

Applications generating intermediate frequency fields have been increasing in recent years and will likely continue to do so. Examples are some anti-theft devices operated at the exits of shops, induction hotplates, computers, compact fluorescent lamps, as well as some radio antennas. Such fields are also generated by some industrial uses such as inductive metal heating and welding. In most cases exposure is limited, but for radio transmitters and industrial applications, exposure can be above the recommended limits, so safety precautions should be taken.

Some medical applications lead to exposures in this frequency range, like interference current nerve and muscle stimulators.

6.2 What possible health effects of intermediate frequency fields have been studied?

Well-known biological effects at the IF range are nerve stimulation at the lower end of the range and heating at the upper end of the range. These are explained by the mechanisms known to occur in the RF and ELF ranges.

There are still too few new studies on health effects from IF exposures in general, and no epidemiological studies have appeared. The data are thus still too limited for a specific risk assessment in this frequency range.

In view of the increasing exposure to IF, experimental studies on biomarkers and health outcomes in this area have been identified as a priority for research.

7. Extremely low frequency fields (ELF) like those from power lines and household appliances

7.1 What are the sources of ELF fields?

In this assessment, extremely low frequency (ELF) fields designate electromagnetic fields with frequencies below 300 Hz, the frequencies that are lower than intermediate frequencies. The main source of ELF is alternating current carried in overhead lines of railways, power lines, electric installations and household appliances. The magnetic field generated has the same frequency as the current that produces it, i.e.
16 $_{2/3}$ Hz, 50Hz or 60Hz (the latter predominantly in US). Additional important sources of ELF magnetic fields include power plants and substations, welding machines, induction heaters and tramway and subway systems.


Power lines generate ELF fields Credit: Miguel Saavedra

ELF fields can be electric or magnetic:

- **An electric field** is the created by electric charges and characterised by forces acting upon other electric charges. It is measured in volts per meter (V/m).
- **A magnetic field** is created as a consequence of the movement of electric charges (electric current) and characterised by the force acting upon resting or moving electric charges. The strength of a magnetic field is usually measured in ampere per meter (A/m), alternatively, by accounting for the magnetic properties of material as magnetic induction, in tesla (T).

The amplitude of both electric and magnetic fields strongly decreases with distance from the field source.

ELF **electric** fields tend to be strongest below high voltage overhead power lines (up to several kV/m), and ELF **magnetic** fields are particularly strong near cables with high current load such as at welding machines and induction furnaces (up to a few mT). To determine compliance with exposure limits, the maximum possible exposure next to the source must be assessed, in general by comparing measured field quantities with the given reference level. The maximum field level of inhomogeneous fields next to a source may be several orders of magnitudes higher than the reference level of equivalent homogeneous fields.

7.2 What is the level of exposure to ELF fields?

The **general public** can be exposed to extremely low frequency (ELF) fields from various fixed sources that are operative in our environment, such as power lines and transformer stations, in particular if those are placed inside houses.

Passing directly below a **high voltage power line**, exposure to *electric fields* can be of several kV/m and to *magnetic fields* of several 10 µT. The amplitude of electric and magnetic fields decreases rapidly with increasing distance to the line;

At home, the magnetic fields are strongest close to distribution boxes and to household appliances in particular those, that contain motors, transformers, or consume high power such as electric ovens or heaters. The smaller the dimension of a source, the more effective is increasing distance in reducing field levels.

7.3 Can ELF fields increase the risk of childhood leukaemia and other cancers?

Studies on ELF MF are focusing on power frequency fields. In 2002, the International Agency for Research on Cancer (IARC) classified **ELF magnetic fields** as "*possibly carcinogenic to humans*" (Group 2B). This was based on epidemiologic studies that reported that children are more likely to develop leukaemia if their time-averaged exposure to **ELF magnetic fields** exceeds 0.3-0.4 µT, which is relatively strong. Experimental studies on animals did not support these findings. Furthermore, the IARC concluded, there was no evidence for a link between **ELF magnetic fields** and any other type of cancer.

This potential link between ELF fields and childhood leukaemia has been further addressed by a number of epidemiological studies which confirm an increased risk of leukaemia in children living close to high voltage power lines with estimated daily average exposures (above 0.3 to 0.4 µT) much higher than average magnetic field exposure at homes.

But it remains difficult to judge whether this apparently quite robust association is likely to be causal or a result of methodological shortcomings of the studies such as information bias, selection bias and confounding factors.

Indeed, little progress has been made in verifying the causality of the reported association or in explaining the finding, neither by a plausible mechanism nor in identifying an alternative explanation. Besides, a large and more recent study investigating childhood leukaemia survival in relation to ELF magnetic field exposure did not observe an association, adding no support to the hypothesis that ELF magnetic field may promote pre-leukemic clones both related to the risk of developing leukaemia as well as the risk of a relapse of leukaemia after successful treatment.

Studies on other childhood cancers or adult cancers showed no consistent association and no new influential study has appeared over the last few years concerning any other type of cancer.

7.4 Can exposure to ELF cause headaches or other health effects?

As in the case of radio frequency fields, self-reported "electromagnetic hypersensitivity" is an issue that also comes up in the case of ELF field exposure including reports on a variety of symptoms such as skin redness, tingling and burning sensations, as well as fatigue, headache, concentration difficulties, nausea, and heart palpitations. There were several studies added to the existing pool of investigations. Overall, the studies do not provide convincing evidence for a causal relationship between ELF MF exposure and self-reported symptoms.

Studies investigating possible effects of ELF MF exposure on brain activity are too heterogeneous to draw a sound conclusion. Largely consistent with earlier results, recent studies have reported that exposure to ELF MF has no effect on activity or locomotion. There is some evidence from animal studies that exposure to ELF magnetic fields may affect the performance of spatial memory tasks (both deficits and improvements have been reported) and engender subtle increases in behavioural anxiety and stress.

Other studies have investigated potential molecular and cellular mechanisms, and despite a number of studies continue to report candidate mechanisms, particularly regarding effects on reactive oxygen species, none has been firmly identified that operates at exposure levels found in the everyday environment.

Epidemiological studies do not provide convincing evidence of an increased risk of neurodegenerative diseases, including dementia, related to power frequency MF exposure.

7.5 Can ELF magnetic fields have effects on human reproduction?

Epidemiological studies showed no evidence for adverse effects on pregnancy or on the health of the children. Some studies report some implausible effects but need to be replicated independently, before they can be used for risk assessment.

7.6 What can be concluded about ELF fields?

The new epidemiological studies are consistent with earlier findings of an increased risk of childhood leukaemia with estimated daily average exposures above 0.3 to 0.4 μT. As stated in the previous Opinions, no mechanisms have been identified and no experimental studies have been able explain these findings, which, together with shortcomings of the epidemiological studies prevent a causal interpretation.

Overall, existing studies do not provide convincing evidence for a causal relationship between ELF MF exposure and self-reported symptoms.

Studies investigating possible effects of ELF exposure on the power spectra of the waking EEG are too heterogeneous with regard to applied fields, duration of exposure, number of considered leads and statistical methods to draw a sound conclusion. The same is true for behavioural outcomes and cortical excitability.

Epidemiological studies do not provide convincing evidence of an increased risk of neurodegenerative diseases, including dementia, related to ELF MF exposure. Furthermore, they show no evidence for adverse pregnancy outcomes in relation to ELF MF. The studies concerning childhood health outcomes in relation to maternal residential ELF MF exposure during pregnancy involve some methodological issues that need to be addressed. They report implausible effects but need to be replicated independently before they can be used for risk assessment.

Recent results do not show that ELF fields have any effect on the reproductive function in humans.

8. Static magnetic fields like those from battery devices and high voltage overhead DC power lines

8.1 What are the sources of static magnetic fields?

A magnetic field is created as a consequence of the movement of electric charges (electric current) and characterised by the force acting upon resting or moving electric charges. The strength of a magnetic field is usually measured in ampere per meter (A/m), alternatively, by accounting for the magnetic properties of material, as magnetic induction, in tesla (T).


MRI scanners use static magnetic fields
Credit: Kasuga Huang

Static magnetic fields do not oscillate, and therefore do not have a zero frequency (0 Hz). Examples of fields of natural origin are the magnetostatic fields generated by permanent magnets or the Earth's magnetic field.

Man-made static magnetic fields are generated wherever electricity is used in the form of direct current (DC), such as in some rail and subway systems, in industrial processes such as aluminium production, the chloralkali process, and gas welding or where permanent magnets are sometimes technically used such as for clasps and closures in necklaces, underwear or handbags.

The variety of artificial sources of such fields is limited, but there are rapid developments of new technologies producing static fields. The number of people with implanted metallic

devices such as pacemakers that can be affected by strong static magnetic fields is also growing.

One prominent application of strong static magnetic fields is Magnetic Resonance Imaging (MRI) that high-resolution cross-sectional images of the body including the head without shadowing by bony structures. This medical imaging technique uses very high static magnetic fields of several Tesla, which can lead to high exposure levels both for patients and for operators.

Previous health assessments looked mainly at exposure to static fields alone, but many applications, particularly MRI, can lead to exposure to strong static fields in combination with radio frequency and other fields. Recent studies have thus started to look at different field combinations and their potential effects.

8.2 What possible health effects of static magnetic fields have been studied?

In daily life, geomagnetic fields are too weak to generate relevant effects. The strong magnetic fields in and around Magnetic Resonance (MRI) scanners at present operating with 0.3 – 9.4 T are strong enough to produce relevant effects, which may necessitate taking protective measures such as using detector gates for control access to avoid having ferromagnetic devices brought in the vicinity of MRI scanners, to prevent from adverse interference with implanted cardiac pacemakers and – at magnetic fields at or above 4T - to prevent from dangerous stimulation of nerves and muscles.

In most of the available *in vitro* studies, SMF above 30 μT induced neuronal effects, although in some cases the effects were temporary and reversible. Gene expression was affected in all studies with predominantly several genes involved in cell growth and division.

A number of studies are reporting that effects of SMF exposures occur in animals, at levels ranging from mT to T. However, since many of the findings are limited to single studies, they do not provide any firm foundation for risk assessment. Some animal studies show an effect of static MF on blood flow, vessel growth and on growth and development, but some results are contradictory and do not clarify the mixed results of previous studies.

Since the previous SCENIHR Opinion (2009) a meta-analysis of studies, which have assessed the health effects of static magnetic fields, identified four studies which reported effects including dizziness, nausea, and vertigo. The exposure was not found to have a significant effect on cognitive function at any field strength. The frequency of occurrence of these symptoms seemed mainly to be associated with the strength of the MRI systems, the time spent in their vicinity, and the speed with which workers move through these fields. These effects can be explained by established interaction mechanisms and are more likely to occur in fields above 2 T. The relevance of these effects for the health of personnel remains unclear but, according to some studies, these dose-dependent effects could theoretically lead to an increased risk of accidents and errors by workers that are harmful for themselves or for patients under their care.

While these new studies confirm the conclusion that these effects can be repaired and are not permanent, there is also some evidence of genotoxic effects in patients undergoing MRI examination but it seems unlikely that the static field alone could cause such effects. Further studies on DNA integrity and MRI exposure are thus needed. Magnetic fields in and around MRI scanners are thus strong enough to enable relevant side-effects such as accelerating ferromagnetic objects or magnetic interference with electronic devices. These justify protective measures such as access control by detector gates or restricting access to pacemaker patients with not MRI-compliant implants to prevent adverse interference with implanted cardiac pacemakers.

Globally, there is no consistent evidence for sustained adverse health effects from short-term exposure up to several Teslas.

9. Are there health effects from combined exposures to different EMFs or co-exposure with other agents?

The few available studies on **combined exposure** to different EMFs do not provide sufficient evidence for specific risk assessment. The studies on effects on DNA integrity after an MRI investigation are clearly of interest to follow up. However, it is not clear which component of the complex EMF exposure during scanning may cause the effect: SMF, switched gradient MF or the pulsed RF EMF with its heating effect. Further studies on DNA integrity and MRI exposure are needed, and the feasibility of cohort studies of MRI patients and occupationally exposed personnel should be discussed.

Regarding **co-exposure** to ELF or RF with several chemical or physical agents, an increase or a decrease in the effects of some chemicals or physical agents have been observed in some cases. However, due to the small number of investigations available and the large variety of protocols adopted (different chemical or physical treatments and different EMF exposure conditions), it is not possible to draw conclusions. Further investigations should be carried out to clarify the role of EMFs in increasing/decreasing the effect of other treatments such as UV radiation and ionising radiation and to explore the potentially beneficial (protective) effects of such exposures on humans.

10. Conclusions on health effects of electromagnetic fields

10.1 Conclusions on Radio Frequency (RF) fields

Radio frequency fields (100 kHz - 300 GHz) are generated from a large variety of sources such as by broadcasting, mobile telephony and wireless networks.

Overall, the epidemiological studies on RF EMF exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region. Some studies raised questions regarding an increased risk of glioma and acoustic neuroma in heavy users of mobile phones. The results of cohort and incidence time trend studies do not support an increased risk for glioma. The possibility of an association with acoustic neuroma remains open. Epidemiological studies do not indicate increased risk for other cancers including childhood cancer.

A large number of *in vitro* studies have been published since the last Opinion. In most of the studies, no effects, genotoxic as well as non-genotoxic, were recorded at levels of exposure below exposure limits. Previous studies suggesting that RF exposure may affect brain activities as reflected by changes in the EEG during wake and sleep are confirmed by results of more recent studies. However, given the variety of applied fields, duration of exposure, number of considered leads, and statistical methods it is difficult to derive firm conclusions. Studies on cognitive functions in humans lack consistency. The biological relevance of reported small physiological EEG changes remains unclear and a mechanistic explanation is still lacking.

A reasonable body of experimental evidence now suggests that exposure to RF does not trigger the self-reported symptoms that are known as "Electromagnetic hypersensitivity", at least in the short-term. While additional observational studies are required to assess

whether longer-term exposure could be associated with symptoms, the evidence to date weighs against a causal effect.

Human studies on neurological diseases and symptoms show no or no consistent effects.

10.2 Conclusions on Intermediate Frequency (IF) fields

Intermediate frequency (IF) fields (300 Hz – 100 kHz) are generated by sources like computers, induction hotplates, compact fluorescent lamps and anti-theft devices. Exposure to IF fields at the work place is in some cases considerably higher than exposure to the general public. However, very little research on IF fields and health risks in occupational settings or for the general public has been published and the data are still too limited for an appropriate risk assessment.

In view of the increasing exposure to IF fields at the work place, for instance in shops and certain industries, it is important that research in this area is given priority.

10.3 Conclusions on Extremely Low Frequency (ELF) fields

Extremely low frequency fields (ELF) (below 300 kHz) are generated by sources like power lines, and electric appliances. Studies investigating possible effects of ELF magnetic fields (ELF MF) exposure on the brain activity of volunteers are too heterogeneous with regard to applied fields, duration of exposure, number of considered leads, and statistical methods to draw any sound conclusion. The same applies for the results concerning behavioural outcomes and cortical excitability.

The new epidemiological studies are consistent with earlier findings of an increased risk of childhood leukaemia with estimated daily average exposures above 0.3 to 0.4 μT. As stated in the previous Opinions, no mechanisms have been identified in the meanwhile and no support exists from experimental studies that could explain these findings, which, together with shortcomings of the epidemiological studies prevent a causal interpretation.

Only a few new epidemiological studies on neurodegenerative diseases have been published since the previous Opinion was adopted. They do not provide support for the previous conclusion that ELF magnetic field exposure could increase the risk for Alzheimer's disease or any other neurodegenerative diseases or dementia.

10.4 Conclusions on static magnetic fields

Static magnetic fields are generated by sources such as permanent magnets and those using direct electric currents.

Taken together, the new findings reported do not challenge previous risk assessment of static MF exposure which was made in the previous Opinion. Globally, there is no consistent evidence for lasting adverse health effects from short term exposure up to several Teslas.

10.5 Conclusions on combined exposure of EMFs and co-exposure to environmental stressor

The few available studies on **combined exposure** to different EMFs do not provide sufficient evidence for risk assessment.

The Opinion of 2009 concluded that there was some evidence from *in vivo* studies to suggest that **co-exposure** with ELF fields may act as a co-carcinogen, while there was no evidence that RF fields could act in a similar way. The results reported since then indicate that co-exposure to ELF or RF with several chemical or physical agents can indeed result in either an increase or a decrease in their effect, but due to the small number of available investigations and the large variety of protocols adopted, it is not possible to assess these risks at present.

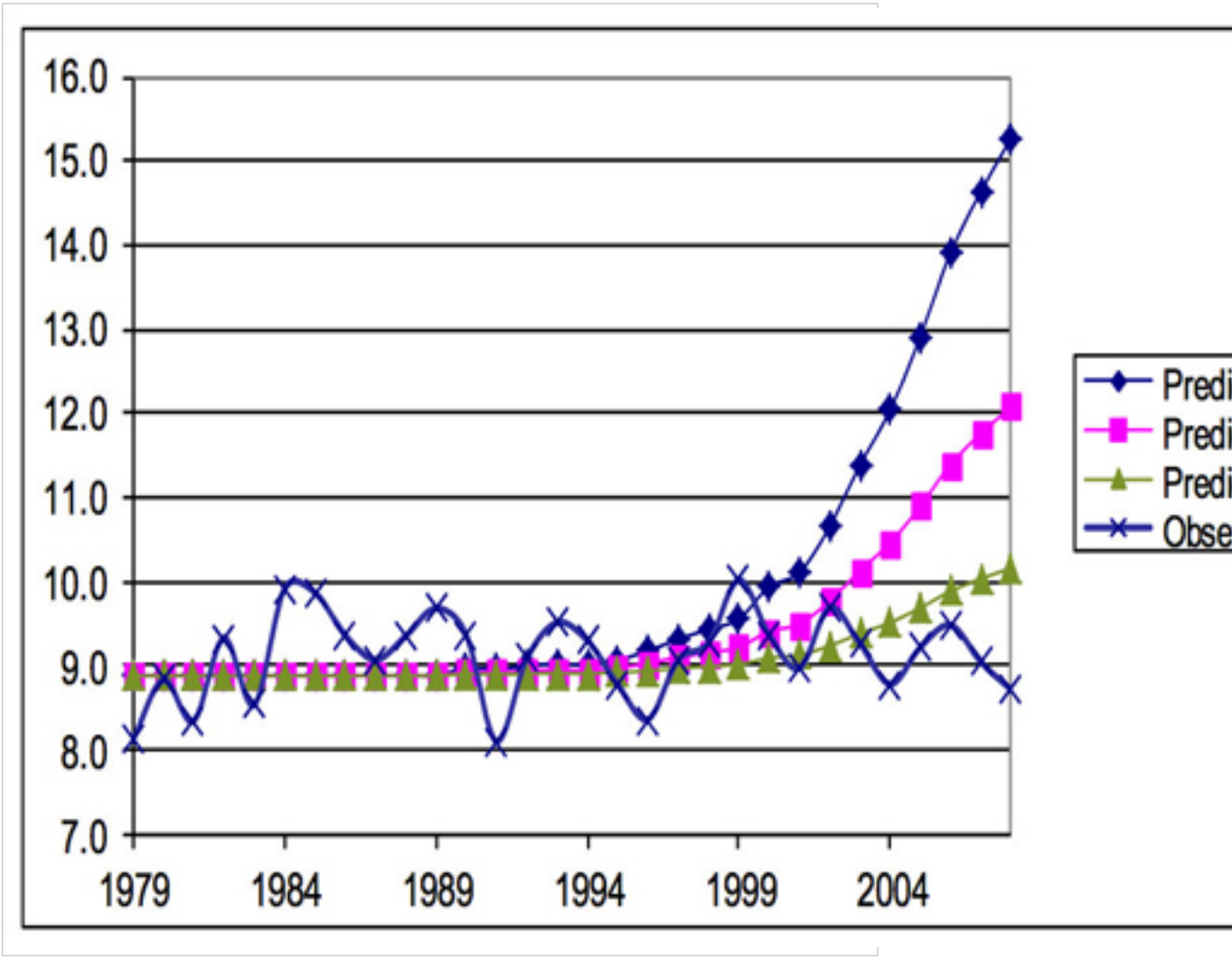
10.6 Research recommendations

A set of prioritised research recommendations and methodological guidance on the experimental design and minimum requirements to ensure data quality and usability for risk assessment are provided in chapters 3.14 and 3.15 of the Opinion.

Annex

Annex 1:

Figure 5. Observed glioma incidence rate in the Nordic countries and expected rates assuming mobile phone



(regular mobile phone use of 10 years or more) related relative risk increases of 1.2, 1.5 and 2, respectively

[Based on data from Deltour et al. 2012]

Source: SCENIHR Potential health effects of exposure to electromagnetic fields [see http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf], 3.6.1.1. Epidemiological studies, p.79